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The World Nuclear Industry
Status Report 2019

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The World Nuclear Industry Status Report 2019

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NOTE

This report contains a very large amount of factual and numerical data. While we do our utmost to verify and double-check, nobody is perfect. The authors are always grateful for corrections and suggested improvements.

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TABLE OF CONTENTS

ACKNOWLEDGMENTS . . . 3

FOREWORD 13

KEY INSIGHTS 15

EXECUTIVE SUMMARY AND CONCLUSIONS 16

Reactor Startups & Closures . . . 16

Operation & Construction Data . . . 17

Construction Starts & New-Build Issues . . . 18

Potential Newcomer Countries - Program Delays & Cancellations . . . 18

Small Modular Reactors (SMRs) . . . 19

Focus Countries – Widespread Extended Outages . . . 20

Fukushima Status Report . . . 21

Decommissioning Status Report – Soaring Costs . . . 22

Nuclear Power vs. Renewable Energy Deployment . . . 23

Climate Change and Nuclear Power . . . 24

INTRODUCTION 26

GENERAL OVERVIEW WORLDWIDE 29

THE HISTORIC EXPANSION OF NUCLEAR POWER – FORECASTING VS. REALITY . . . 29

PRODUCTION AND ROLE OF NUCLEAR POWER . . . 31

OPERATION, POWER GENERATION, AGE DISTRIBUTION . . . 34

OVERVIEW OF CURRENT NEW-BUILD . . . 38

CONSTRUCTION TIMES . . . 40

Construction Times of Reactors *Currently Under Construction* . . . 40

Construction Times of Past and *Currently Operating Reactors* . . . 40

CONSTRUCTION STARTS AND CANCELLATIONS . . . 43

OPERATING AGE . . . 46

LIFETIME PROJECTIONS . . . 49

FOCUS COUNTRIES 52

BELGIUM FOCUS . . . 52

Hydrogen Crack Indications and Legal Issues . . . 54

Serious Flaws in Reinforced Concrete . . . 55

Performance Assessment . . . 56

Lifetime Extensions = Extended Outages? . . . 57

Compliance Issue Solved . . . 58
CHINA FOCUS . . . 59
FINLAND FOCUS . . . 62
Olkiluoto-3 (OL3) . . . 63
Hanhikivi-1 . . . 67
FRANCE FOCUS . . . 68
Multi Annual Energy Plan and The Energy Bill . . . 68
French Nuclear Power Performance Remains Poor . . . 69
Power Trade . . . 70
Nuclear Unavailability Review 2018 . . . 71
The Ongoing Flamanville-3 EPR Saga . . . 74
Other Ongoing Quality Issues . . . 76
Ongoing Fallout from Creusot Forge Affair . . . 76
The Ongoing Tricastin Canal Embankment Case . . . 77
GERMANY FOCUS . . . 78
JAPAN FOCUS . . . 81
Reactor Closures . . . 83
Restart Prospects . . . 88
Financing Meltdowns . . . 95
Multiple Reactor Shutdowns from Spring 2020? . . . 95
SOUTH KOREA FOCUS . . . 97
Reactor Startup . . . 99
New Reactor Construction . . . 100
Energy Policy Under Attack . . . 101
Containment Liner Plate Corrosion . . . 102
Hanbit Power Surges . . . 103
TAIWAN FOCUS . . . 104
Reactor Closures . . . 106
Referendum . . . 106
No Future for Lungmen? . . . 107
UNITED KINGDOM FOCUS . . . 109
Hinkley Point C Construction Start – Not That Concrete? . . . 112
Other U.K. New-Build Projects . . . 114
A New Funding Model for Nuclear? . . . 116

Renewables Kicking In . . . 117
Plutonium – From Long-Term Resource Dream to Endless Liability . . . 118
UNITED STATES FOCUS . . . 119
Reactor Closures . . . 122
New Reactor Construction . . . 126
Securing Subsidies to Prevent Closures . . . 132

FUKUSHIMA STATUS REPORT 143
INTRODUCTION . . . 143
ONSITE CHALLENGES . . . 143
Current Status Reactors . . . 143
Contaminated Water Management . . . 145
Worker Exposure . . . 147
OFFSITE CHALLENGES . . . 149
Current Status of Evacuation . . . 149
Radiation Exposure and Health Effects . . . 153
Food Contamination . . . 154
Decontamination . . . 155
CONCLUSION ON FUKUSHIMA STATUS . . . 156

DECOMMISSIONING STATUS REPORT 2019 157
INTRODUCTION AND OVERVIEW . . . 157
Decommissioning Worldwide . . . 157
Overview of Reactors with Completed Decommissioning . . . 158
ELEMENTS OF NATIONAL DECOMMISSIONING POLICIES . . . 159
CASE STUDIES NORTH AMERICA, EUROPE, AND ASIA . . . 159
CASE STUDIES: WESTERN EUROPE, CENTRAL AND EASTERN EUROPE, AND ASIA . . . 162
Spain . . . 162
Italy . . . 165
Lithuania . . . 168
Russia . . . 170
South Korea . . . 172
CONCLUSION ON REACTOR DECOMMISSIONING . . . 173

POTENTIAL NEWCOMER COUNTRIES 175
UNDER CONSTRUCTION . . . 176
Bangladesh . . . 176

Belarus . . . 178
Turkey . . . 181
United Arab Emirates . . . 185
"CONTRACTS SIGNED" . . . 188
Lithuania . . . 188
Poland . . . 188
Vietnam . . . 190
"COMMITTED PLANS" . . . 191
Egypt . . . 191
Jordan . . . 192
"WELL DEVELOPED PLANS" . . . 193
Indonesia . . . 193
Kazakhstan . . . 194
Saudi Arabia . . . 195
Thailand . . . 197
Uzbekistan . . . 197
CONCLUSION ON POTENTIAL NEWCOMER COUNTRIES . . . 199

SMALL MODULAR REACTORS 200
ARGENTINA . . . 200
CANADA . . . 200
CHINA . . . 202
INDIA . . . 204
RUSSIA . . . 204
SOUTH KOREA . . . 206
UNITED KINGDOM . . . 206
UNITED STATES . . . 207
CONCLUSION ON SMRs . . . 209

NUCLEAR POWER VS. RENEWABLE ENERGY DEPLOYMENT 210
INTRODUCTION . . . 210
INVESTMENT . . . 211
TECHNOLOGY COSTS . . . 213
INSTALLED CAPACITY AND ELECTRICITY GENERATION . . . 214
STATUS AND TRENDS IN CHINA, THE EU, INDIA, AND THE UNITED STATES . . . 217
CONCLUSION ON NUCLEAR POWER VS. RENEWABLE ENERGY . . . 226

CLIMATE CHANGE AND NUCLEAR POWER 228

THE STAKES . . . 228

NUCLEAR POWER DISPLACES OTHER CLIMATE SOLUTIONS . . . 230

NON-NUCLEAR OPTIONS SAVE MORE CARBON *PER DOLLAR* . . . 232

New-build Costs . . . 232

Non-Economic Arguments for Nuclear Need . . . 235

Costs of Lifetime-Extended Nuclear Plants . . . 238

Operating Costs of Existing Nuclear Plants . . . 238

Climate Implications of Substantial Nuclear Operating Costs . . . 245

PRACTICAL SOLUTIONS FOR CLIMATE-EFFECTIVENESS . . . 247

Substitution for Existing Nuclear Plants: 5 Case Studies from the U.S. . . . 249

NON-NUCLEAR OPTIONS SAVE MORE CARBON *PER YEAR* . . . 250

IS NUCLEAR POWER A CLIMATE IMPERATIVE? . . . 253

CONCLUSION ON CLIMATE CHANGE AND NUCLEAR POWER . . . 256

ANNEXES 257

ANNEX 1 OVERVIEW BY REGION AND COUNTRY 258

AFRICA . . . 258

South Africa . . . 258

THE AMERICAS . . . 260

Argentina . . . 260

Brazil . . . 262

Canada . . . 263

Mexico . . . 265

United States . . . 266

ASIA AND MIDDLE EAST . . . 266

China . . . 266

India . . . 266

Iran . . . 269

Pakistan . . . 269

South Korea . . . 270

Taiwan . . . 270

EUROPEAN UNION (EU28) . . . 270

WESTERN EUROPE . . . 273

Belgium . . . 273

Finland . . . 273
France . . . 273
Germany . . . 273
The Netherlands . . . 273
Spain . . . 275
Sweden . . . 278
Switzerland . . . 280
CENTRAL AND EASTERN EUROPE . . . 283
Bulgaria . . . 283
Czech Republic . . . 284
Hungary . . . 287
Romania . . . 289
Slovakia . . . 291
Slovenia . . . 293
FORMER SOVIET UNION . . . 294
Armenia . . . 294
Russia . . . 295
Ukraine . . . 299

ANNEX 2 – STATUS OF CHINESE NUCLEAR FLEET 302

ANNEX 3 – STATUS OF JAPANESE NUCLEAR FLEET 304

ANNEX 4 – ABOUT THE AUTHORS 306

ANNEX 5 – ABBREVIATIONS 310

ANNEX 6 - STATUS OF NUCLEAR POWER IN THE WORLD 318

ANNEX 7 - NUCLEAR REACTORS IN THE WORLD "UNDER CONSTRUCTION" 319

TABLE OF FIGURES

Figure 1 | National Nuclear Power Program Startup and Phase-out 29
Figure 2 | Forecasted and Real Expansion of Nuclear Capacity in the World. 30
Figure 3 | Nuclear Electricity Generation in the World... and China 32
Figure 4 | Nuclear Electricity Generation and Share in Global Power Generation. 33
Figure 5 | Nuclear Power Reactor Grid Connections and Closures in the World 34
Figure 6 | Nuclear Power Reactor Grid Connections and Closures – The Continuing China Effect 35
Figure 7 | World Nuclear Reactor Fleet, 1954–2019 37
Figure 8 | Nuclear Reactors "Under Construction" in the World 38
Figure 9 | Average Annual Construction Times in the World 41
Figure 10 | Delays for Units Started Up 2018–2019. 41
Figure 11 | Construction Starts in the World 43
Figure 12 | Construction Starts in the World/China 44
Figure 13 | Cancelled or Suspended Reactor Constructions 45
Figure 14 | Age Distribution of Operating Reactors in the World. 46
Figure 15 | Age Distribution of Closed Nuclear Power Reactors 47
Figure 16 | Nuclear Reactor Closure Age 1963 – 1 July 2019. 48
Figure 17 | The 40-Year Lifetime Projection (not including LTOs) 49
Figure 18 | The PLEX Projection (not including LTOs) 50
Figure 19 | Forty-Year Lifetime Projection versus PLEX Projection 51
Figure 20 | Unavailability of Belgian Nuclear Reactors in 2018 (Cumulated) 56
Figure 21 | Unavailability of Belgian Nuclear Reactors in 2018 (by Outage Period) 57
Figure 22 | The Doel-1 Case 58
Figure 23 | Age Distribution of Chinese Nuclear Fleet 59
Figure 24 | Reactor Outages in France in 2018 (in number of units and GWe) 71
Figure 25 | Forced and Planned Unavailability of Nuclear Reactors in France in 2018 72
Figure 26 | Age Distribution of French Nuclear Fleet (by Decade). 73
Figure 27 | Main Developments of the German Power System Between 2010 and 2018 80
Figure 28 | Rise and Fall of the Japanese Nuclear Program 82
Figure 29 | Age Distribution of Japanese Fleet. 85
Figure 30 | Status of Japanese Reactor Fleet 86
Figure 31 | Age Distribution of U.K. Nuclear Fleet 111
Figure 32 | Age Distribution of U.S. Nuclear Fleet 121
Figure 33 | Timelines of Early Retirement in the United States. 124
Figure 34 | Change in the Number of Evacuees 151
Figure 35 | Number of Disaster-related Deaths of the Great East Japan Earthquake 152

Figure 36 | Closed Reactors Worldwide by Country and Reactor Technology 157
Figure 37 | Overview of Completed Reactor Decommissioning Projects, 1953–2017 158
Figure 38 | Global Investment Decisions in Renewables and Nuclear Power 2004–2018 211
Figure 39 | Regional Breakdown of Nuclear and Renewable Energy Investment Decisions 2008–2018 212
Figure 40 | The Declining Costs of Renewables vs. Traditional Power Sources 213
Figure 41 | Variation of Wind, Solar and Nuclear Capacity and Electricity Production in the World 215
Figure 42 | Net Added Electricity Generation by Power Source 2008–2018 216
Figure 43 | Wind, Solar and Nuclear Capacity and Electricity Production in the World 217
Figure 44 | Installed Wind, Solar and Nuclear Capacity and Electricity Production in China 2000–2018 218
Figure 45 | Startup and Closure of Electricity Generating Capacity in the EU in 2018 220
Figure 46 | Changes in Electricity Generating Capacity in the EU in 2000–2018 221
Figure 47 | Wind, Solar and Nuclear Capacity and Electricity Production in the EU 221
Figure 48 | Wind, Solar and Nuclear Capacity and Electricity Production in the EU 223
Figure 49 | Wind, Solar and Nuclear Installed Capacity and Electricity Production in India 224
Figure 50 | Increases in Electricity Production from Nuclear, Solar and Wind Since 2000 in the United States . . . 225
Figure 51 | Cost Evolution of New Renewables vs. Operating Nuclear 240
Figure 52 | Average Annual Increase of Nuclear, Wind, and Solar 251
Figure 53 | Average Annual Increase of Nuclear, Wind, and Solar 252
Figure 54 | Nuclear Reactors Startups and Closures in the EU28, 1956–1 July 2019 271
Figure 55 | Nuclear Reactors and Net Operating Capacity in the EU28 272
Figure 56 | Age Distribution of the EU28 Reactor Fleet 272
Figure 57 | Age Distribution of the Swiss Nuclear Fleet 281
Figure 58 | Age Distribution of the Russian Nuclear Fleet 298

TABLE OF TABLES

Table 1 | Nuclear Reactors "Under Construction" (as of 1 July 2019) . . . 39
Table 2 | Reactor Construction Times 2009–mid-2019 . . . 42
Table 3 | Belgian Nuclear Fleet (as of 1 July 2019) . . . 53
Table 4 | Legal Closure Dates for German Nuclear Reactors 2011–2022 . . . 79
Table 5 | Official Reactor Closures Post-3/11 in Japan . . . 84
Table 6 | Schedule Closure Dates for Nuclear Power Reactors in Korea 2023–2029 . . . 98
Table 7 | Scheduled Closure Dates for Nuclear Reactors in Taiwan 2018–2025 . . . 108
Table 8 | Early-Retirements for U.S. Reactors 2009-2025 . . . 125
Table 9 | U.S. State Emission Credits for Uneconomic Nuclear Reactors 2016–2019 . . . 134
Table 10 | Thyroid Cancer Statistics in Fukushima Prefecture . . . 154
Table 11 | Update Decommissioning Status in Three Selected Countries . . . 162
Table 12 | Current Status of Reactor Decommissioning in Spain . . . 164
Table 13 | Current Status of Reactor Decommissioning in Italy . . . 166
Table 14 | Current Status of Reactor Decommissioning in Lithuania . . . 169
Table 15 | Overview of Reactor Decommissioning in 11 Selected Countries . . . 174
Table 16 | Summary of Potential Nuclear Newcomer Countries . . . 198
Table 17 | Vendor design review service agreements in force between vendors and the CNSC . . . 202
Table 18 | Vendor design review service agreement between vendors and the CNSC under development . . . 202
Table 19 | New-build Costs for Nuclear, Renewables and Efficiency . . . 232
Table 20 | Average Nuclear Generating Costs in the United States (by Quartile) . . . 239
Table 21 | Average Nuclear Generating Costs in the United States (by Category) . . . 241
Table 22 | Spain's Nuclear Phase-Out Timetable . . . 276
Table 23 | Chinese Nuclear Reactors in Operation . . . 302
Table 24 | Chinese Nuclear Reactors in LTO . . . 303
Table 25 | Status of Japanese Nuclear Reactor Fleet . . . 304
Table 26 | Status of Nuclear Power in the World . . . 318
Table 27 | Nuclear Reactors in the World "Under Construction" . . . 319

FOREWORD

By Diana Ürge-Vorsatz[1]

There is no doubt that climate change is with us. Record temperatures around the globe, higher frequency of droughts, severe fires, storms and flooding are becoming evident even to the starkest of skeptics. The Intergovernmental Panel on Climate Change (IPCC), that I have the honor to serve on as Vice-Chair of Working Group III, made it clear in a Special Report "Global Warming of 1.5°C" that urgent action is needed, as

> challenges from delayed actions to reduce greenhouse gas emissions include the risk of cost escalation, lock-in in carbon-emitting infrastructure, stranded assets, and reduced flexibility in future response options in the medium to long term.[2]

Therefore, time is of the essence. While climate scientists have been aware of the notion of urgency for many years, the notion of "Climate Emergency" has only hit public awareness and decision-makers' attention recently.

The energy sector is the largest cause of global greenhouse gas emissions. The pertinence of mitigation strategy options needs to be judged, among others, according to three key criteria: feasibility, cost and speed.

The aforementioned IPCC Special Report notes that scenarios achieving the 1.5°C target "generally meet energy service demand with lower energy use, including through enhanced energy efficiency and show faster electrification of energy end use compared to 2°C". There is no doubt that the key to successfully addressing the climate crises lies in more efficient buildings, mobility and industry, as well as a dramatic transformation in the way we use our land. The IPCC also notes that "in electricity generation, shares of nuclear and fossil fuels with carbon dioxide capture and storage (CCS) are modelled to increase in most 1.5°C pathways", and several scenarios that reach this temperature target rely heavily on nuclear power. Similarly to other options relied heavily on by 1.5°C pathways, these scenarios raise the question whether the nuclear industry will actually be able to deliver the magnitude of new power that is required in these scenarios in a cost-effective and timely manner. This report is perhaps the most relevant publication to answer this pertinent question.

The *World Nuclear Industry Status Report* (*WNISR*) focuses on the commercial power sector. It assesses in great detail the industry's past and present performance, following a multi-criteria analysis that looks at planning, licensing, siting issues, construction, operation, age, lifetime extensions and decommissioning. Its international reputation is beyond doubt. Already in 2011, an official USAID publication called the WNISR "the authoritative report on the status of nuclear power plants worldwide"[3]; the Founding Director of the Forum for the Future and former Head of the UK Sustainable Development Commission stated that "the WNISR is the single most important reference document in this space"; the *World Scientific's* upcoming *Encyclopedia of Climate Change*[4] will carry a paper on the WNISR. The former Vice-Chairman

1 - Professor and Former Director of the Center for Climate Change and Sustainable Energy Policy (3CSEP), Central European University (CEU), Budapest, and Vice-Chair of Working Group III, Intergovernmental Panel on Climate Change (IPCC).

2 - IPCC, "Global Warming of 1.5°C — Summary for Policymakers", WMO, UNEP, October 2018

3 - USAID-Asia, "Energy Trends in Developing Asia: Priorities for a Low-Carbon Future", September 2011.

4 - World Scientific, "Encyclopedia of Climate Change", forthcoming in 2020, see https://www.worldscientific.com/page/encyclopedia-of-climate-change, accessed 6 September 2019.

of the Japan Atomic Energy Commission recommended: "All concerned parties, including nuclear industry organizations as well as government institutions, should read the WNISR to understand the real issues the nuclear industry is facing."

The WNISR2019 paints a picture of an international nuclear industry with substantial challenges. Remarkably, over the past two years, the largest historic nuclear builder Westinghouse and its French counterpart AREVA went bankrupt. Trend indicators in the report suggest that the nuclear industry may have reached its historic maxima: nuclear power generation peaked in 2006, the number of reactors in operation in 2002, the share of nuclear power in the electricity mix in 1996, the number of reactors under construction in 1979, construction starts in 1976. As of mid-2019, there is one unit less in operation than in 1989.

The WNISR provides the most detailed annual account of the status and outlook of the nuclear power industry based on empirical analysis of its 65-year history. If it is difficult to forecast the future, it is all the more important to understand the past and present in order to be able to design realistic, feasible, affordable strategies for the coming decades. For example, according to the WNISR, the building rate would have to roughly triple over the coming decade in order to *maintain the status quo*. However, after less than a decade of China-driven modest growth, building is on the decline again as the number of units under construction dropped from 68 in 2013 to 46 as of mid-2019.

The IPCC Special Report notes:

> The political, economic, social and technical feasibility of solar energy, wind energy and electricity storage technologies has improved dramatically over the past few years, while that of nuclear energy and carbon dioxide capture and storage (CCS) in the electricity sector have not shown similar improvements.[5]

The WNISR2019 echoes these findings. In 2018, ten nuclear countries generated more power with renewable than with fission energy. In spite of its ambitious nuclear program, China produced more power from wind alone than from nuclear plants. In India, in the fiscal year to March 2019, not only wind, but for the first time solar out-generated nuclear, and new solar is now competitive with existing coal plants in the market. In the European Union, renewables accounted for 95 percent of all new electricity generating capacity added in the past year.

The WNISR is full of pieces of information that put data into perspective. The 2019-Edition also contains a new focus on **Climate Change and Nuclear Power** that reflects in depth about the capacity of the nuclear industry to deliver the magnitude of new power and capacity modeled in several ambitious climate scenarios—whether with new or existing plants—in a cost-effective and timely manner.

The WNISR is an excellent resource as it provides insights into the choices facing policymakers and its historic perspective is invaluable to the energy sector where investment and management decisions have decade-long effects. I would therefore recommend that decision makers and investors all read this report prior to making their decisions.

5 - IPCC, "Global Warming of 1.5°C – Strengthening and Implementing the Global Response", Chapter 4, WMO, UNEP, October 2018.

KEY INSIGHTS

China Still Dominates Developments, But...

- In 2018, nuclear power generation in the world increased by 2.4% of which 1.8% due to a 19% increase in China. Global nuclear power generation excluding China increased by 0.6% for the first time after decreasing three years in a row, but without making up for the decline since 2014.
- Nine reactors started up in 2018 of which seven were in China and two in Russia.
- Four units started up in the first half of 2019, of which two were in China.
- The number of units under construction globally declined for the sixth year in a row, from 68 reactors at the end of 2013 to 46 by mid-2019, of which 10 are in China.

But...

- Still no construction start of any commercial reactor in China since December 2016.
- China will by far miss its Five-Year-Plan 2020 nuclear targets of 58 GW installed and 30 GW under construction.
- China spent a record US$146 billion on renewables in 2017—more than half of the world's total—and saw a decline to US$91 billion in 2018, but still close to twice the U.S., the second largest investor with US$48.5 billion.

No More Reactor Restarts in Japan and Global Construction Delays

- The nuclear share of global electricity generation has continued its slow decline from a historic peak of about 17.5 percent in 1996 to 10.15 percent in 2018.
- Japan had restarted nine reactors by mid-2018 and none since.
- As of mid-2019, 28 reactors—including 24 in Japan—are in Long-Term Outage (LTO).
- At least 27 of the 46 units under construction are behind schedule, mostly by several years; 11 have reported *increased* delays and 3 have had documented delays for the first time over the past year.
- Only nine of the 17 units scheduled for startup in 2018 were actually connected to the grid.

Renewables Continue to Thrive

- A record 165 GW of renewables were added to the world's power grids in 2018, up from 157 GW added the previous year. The nuclear operating capacity increased by 9 GW[6] to reach 370 GW (excluding 25 GW in LTO), a new historic maximum, slightly exceeding the previous peak of 368 GW in 2006.
- Globally, wind power output grew by 29% in 2018, solar by 13%, nuclear by 2.4%. Compared to a decade ago, non-hydro renewables generate over 1,900 TWh *more* power, exceeding coal and natural gas, while nuclear produces *less*.
- Over the past decade, levelized cost estimates for utility-scale solar dropped by 88%, wind by 69%, while nuclear increased by 23%. Renewables now come in below the cost of coal and natural gas.

Climate Change and Nuclear Power

- To protect the climate, we must abate the most carbon at the least cost and in the least time, so *we must pay attention to carbon, cost, and time, not to carbon alone.*
- Non-Nuclear Options Save More Carbon *Per Dollar.* In many nuclear countries, new renewables can now compete economically with *existing* nuclear power plants. The closure of uneconomic reactors will not directly save CO_2 emissions but can indirectly save *more* CO_2 than closing a coal-fired plant, *if the nuclear plant's larger saved operating costs are reinvested* in efficiency or cheap modern renewables that in turn displace more fossil-fueled generation.
- Non-Nuclear Options Save More Carbon *Per Year.* While current nuclear programs are particularly slow, current renewables programs are particularly fast. New nuclear plants take 5–17 years longer to build than utility-scale solar or onshore wind power, so existing fossil-fueled plants emit far more CO_2 while awaiting substitution by the nuclear option. Stabilizing the climate is urgent, nuclear power is slow.

6 - All figures are given for nominal net electricity generating capacity. GW stands for gigawatt or thousand megawatts.

EXECUTIVE SUMMARY AND CONCLUSIONS

As its preceding editions, the *World Nuclear Industry Status Report 2019* (*WNISR2019*) provides a comprehensive overview of nuclear power plant data, including information on age, operation, production and construction. A new chapter on **Climate Change and Nuclear Power** addresses the crucial question of the performance of the nuclear option in countering the increasingly obvious climate emergency. The WNISR assesses the status of new-build programs in the 31 current nuclear countries as well as in potential newcomer countries. WNISR2019 has put particular attention on **10 Focus Countries** representing about two-thirds of the global fleet. The **Fukushima Status Report** gives an overview of the standing of onsite and offsite issues eight years after the beginning of the catastrophe. The **Decommissioning Status Report** for the second time provides an overview of the current state of nuclear reactors that have been permanently closed. The **Nuclear Power vs. Renewable Energy** chapter offers global comparative data on investment, capacity, and generation from nuclear, wind and solar energy. Finally, as usual, **Annex 1** presents a country-by-country overview of the remaining countries' operating nuclear power plants.

Reactor Startups & Closures

Startups. At the beginning of 2018, 15 reactors were scheduled for startup during the year; seven of these made it, plus two that were expected in 2019; of these nine startups, seven were in China and two in Russia.

In mid-2018, 13 reactors were scheduled for startup in 2019, of which five had been connected to the grid as of mid-2019 (including the two started up in 2018)—and four have already been officially delayed until at least 2020. One reactor that was connected to the grid in June 2019, was listed in WNISR2018 as expected to start up only in 2020. The startups in China over the 18 months to July 2019 include the long-awaited grid connections for two Framatome-Siemens designed European Pressurized Water Reactors (EPR) and four Westinghouse AP-1000s.

Closures. Three reactors were closed in 2018, two in Russia and one in the U.S., and a further reactor was closed in the U.S. in May 2019. The Wolsong-1 reactor in South Korea also ceased operation in June 2018, which was only officially confirmed later. In July 2019, Japanese utility Tokyo Electric Power Company (TEPCO) announced the closure of the four Fukushima Daini reactors, situated 15 km from the site of Fukushima Daichi subject to disastrous accidents in 2011. WNISR had already registered all four units as closed. TEPCO announced in August 2019 that it will also decommission five of its seven units at Kashiwazaki-Kariwa, leaving the company with only two of its original fleet of 17 reactors.

Operation & Construction Data[7]

Reactor Operation and Production. There are 31 countries operating 417 nuclear reactors[8]—excluding Long-Term Outages (LTOs)—an increase of four units compared to mid-2018, but one less than in 1989 and 21 fewer than the 2002 peak of 438. The increase is partially due to the restart of 4 reactors previously in LTO.[9] The total operating capacity increased over the past year by 3.4 percent to reach 370 GW,[10] which is a new historic maximum, exceeding the previous peak of 368 GW in 2006. Annual nuclear electricity generation reached 2,563 TWh in 2018—a 2.4 percent increase over the previous year, mainly due to China—but remained 3.7 percent below the historic peak in 2006. After three years of decline, the world nuclear power generation outside China grew by 0.7 percent in 2018 but was still below the level of 2014.

WNISR classifies 28 reactors around the world as being in LTO, all considered operating by the International Atomic Energy Agency (IAEA).[11] These include 24 reactors in Japan, and one each in Canada, China, South Korea and Taiwan[12]. Four reactors have been restarted from LTO since mid-2018, two in India (Kakrapar-1 and -2) and one each in Argentina (Embalse) and France (Paluel-2). Three reactors, two in Japan (Genkai-2, Onagawa-1) and one in Taiwan (Chinshan-1), moved from LTO to closed.

As in previous years, in 2018, the "big five" nuclear generating countries—by rank, the United States, France, China, Russia and South Korea—generated 70 percent of all nuclear electricity in the world. As in 2017, two countries, the U.S. and France, accounted for 47.5 percent of 2018 global nuclear production.

Share in Electricity/Energy Mix. The nuclear share of the world's gross power generation has continued its slow decline from a historic peak of 17.46 percent in 1996 to 10.15 percent in 2018. Nuclear power's share of global commercial primary energy consumption has remained stable since 2014 at around 4.4 percent.

Reactor Age. In the absence of major new-build programs apart from China, the unit-weighted average age of the world operating nuclear reactor fleet continues to rise, and by mid-2019 reached 30.1 years, exceeding the figure of 30 years for the first time. A total of 272 reactors, two-thirds of the world fleet, have operated for 31 or more years, including 80 (19 percent) that have reached 41 years or more.

Lifetime Projections. If all currently operating reactors were closed at the end of a 40-year lifetime—with the exception of the 85 that are already operating for more than 40 years—with all units under construction scheduled to have started up, installed nuclear capacity would still decrease by 9.5 GW by 2020. In total, 14 additional reactors (compared to the end-of-2018

7 - See Focus Countries and Annex 1 for a country-by-country overview of reactors in operation and under construction as well as the nuclear share in electricity generation.

8 - Unless otherwise noted, all figures indicated reflect the situation as of 1 July 2019.

9 - +8 startups +4 restarts –3 new LTOs –5 closures = +4 net

10 - All figures are given for nominal net electricity generating capacity. GW stands for gigawatt or thousand megawatts.

11 - WNISR considers that a unit is in Long-Term Outage (LTO) if it produced zero power in the previous calendar year and in the first half of the current calendar year. This classification is applied retroactively starting on the day the unit is disconnected from the grid. WNISR counts the startup of a reactor from its day of grid connection, and its closure from the day of grid disconnection.

12 - The Taiwanese unit, Chinshan-2, was officially closed in July 2019.

status) would have to be started up or restarted prior to the end of 2020 in order to maintain the status quo of operating units. In the following decade to 2030, 188 units (165.5 GW) would have to be replaced—3.2 times the number of startups achieved over the past decade. In the meantime, construction starts are on a declining trend since 2010.

Construction. Sixteen countries are currently building nuclear power plants, one more than in mid-2018, as the United Kingdom officially started building the first unit of Hinkley Point C. As of 1 July 2019, 46 reactors were under construction—4 fewer than mid-2018 and 22 fewer than in 2013—of which 10 in China. Total capacity under construction is 44.6 GW, 3.9 GW less than one year earlier.

- The current average time since work started at the 46 units under construction is 6.7 years, on the rise for the past two years from an average of 6.2 years as of mid-2017. Many units are still years away from completion.
- *All* reactors under construction in at least half of the 16 countries have experienced delays, mostly several years long. At least 27 (59 percent) of the building projects are delayed.
- Of 27 reactors behind schedule, at least eleven have reported increased delays and three more have documented delays for the first time over the past year since WNISR2018.
- Two reactors have been listed as "under construction" for more than 34 years, Mochovce-3 and -4 in Slovakia, and their startup has been further delayed, currently to 2020–21.
- Six additional reactors have been listed as "under construction" for a decade or more: the two "swimming reactors" Akademik Lomonosov-1 and -2 in Russia, the Prototype Fast Breeder Reactor (PFBR) in India, the Olkiluoto-3 reactor project in Finland, Shimane-3 in Japan and the French Flamanville-3 unit. The Finnish, French and Indian projects have been further delayed over the past year while the Japanese one does not even have a provisional startup date.
- The average construction time of the latest 63 units in nine countries (of which 37 in China) that started up since 2009 was 9.8 years—the first time in years to slip just below ten years—with a very large range from 4.1 to 43.5 years.

Construction Starts & New-Build Issues

Construction Starts. In 2018, construction began on 5 reactors and in the first half of 2019 on one (in Russia). This compares to 15 construction starts in 2010 and 10 in 2013. There has been no construction start of any commercial reactor in China since December 2016. Analysis shows that construction starts in the world peaked in 1976 at 44.

Construction Cancellations. Between 1970 and mid-2019, a total of 94 (12 percent or one in eight) of all construction projects were abandoned or suspended in 20 countries at various stages of advancement.

Potential Newcomer Countries - Program Delays & Cancellations

Construction Ongoing. Four newcomer countries are actually building reactors—Bangladesh, Belarus, Turkey and United Arab Emirates (UAE). The first reactor startup in UAE is at least three years behind schedule. The first unit in Belarus is at least one year delayed. At the

Turkish Akkuyu site, cracks were identified in the foundation of the reactor building, leading to replacement work and likely to delays. The project in Bangladesh only started recently and it is therefore difficult to assess potential delays.

Cancellations and Delays. New-build plans have been cancelled including in Turkey with the second Japanese shareholder Mitsubishi pulling out of the Sinop project in late 2018. The perennial Polish nuclear projects have been postponed again with first power generation now envisaged by 2033. In Egypt, a site permit was issued, but nuclear electricity is not expected before 2026–27. In Jordan and Indonesia, after the cancellation of large nuclear projects, nuclear proponents are back to the drawing board, with Small Modular Reactors this time. In Kazakhstan, after years of talks, the Deputy Energy Minister stated that there was no "concrete decision" to build a nuclear plant. Saudi Arabia ploughs ahead with its nuclear plans, however, "at a slower pace than originally expected", as *Reuters* put it. Thailand's largest private power company prefers to invest in a nuclear plant in China rather than at home. Vietnam's national energy company EVN does not even mention nuclear anymore.

Small Modular Reactors (SMRs)

Following assessments of the development status and prospects of Small Modular Reactors (SMRs) in WNISR2015 and WNISR2017, this year's update does not reveal great changes.

Argentina. The CAREM-25 project under construction since 2014 is at least three years late.

Canada. A massive lobbying effort is underway to promote SMRs for remote communities and mining operations. Development is in the design stage.

China. A high-temperature reactor under development since the 1970s has been under construction since 2012. It is currently at least three years behind schedule.

India. An Advanced Heavy Water Reactor (AHWR) design has been under development since the 1990s, and its construction start is getting continuously delayed.

Russia. Two "floating reactors" have been built. The first one went critical, with construction starting in 2007, it took at least four times as long as planned.

South Korea. The System-Integrated Modular Advanced Reactor (SMART) has been under development since 1997. In 2012, the design received approval by the Safety Authority, but nobody wants to build it in the country, because it is not cost-competitive.

United Kingdom. Rolls-Royce is the only company interested in participating in the government's SMR competition but has requested significant subsidies that he government is apparently resisting. The Rolls-Royce design is at a very early stage but, at 450 MW, it is not really small.

United States. The Department of Energy (DOE) has generously funded companies promoting SMR development. A single design by NuScale is currently undergoing the design certification process.

Overall, there is no sign of any major breakthroughs for SMRs, either with regard to the technology or with regard to the commercial side.

Focus Countries – Widespread Extended Outages

The following nine Focus Countries plus Taiwan, covered in depth in this report, represent one-third of the nuclear countries hosting about two-thirds of the global reactor fleet and six of the world's ten largest nuclear power producers. Key facts for year 2018:

Belgium. Nuclear provided a third less power than in 2017 and represented only 34 percent of the country's electricity, and little more than half of the peak in 1986. Reactors were shut down for repair and upgrading for half of the year *on average*.

China. Nuclear power generation grew by 19 percent in 2018 and contributed 4.2 percent of all electricity generated in China, up from 3.9 percent in 2017.

Finland. Nuclear generation was stable compared to previous years. The Olkiluoto-3 EPR project was delayed again, and grid connection might take until April 2020 at least, due to pressurizer vibration problems.

France. Nuclear plants generated 3.7 percent more power than in 2017, representing 71.7 percent of the country's electricity, just 0.1 percentage points better than in the previous year, which is the lowest share since 1988. Outages at zero capacity cumulated over 5,000 reactor-days or almost three months per reactor *on average*. The Flamanville-3 EPR project was delayed until at least the end of 2022. The target date to reduce the nuclear share to 50 percent was pushed back from 2025 to 2035 in the draft energy bill.

Germany. Germany's remaining seven nuclear reactors' generation remained almost stable (–0.4 percent) at 71.9 TWh net in 2018, about half of record year 2001. They provided a stable 11.7 percent of Germany's electricity generation, little more than one-third of the historic maximum two decades ago (30.8 percent in 1997). In the meantime, renewables have generated close to twice as much more power (+113 TWh) than was lost through the fading nuclear production (–64 TWh) since 2010. In 2018, renewables provided 16.7 percent of final energy in Germany (in comparison, nuclear provided 17.4 percent of French final energy).

Japan. Nuclear plants provided 6.2 percent of the electricity in Japan in 2018, a significant increase over the 3.6 percent in 2017 (36 percent in 1998). As of mid-2019, nine reactors had restarted—no restart since mid-2018—and 24 remained in LTO (two were moved from LTO to closed).

South Korea. Nuclear power output dropped by another 10 percent leading to a decline of 19 percent since 2015, and supplied 23.7 percent of the country's electricity, significantly less than half of the maximum 30 years ago (53.3 percent in 1987).

United Kingdom. Nuclear generation decreased by a further 7.5 percent and provided only 17.7 percent of the power in the country, down from the maximum of 26.9 in 1997. While construction officially started at Hinkley Point C, prospects for other new-build projects have receded with further potential investors pulling out (Japan's Toshiba, Hitachi, Korea's KEPCO).

United States. Nuclear power plants generated a historic maximum of 808 TWh (+3 TWh), while their share in the electricity mix dropped below 20 percent (19.3 percent), 3.2 percentage points below the record level of 22.5 percent in 1995. State subsidies have been granted to four uneconomic nuclear plants to avoid their "early closure", four more are likely, and several

others are under negotiation. However, many units remain threatened with early closure because they cannot compete in the market.

Fukushima Status Report

Over eight years have passed since the Fukushima Daiichi nuclear power plant accident (Fukushima accident) began, triggered by the East Japan Great Earthquake on 11 March 2011 (also referred to as 3/11 throughout the report) and subsequent events.

Onsite Challenges

Spent Fuel Removal from the pool of Unit 3 finally started in April 2019. Target dates for the start of the operation for Units 1 and 2 are "around FY 2023". Debris removal from the pool of Unit 1 was completed in February 2019. For Unit 2 work has not begun, as the spent fuel removal process has been redesigned.

A Fuel Debris Removal method was supposed to be designed by FY 2019. However, as of mid-year, no announcement has been made. Removal from the first unit was supposed to start by 2021, which does not seem credible at this point.

Contaminated Water Management. Large quantities of water are still continuously being injected to cool the fuel debris of Units 1–3. The highly contaminated water runs out of the cracked containments into the basements where it mixes with water that has penetrated the basements from an underground river. The commissioning of a dedicated bypass system and the pumping of groundwater has reduced the influx of water from around 400 m^3/day to about 170 m^3/day. An equivalent amount of water is partially decontaminated and stored in 1,000-m^3 tanks. Thus, a new tank is needed every six days. The storage capacity onsite has been increased to over 1.1 million m^3 and will be enlarged to 1.4 million m^3 by the end of 2020. The ocean release of the water remains widely contested, especially since it was revealed that a large share of the water does not even meet the safety regulations for release.

Worker Health. As of February 2019, there were almost 7,300 workers involved in decommissioning work on-site, 87 percent of whom were subcontractors of Tokyo Electric Power Company (TEPCO). A Health Ministry investigation showed that over half of 290 involved companies were in violation of some kind of labor legislation. In 2018, two additional workers' illnesses were recognized as radiation-induced, bringing to six the number of acknowledged occupational diseases due to work at Fukushima.

Offsite Challenges

Amongst the main offsite issues are the future of tens of thousands of evacuees, the assessment of health consequences of the disaster, the management of decontamination wastes and the costs involved.

Evacuees. As of April 2019, almost 40,000 Fukushima Prefecture residents—not including "self-evacuees"—are still officially designated evacuees of whom about 7,200 are living in the prefecture. According to the Prefecture, the number peaked just under 165,000 in

May 2012. The government has continued to lift restriction orders for affected municipalities. However, according to a recent survey by the Reconstruction Agency, e.g. only 5 percent of the people returned to Namie Town, while half of the former residents already decided not to return. Others remain undecided. The treatment of voluntary evacuees[13] is worsening. Fukushima Prefecture stopped providing free housing in March 2017 and terminated rent assistance for low-income households in March 2019. Once the free housing offer is terminated, they are no longer considered voluntary evacuees and disappear from the statistics. The Special Rapporteurs from the UN Human Rights Commission repeatedly raised concerns about the Japanese policies concerning evacuees and human rights violations linked to families and workers.

Health Issues. Officially, as of April 2019, a total of 212 people have been diagnosed with a malignant tumor or suspected of having a malignant tumor and 169 people underwent surgery. While the cause-effect relationship between Fukushima-related radiation exposure and illnesses has not been established, questions have been raised about the examination procedure itself and the processing of information.

Food Contamination. According to official statistics, among 300,000 samples taken in FY 2018 a total of 313 food items were identified in excess of the legal limits (a significant increase over the 200 items found in FY 2017). As of April 2019, in 23 countries post-3/11 import restrictions remain in place.

Decontamination. Decontamination activities in the Special Decontamination Area ended in March 2018 and generated 16.5 million m^3 of contaminated soil. Outside Fukushima Prefecture, contaminated soil is stored in more than 28,000 places (333,000 m^3). As of April 2019, only about 20 percent of the soil had been moved to dedicated storage areas.

Decommissioning Status Report – Soaring Costs

As an increasing number of nuclear facilities either reaches the end of their pre-determined operational lifetimes or closes due to deteriorating economic conditions, the challenges of reactor decommissioning are coming to the fore.

- As of mid-2019, 162 of the 181 closed reactors in the world (eight more than a year earlier) are awaiting or are in various stages of decommissioning.
- Only 19 units have been fully decommissioned: 13 in the U.S., five in Germany, and one in Japan. Of these, only 10 have been returned to greenfield sites. No change over the year since WNISR2018.
- **Case Studies**: In **France**, decommissioning of the small 80 MW Brennilis reactor will be further delayed, with the earliest possible completion in 2038. In **Germany**, Neckarwestheim-1 and Philippsburg-1 were defueled. In **Italy**, decommissioning cost estimates for the four reactors that used to be operated have almost doubled since 2004 to US$8.1 billion. In **Lithuania**, decommissioning cost estimates for two Soviet, Chernobyl-type reactors increased by two-thirds in five years to US$3.7 billion. If waste management and disposal was included, costs would increase to US$6.8 billion, leaving an estimated funding gap of US$4.7 billion. In **Spain**, decommissioning cost estimates for the

13 - People who lived outside the evacuation zones but evacuated voluntarily.

first 240-MW unit to close in 2006 have doubled since to US$292 million. In the **U.S.**, sales of closed reactors and transfers of decommissioning funds to private waste management companies is spreading. Of ten units undergoing decommissioning, six were sold to such commercial decommissioning companies. The practice raises obvious liability questions in case the available funds run out.

Nuclear Power vs. Renewable Energy Deployment

Cost. Levelized Cost of Energy (LCOE) analysis for the U.S. shows that the total costs of renewables are now below of coal and combined cycle gas. Between 2009 and 2018, utility-scale solar costs came down 88 percent and wind 69 percent, while new nuclear costs increased by 23 percent.

Investment. In 2018, the reported global investment decisions for the construction of nuclear power totaled around US$33 billion for 6.2 GW, which is less than a quarter of the investment in wind and solar individually, with over US$134 billion investment in wind power and US$139 billion in solar, and this year's investment was higher than previous years, but skewed by the start of construction of the extremely expensive Hinkley Point C in the U.K. China remains the top investor in renewables, spending US$91 billion in 2018; however, this was significantly lower than the record US$146 billion invested in 2017[14], due to dropping prices and to policy changes over the year.

Installed Capacity. In 2018, the 165 GW of renewables added to the world's power grids, up from 157 GW added the previous year, set a new record. Wind added 49.2 GW and solar-photovoltaics (PV) 96 GW, both slightly below the 2017-levels. These numbers compare to a net 8.8 GW increase for nuclear power.

Electricity Generation. Ten of the 31 nuclear countries, Brazil, China, Germany, India, Japan, Mexico, Netherlands, Spain, South Africa and U.K.—a list that includes three of the world's four largest economies—generated more electricity in 2018 from non-hydro renewables than from nuclear power. That is one more, South Africa, than in 2017.

In 2018, annual growth for global electricity generation from solar was 29 percent, for wind power about 13 percent. Both growth rates are down compared to 2017, from 38 percent and 18 percent respectively. Nuclear power increased output by 2.4 percent in 2018, mainly due to China, versus +1 percent in 2017.

Compared to 1997, when the Kyoto Protocol on climate change was signed, in 2018 an additional 1,259 TWh of wind power was produced globally and 584 TWh of solar PV electricity, compared to nuclear's additional 299 TWh. Over the past decade, non-hydro renewables have added more kilowatt-hours than coal or gas and twice as many as hydropower, while nuclear plants generated less power in 2018 than in 2008.

In **China**, as in the previous six years, in 2018, electricity production from wind alone (366 TWh) by far exceeded that from nuclear (277 TWh), with solar power catching up quickly (178 TWh).

14 - The number was increased by US$20 billion from earlier estimates.

The same phenomenon is seen in **India**, where wind power (60 TWh) outpaced nuclear—stagnating at 35 TWh—for the third year in a row. At the same time, solar power soared from 11 TWh in 2016 to 31 TWh in 2018, now hot on nuclear's tail.

In the **U.S.**, in 2018, 211 GW of existing coal capacity, or 74 percent of the national fleet, was at risk from local wind or solar that could provide the same amount of electricity more cheaply. In April 2019, for the first time ever, renewables (hydro, biomass, wind, solar and geothermal) generated more electricity than coal-fired plants across the U.S. Wind and solar generation topped coal's output in Texas in the first quarter of 2019, the first time that this has happened on a quarterly basis.

In the **European Union** virtually all new capacity added in 2018 was renewable (95 percent wind, solar and biomass). Wind alone supplied 11.6 percent of the EU's total power in 2018, led by Denmark at a remarkable 41 percent, Portugal and Ireland at 28 percent, and Germany at 21 percent with Spain and the U.K. at 19 percent (up from 13.5 percent in 2017). Compared to 1997, in 2018, EU wind turbines produced an additional 371 TWh and solar 128 TWh, while nuclear power generation *declined* by 94 TWh.

Climate Change and Nuclear Power

The Stakes. To protect the climate, we must abate the most carbon at the least cost—and in the least time—so *we must pay attention to carbon, cost, and time, not to carbon alone.*

Nuclear Power vs. Climate Protection Options. If existing nuclear generation (one-tenth of global commercial electricity) displaced an average mix of fossil-fueled power generation, it would offset the equivalent of 4 percent of total global CO_2 emissions. Expanding nuclear power could displace other generators—fossil-fueled or renewable. Renewables and efficiency can "bolster energy security" at least as well as nuclear power can. The nuclear industry has become one of the most potent obstacles to renewables' further progress by diverting demand and capital to itself. New operating subsidies for uneconomic reactors in the U.S. or preferential dispatch like the "nuclear-must-run" rule in Japan lead to uncompetitive generation to serve demand for which efficiency and renewables are not allowed to compete.

Non-Nuclear Options Save More Carbon *Per Dollar*. Nuclear new-build costs have been on the rise for many years (see previous WNISR editions). Just in the past five years, U.S. solar and wind prices fell by two-thirds, putting new nuclear power out of the money by about 5–10-fold (see **Nuclear Power vs. Renewable Energy Deployment**). Nuclear new-build costs many times more per kWh, so it buys many times less climate solution per dollar than major low-carbon competitors—efficiency, wind and solar. Newer technologies do not change this: in the latest nuclear designs, so-called Gen-III+ reactors, ~78–87 percent of total costs is for the *non*-nuclear part. Thus, if the other ~13–22 percent, the "nuclear island", were free, the rest of the plant would still be grossly uncompetitive with renewables or efficiency. That is, even *free* steam from any kind of fuel or fission is not good enough, because the rest of the plant costs too much. The business case for modern renewables is so convincing to investors that the latest official U.S. forecast foresees 45 GW of renewable additions from mid-2019 to mid-2022, *vs*. net retirements of 7 GW for nuclear and 17 GW for coal.

In many nuclear countries, new renewables can now compete with *existing* nuclear power plants and their operating, maintenance and fuel costs. While reactor-by-reactor data is not available, published information illustrates that many nuclear plants are not competitive anymore. Their closure will not directly save CO_2 emissions but can indirectly save *more* CO_2 than closing a coal-fired plant, *if the nuclear plant's larger saved operating costs are reinvested* in efficiency or cheap modern renewables that in turn displace *more* fossil-fueled generation.

Substitution for Closed Nuclear Plants. Four cases from four different states in the U.S. illustrate that the combination of strong efficiency and renewables policies could not only make up for the loss of nuclear production but allowed for the decrease of coal-based power generation and led to overall CO_2 emissions reductions.

Non-Nuclear Options Save More Carbon *Per Year*. While some nuclear countries had a particularly fast buildup in the 1970s and 1980s (Belgium, France, Sweden, U.S.), many nuclear countries show *faster* buildup of renewables than in their nuclear program (China, Germany, Italy, India, Spain, U.K., and Scotland individually). A key point is that while current nuclear programs are particularly slow, current renewables programs are particularly fast (as WNISR has documented over the past decade). According to a recent assessment, new nuclear plants take 5–17 years longer to build than utility-scale solar or onshore wind power, so existing fossil-fueled plants emit far more CO_2 while awaiting substitution by the nuclear option. In 2018, non-hydro renewables outpaced the world's most aggressive nuclear program, in China, by a factor of two, in India by a factor of three.

Stabilizing the climate is urgent, nuclear power is slow. It meets no technical or operational need that these low-carbon competitors cannot meet better, cheaper, and faster. Even sustaining economically distressed reactors saves less carbon per dollar and per year than reinvesting its avoidable operating cost (let alone its avoidable new subsidies) into cheaper efficiency and renewables.

INTRODUCTION

The first word in the introduction to the 2018-edition of the *World Nuclear Industry Status Report* (*WNISR*) was "Heat". Since then, many registered temperature records around the world were broken and the Intergovernmental Panel on Climate Change (IPCC) issued its most urgent report to date. Over the past year, more than 900 local governments in 18 countries representing over 200 million people have "declared a climate emergency and committed to action to drive down emissions at emergency speed", a movement spreading rapidly.[15]

As the greenhouse gas emissions generated by the construction and operation of nuclear power systems are relatively low[16]—depending on the systems providing the energy necessary to provide mining and milling services, construction materials, transport, waste processing and storage, and, especially, uranium enrichment—some voices have been increasingly audible pushing for lifetime extensions of existing nuclear power plants or the construction of new ones "to address Climate Change".

WNISR2019 devotes a substantial new chapter (see **Climate Change and Nuclear Power**) to the question whether the use of nuclear power represents an effective tool to fight the rapidly worsening Climate Emergency. The question raises a complex mix of economic, industrial and systemic issues. However, the outcome of the analysis is surprisingly clear. The underlying challenge of any potential tool to combat Climate Change is making the best use of every invested dollar, euro or yuan in order to reduce greenhouse gas emissions as quickly as possible. Nuclear new-build turns out to be not only the most expensive, but also the slowest option to bring results. And while other electricity generating technologies are experiencing dramatically declining costs—system costs for utility-scale solar photovoltaics dropped by 88 percent in a decade—the price tag of new nuclear power *increased* (by 23 percent).[17] Even existing, amortized operating nuclear plants are less and less in a position to compete with other options like energy efficiency and renewables, not taking into account system effects like their role as powerful barriers to innovation, investment and effective energy transition measures. We are not assessing here specific technical issues, including the fact that nuclear power is the most water-consuming way to generate electricity and the multiple threats that Climate Change pose to nuclear facilities. It comes as no surprise that in the summer of 2019 a number of reactors again had to reduce output or shut down entirely in several European countries, as water levels were low in rivers and sea temperatures were heating up. Rising sea levels and the increasing frequency of droughts, flooding, severe storms and wildfires raise the risk levels. Operators and regulators only recently began to develop specific programs to address these issues. They could be the subject of a future WNISR focus.

With WNISR2018, we started to assess the performance of the French nuclear sector reactor-by-reactor and this edition presents the complementary analysis to get a full picture of the year 2018. The outcome might come as a big surprise to many readers. The *average* outage

15 - See The Climate Mobilization, "Climate Emergency Campaign", Undated, see https://www.theclimatemobilization.org/climate-emergency-campaign, accessed 3 August 2019.

16 - There are many comparative life-cycle analysis studies and they can vary by one order of magnitude in their results. The level of emissions is also highly sensitive to the electricity mix that powers uranium enrichment plants. However, most studies rate nuclear power at the same level as renewables like wind power in the same grid system.

17 - According to Lazard, "Lazard's Levelized Cost of Energy Analysis—Version 12.0", November 2018, see https://www.lazard.com/media/450784/lazards-levelized-cost-of-energy-version-120-vfinal.pdf, accessed 30 August 2019.

(at zero power, not including reduced output) per unit for the 58 French reactors was almost three months (87.6 days) per year, totaling over 5,000 reactor-days (see **France Focus**). A new, equivalent analysis on Belgium shows that the seven units in the country were down half of the year *on average* (see **Belgium Focus**). There are multiple reasons for this poor performance, with systematically extended maintenance and refurbishment outages at these aging facilities being the principal cause.

The past year since the release of WNISR2018 has seen China completing the commissioning of the first Generation-III reactors, designed by western companies Framatome-Siemens (two EPRs at Taishan) and Westinghouse (four AP-1000 with two each at Sanmen and Haiyang). Questions remain about the pace at which China will continue to expand its nuclear program. Another year went by without any new commercial reactor construction being launched in China, with the latest one started in December 2016 (see **China Focus**). There were press reports about three new government authorizations but any new project has yet to officially begin (pouring of concrete for the base slab of the reactor building).

While the first foreign Generation III reactors went into commercial operation in China, the European EPR projects in France and Finland continue their erratic path towards completion. The French regulator requires the costly, time-consuming repair of welding defects in the main steam line of the Flamanville-3 project, delaying startup to at least end of 2022. Meanwhile, builder AREVA-Siemens is struggling with so-far-unresolved pressurizer vibration issues at the Olkiluoto-3 unit in Finland, delaying grid connection at least to April 2020 (see **Finland Focus**).

In Japan, no new units have been restarted since mid-2018—four restarted in the first half of 2018—and there are still only nine operating reactors in the country. Two additional reactors have been slated for decommissioning, bringing the total of units abandoned since 3/11—the beginning of the Fukushima disaster—to 17. In addition, in July 2019, operator Tokyo Electric Power Company (TEPCO) announced its decision to decommission the four Fukushima Daini reactors (15 km from the Fukushima Daichi site). WNISR has for years considered the Fukushima Daini units as closed. As of mid-2019, 24 reactors remain in Long-Term Outage (LTO) with uncertain prospects for restart, still highly controversial amongst the Japanese public (see **Japan Focus**).

On 28 June 2019, the EPR project at Hinkley Point C project in the U.K. was finally officially declared as "under construction", almost seven months after the beginning of the concreting of the foundations for the reactor building—the usual international setpoint for construction start. Other new-build projects in the U.K. continue to run into trouble. After the pullout of various English, French, German and Spanish utilities from the U.K. "market", the Japanese Hitachi Group abandoned the Wylfa and Oldbury projects, writing off a ¥300 billion (US$2.75 billion) impairment (see **United Kingdom Focus**).

In the U.S., there has been little change in the outlook. Many reactors remain threatened with closure long before their licenses expire because they cannot compete in the market. In some cases, the nuclear industry has been lobbying successfully for subsidies at state level, to help avoiding "early closures" of uneconomic reactors. Five reactors in three states have thus been "saved" for a few years, a mere postponement of closure in an economic environment that is likely to only get worse. The only active new-build project in the U.S., at the Vogtle plant in

Georgia, is accumulating cost and time overruns. Unlike in other states, Georgia Power was authorized to charge its customers for increasing construction costs. It was estimated that by 2018 each 1,000 kWh/month Georgia Power customer would pay US$10 *every month* towards the project, currently scheduled to bring the first of two units online by November 2021. Tennessee Valley Authority (TVA), the public utility that started up the last nuclear reactors ever commissioned in the U.S. in 1996 (Watts Bar-1) and 2016 (Watts Bar-2), stated in its latest Integrated Resource Plan that, while new capacity would be necessary, it would not add any "baseload resources" capacity such as nuclear or coal over the next 20 years "except in the case where Small Modular Reactors are promoted for resiliency".[18]

Small Modular Reactors or SMRs have made little progress since the WNISR2017 assessment as this edition's update concludes "it has become evident that they will be even less capable of competing economically than large nuclear plants, which have themselves been increasingly uncompetitive" (see **Small Modular Reactors**).

The WNISR's overview of the status of decommissioning of closed reactors identifies few major developments, except the consolidation of a trend in the U.S. where utilities sell their closed reactors and transfer decommissioning funds to commercial waste management companies. While eight additional reactors are closed, no new decommissioning project has been completed, and the gap between the two indicators keeps widening.

The traditional **Nuclear Power vs. Renewable Energy** chapter shows that it has become increasingly clear: non-hydro renewables are no longer just cheaper than new-build nuclear but they are now broadly competitive with new-coal—and increasingly with operating nuclear and coal plants whose construction costs have been paid off (amortized). Coal is the largest source of electricity globally, with almost four times the output share of nuclear power. Therefore, outcompeting coal will open up new opportunities for renewable energy, which will further drive down their production costs and increase system integration experience, further speeding up their deployment.

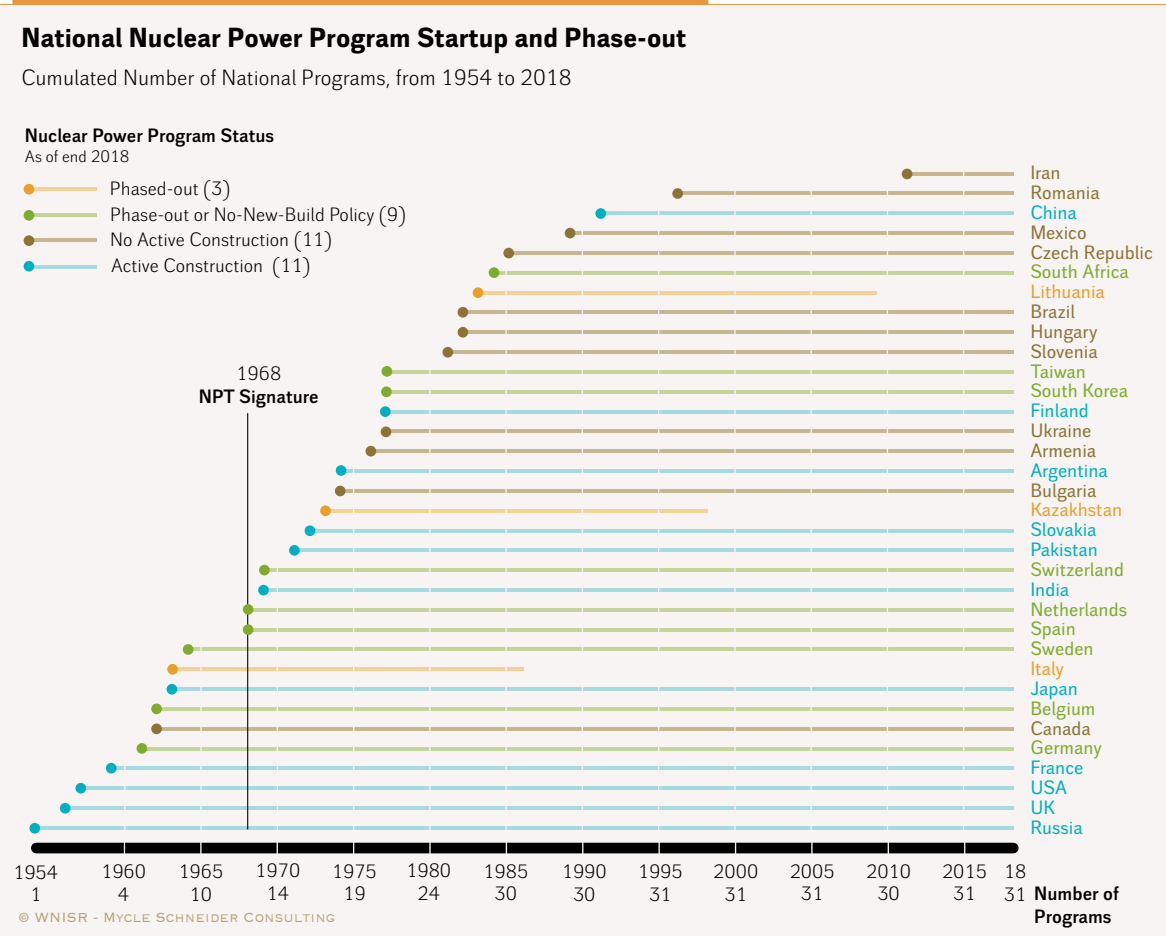
18 - TVA, "2019 Draft Integrated Resource Plan—Executive Summary", Tennessee Valley Authority, 15 February 2019, see https://www.tva.gov/file_source/TVA/Site%20Content/Environment/Environmental%20Stewardship/IRP/2019%20Documents/HDR_TVA%20ExecutiveSummary%20-%20pages.pdf, accessed 10 August 2019.

GENERAL OVERVIEW WORLDWIDE

THE HISTORIC EXPANSION OF NUCLEAR POWER – FORECASTING VS. REALITY

The use of nuclear energy remains limited to a small part of the world, with only 31 countries or 16 percent of the 193 members of the United Nations, operating nuclear power plants. That number has remained stable since Iran started up its first reactor in 2011. When the Nuclear Non-Proliferation Treaty (NPT) was signed in 1968, ten countries had operating nuclear power reactors (grid connected) and twenty additional countries generated nuclear electricity by 1985. But only four countries (Mexico, China, Romania, Iran) started up commercial reactors over the past 30 years, while three countries (Italy, Kazakhstan, Lithuania) abandoned their programs. Nine of the current 31 nuclear countries have either nuclear phase-out, no-new-build

Figure 1 | National Nuclear Power Program Startup and Phase-out



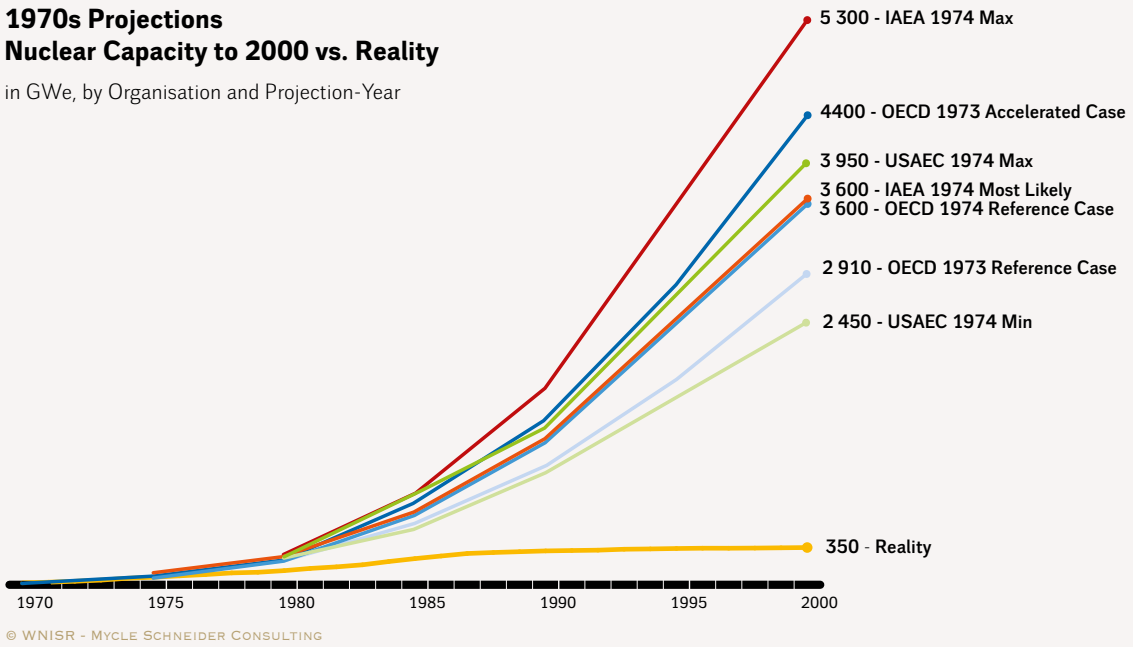
Sources: WNISR, with IAEA-PRIS, 2019

Note: Japan is counted here among countries with "active construction"—however it is possible that the only project under active construction (Shimane-3) will be abandoned.

or no-program-extension policies in place. Eleven countries with operating plants are currently building new reactors; another eleven countries with operating plants currently have no active construction ongoing (see Figure 1). In addition, there are four newcomer countries (Bangladesh, Belarus, Turkey, United Arab Emirates) that are building reactors for the first time.

The NPT was meant to stimulate the development of nuclear energy programs around the world while limiting the spread of military explosives applications to the five historic nuclear weapon states. In 1974, the International Atomic Energy Agency's (IAEA) "most likely" scenario envisaged an installed capacity of over 3,500 GW[19] by year 2000, while the high scenario imagined more than 5,000 GW. It is these forecasts that triggered the launch of massive plutonium separation programs, as the fear of a rapid natural uranium shortage led many nuclear organizations, in particular the French Atomic Energy Commission (CEA), to push for the early, large-scale introduction of plutonium-fueled fast breeder reactors. The U.S. Atomic Energy Commission (AEC), the Organisation for Economic Co-operation and Development (OECD) and other organizations all considered levels above 1,500 GW operating nuclear capacity plausible by 2000. In reality, the expansion of nuclear power remained far below expectations. In 2000, a total capacity of 350 GW was operating in the world, just one tenth of the IAEA's "most likely" scenario of 1974 (see Figure 2). As of mid-2019, total operating capacity has barely grown to its historic peak of 370 GW, a net addition of little more than 1 GW per year over the past two decades.

Figure 2 | Forecasted and Real Expansion of Nuclear Capacity in the World



Source: Klaus Gufler, "Short and Mid-term Trends of the Development of Nuclear Energy", June 2013

19 - Gigawatt or thousand megawatts, about the size of one nuclear reactor; all numbers in GW refer to net electric generating capacity.

PRODUCTION AND ROLE OF NUCLEAR POWER

The world nuclear fleet generated 2,563 net terawatt-hours (TWh or billion kilowatt-hours) of electricity in 2018[20], a 2.4 percent increase over the previous year—essentially due to China's nuclear output increasing by 44 TWh (+19 percent)—but still 4 percent below the historic peak of 2006 (see **Figure 3**). For the first time in four years, without China, global nuclear power generation has slightly increased again (+0.7 percent) in 2018 but remained below the level of 2014. In other words, world nuclear production outside China dropped more in the period 2015–17 than it added in 2018. The numbers illustrate that China continues to dominate the upwards-leaning indicators in nuclear statistics.

Nuclear energy's share of global commercial gross electricity generation continues its slow but steady decline from a peak of 17.5 percent in 1996 to 10.15 percent in 2018 (10.28 percent in 2017). The nuclear contribution to commercial primary energy remained stable at 4.4 percent. It has been at this level since 2014 and constitutes a 30-year low.[21]

In 2018, nuclear generation increased in 14 countries, declined in 12, and remained stable in five.[22] Six countries (China, Hungary, Mexico, Pakistan, Russia, U.S.) achieved their greatest ever nuclear production in 2018.

The following remarkable developments for the year 2018 illustrate the volatile operational situation of the individual national reactor fleets (see country-specific sections for details):

- Armenia's only operating reactor dropped generation by 21 percent. The output will likely decline further in 2019 as the unit was shut down in mid-year for extensive repair and upgrade.
- Belgium's output plunged by 32 percent due to the extension of outages for maintenance, repair and upgrade. On average, Belgium's seven units have each been down for half of the year (see **Belgium Focus**).
- China started up seven new nuclear reactors during the year, a remarkable achievement, and contributed 44 TWh of the total increase of 60 TWh worldwide (see **China Focus**).
- France increased output by 14 TWh (+3.7 percent), remaining however well below expectations (see **France Focus**).
- Japan restarted four more units bringing the total of operating reactors to nine and boosting production by 20 TWh (+68.4 percent) (see **Japan Focus**).
- South Korea's nuclear production dropped by 10 percent (–14 TWh) due to extended outages for inspection and repair. One of the specific issues that has led to delays in restarts of reactors has been the discovery in 2017 of Containment Liner Plate (CLP) corrosion in various reactors (see **South Korea Focus**).

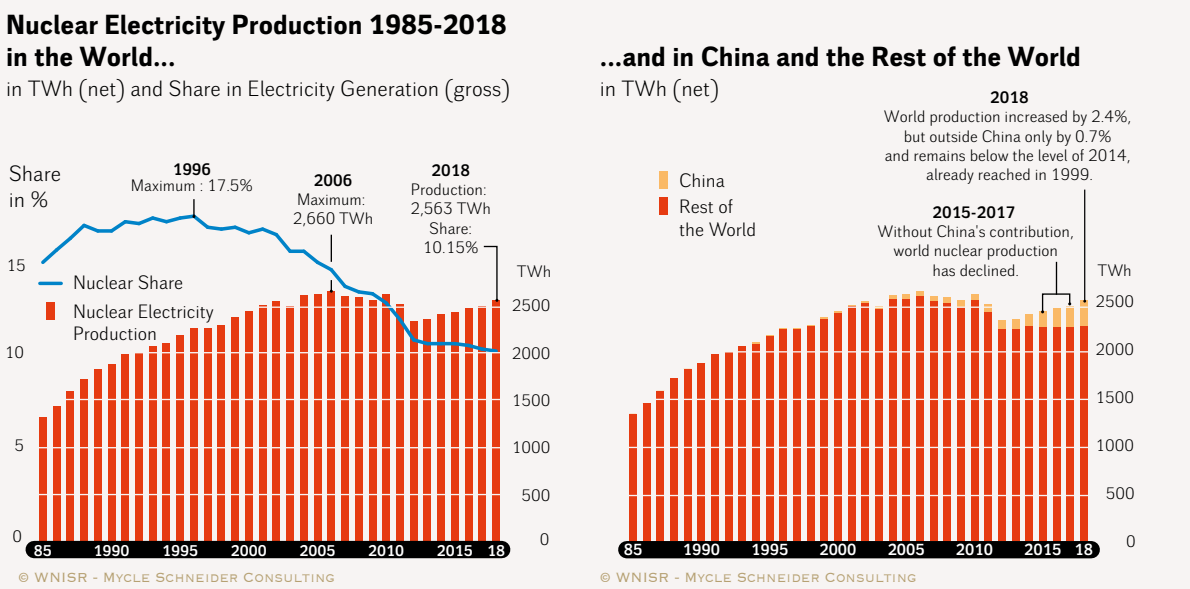
20 - If not otherwise noted, all nuclear capacity and electricity generation figures based on International Atomic Energy Agency (IAEA), Power Reactor Information System (PRIS) online database, see https://prisweb.iaea.org/Home/Pris.asp. Production figures are net of the plant's own consumption unless otherwise noted.

21 - BP, "Statistical Review of World Energy", June 2019, see https://www.bp.com/content/dam/bp/business-sites/en/global/corporate/pdfs/energy-economics/statistical-review/bp-stats-review-2019-full-report.pdf, accessed 11 June 2019.

22 - Less than 1 percentage point variation from the previous year.

- Switzerland's generation increased by 25 percent after the restart of one of the five-reactor fleet that had been down for years following the discovery of numerous crack indications in its pressure vessel (see **Switzerland section**).
- Taiwan increased output by 24 percent after the restart of two reactors following long outages. However, generation remained below the level of 2016 (see **Taiwan Focus**).
- The U.S. registered its all-time highest nuclear electricity generation. While the increase over the previous record in 2010 (+1 TWh) remains marginal, it is noteworthy that the country operated six fewer reactors in 2018 than in 2010 (97/103). Even the installed capacity was slightly lower in 2018 than in 2010 (98.7 GW/100.4 GW), a clear indication that operational efficiency has continued to improve (see **U.S. Focus**).

Figure 3 | Nuclear Electricity Generation in the World... and China[23]



Sources: WNISR, with BP, IAEA-PRIS, 2019

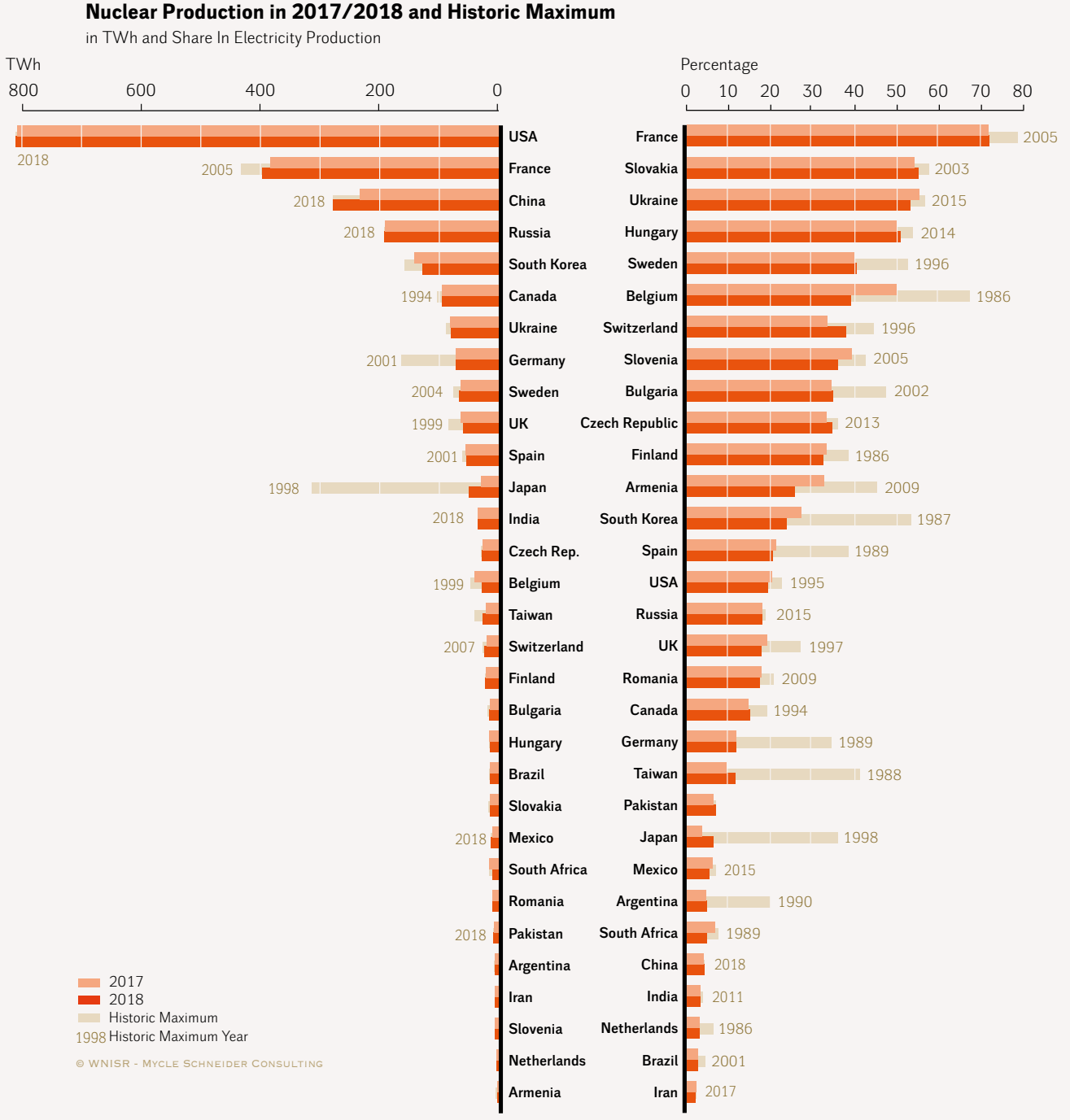
As in previous years, in 2018, the "big five" nuclear generating countries—by rank, the U.S., France, China, Russia and South Korea—generated 70 percent of all nuclear electricity in the world (see **Figure 4**, left side). In 2002, China held position 15, in 2007 it was tenth, before reaching third place in 2016. Two countries, the U.S. and France, with 47 percent accounted again for nearly half of global nuclear production in 2018.

In many cases, even where nuclear power generation increased, the addition is not keeping pace with overall increases in electricity production, leading to a nuclear share below the respective historic maximum (see **Figure 4**, right side). It is therefore remarkable that, in 2018, there were 20 countries that maintained their nuclear share at a constant level (change of less than 1 percentage point) while seven decreased their nuclear shares. Only four countries increased the role of nuclear power in their electricity mix by more than 1 point (Czech Republic, Japan, Switzerland and Taiwan), all of them mainly through restarts of units after prolonged outages. Only two countries (China and Pakistan) reached new historic peak shares of nuclear

23 - BP stands for BP plc; WNISR for World Nuclear Industry Status Report.

in their respective power mix, both at marginal increases getting to still very modest levels, +0.3 percentage points for China (reaching a share of 4.2 percent) and +0.6 percentage points for Pakistan (attaining 6.8 percent.)

Figure 4 | Nuclear Electricity Generation and Share in Global Power Generation

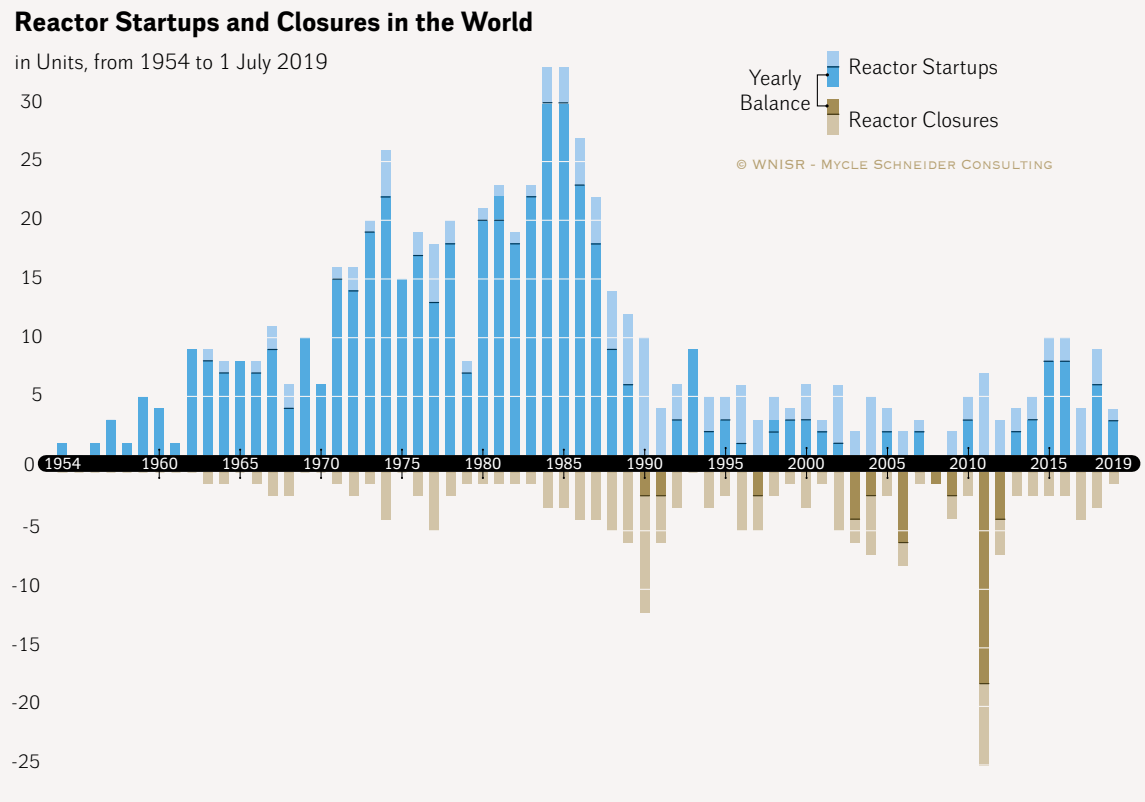


Source: IAEA-PRIS, 2019

OPERATION, POWER GENERATION, AGE DISTRIBUTION

Since the first nuclear power reactor was connected to the Soviet power grid at Obninsk in 1954, there have been two major waves of startups. The first peaked in 1974, with 26 grid connections in that year. The second reached a historic maximum in 1984 and 1985, just before the Chernobyl accident, reaching 33 grid connections in each year. By the end of the 1980s, the uninterrupted net increase of operating units had ceased, and in 1990 for the first time the number of reactor closures[24] outweighed the number of startups. The 1991–2000 decade produced far more startups than closures (52/30), while in the decade 2001–2010, startups did not match closures (32/35). Furthermore, after 2000, it took a whole decade to connect as many units as in a single year in the middle of the 1980s. Between 2011 and mid-2019, the startup of 56 reactors—of which 35 (almost two thirds) in China alone—outpaced by six the closure of

Figure 5 | Nuclear Power Reactor Grid Connections and Closures in the World



Sources: WNISR, with IAEA-PRIS, 2019

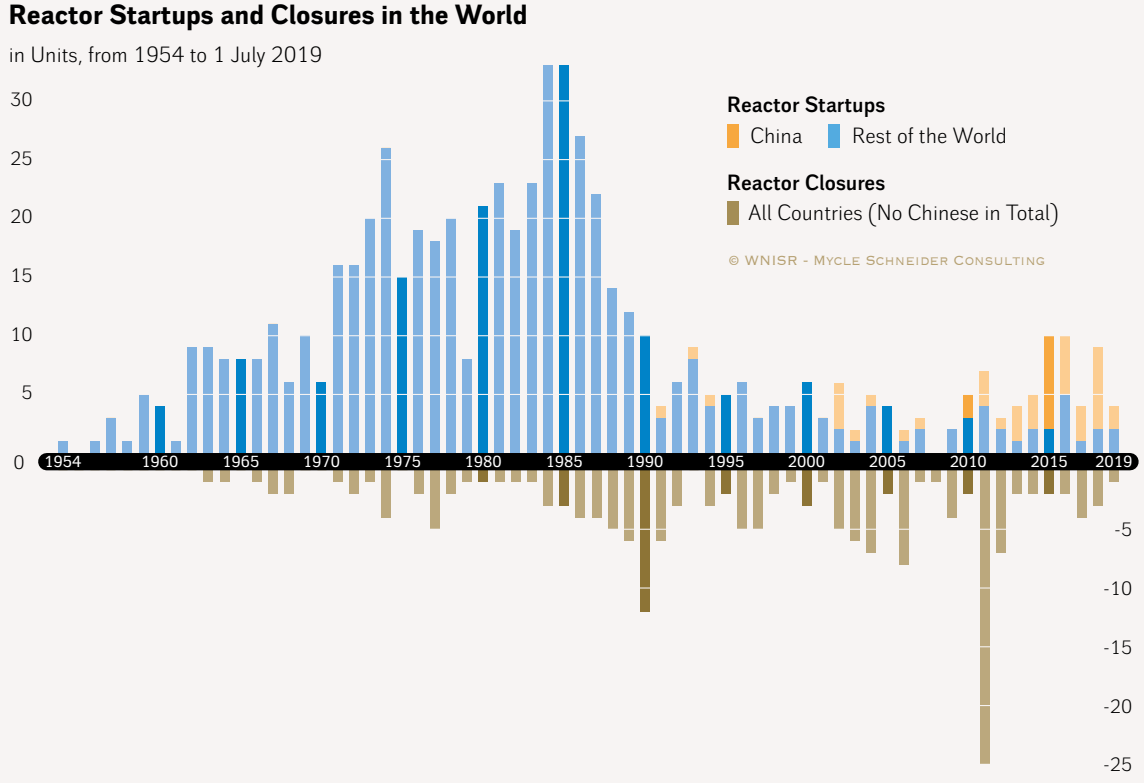
Notes
As of 2019, WNISR is using the term "Closed" instead of "Permanent Shutdown" for reactors that have ceased power production, as WNISR considers the reactors closed as of the date of their last production. Although this definition is not new, it had not been applied to all reactors or fully reflected in the WNISR database; this applies to known/referenced examples like Superphénix in France, which had not produced in the two years before it was officially closed or the Italian reactors that were de facto closed prior to the referendum in 1987, or some other cases. Those changes obviously affect many of the Figures relating to the world nuclear reactor fleet (Startup and Closures, Evolution of world fleet, Age of closed reactors, amongst others.)

24 - With WNISR2019 we are introducing "closure" as general term for permanent shutdown, in order to avoid confusion with the use of "shutdown" for provisional grid disconnections for maintenance, refueling, upgrading or due to incidents. WNISR considers closure from the moment of grid disconnection—and not from the moment of the industrial, political or economic decision—and as the units have not generated power for several years, in WNISR statistics, they are closed in the year of their latest power generation.

50 units over the same period. As there were no closures in China over the period, the 50 closures outside China were only met by 21 startups, a startling decline by 29 units over the period. (See **Figure 5**).

After the startup of 10 reactors in each of the years 2015 and 2016, only four units started up in 2017, of which three in China and one in Pakistan (built by Chinese companies). In 2018, nine reactors generated power for the first time, of which seven in China and one each in Russia and South Korea, while three units were closed, of which two in Russia and one in the U.S. (See **Figure 6**).

Figure 6 | Nuclear Power Reactor Grid Connections and Closures – The Continuing China Effect



Sources: WNISR, with IAEA-PRIS, 2019

In the first half of 2019, four reactors started up in the world, two of which were in China (Taishan-2, Yangjiang-6) and one each in Russia (Novovoronezh 2-2) and South Korea (Shin-Kori-4), while one unit was closed in the U.S. (Pilgrim-1).

As of mid-August 2019, the International Atomic Energy Agency (IAEA) continues to count 37 units in Japan (five less than in mid-2018) in its total number of 451 reactors "in operation" in the world (two less than mid-2018)[25]; yet no nuclear electricity was generated in Japan between September 2013 and August 2015, and as of 1 July 2019, only nine reactors were operating (see **Japan Focus**). Nuclear plants provided only 6.2 percent of the electricity in Japan in 2018.

25 - IAEA, "Power Reactor Information System", International Atomic Energy Agency, Undated, see https://pris.iaea.org/pris/CountryStatistics/CountryDetails.aspx?current=JP, accessed 28 July 2019.

The WNISR reiterates its call for an appropriate reflection in world nuclear statistics of the unique situation in Japan. The attitude taken by the IAEA, the Japanese government, utilities, industry and many research bodies as well as other governments and organizations to continue considering the entire stranded reactor fleet in the country as "in operation" or "operational" is misleading.

The IAEA actually does have a reactor-status category called "Long-term Shutdown" or LTS.[26] Under the IAEA's definition, a reactor is considered in LTS, if it has been shut down for an "extended period (usually more than one year)", and in early period of shutdown either restart is not being "aggressively pursued" or "no firm restart date or recovery schedule has been established". The IAEA currently lists zero reactors anywhere in the LTS category.

The IAEA criteria are vague and hence subject to arbitrary interpretation. What exactly are *extended* periods? What is *aggressively* pursuing? What is a *firm* restart date or recovery schedule? Faced with this dilemma, the WNISR team in 2014 decided to create a new category with a simple definition, based on empirical fact, without room for speculation: "Long-term Outage" or LTO. Its definition:

> A nuclear reactor is considered in Long-term Outage or LTO if it has not generated any electricity in the previous calendar year and in the first half of the current calendar year. It is withdrawn from operational status retroactively from the day it has been disconnected from the grid.

When subsequently the decision is taken to close a reactor, the closure status starts with the day of the last electricity generation, and the WNISR statistics are retroactively modified accordingly.

Applying this definition to the world nuclear reactor fleet, as of 1 July 2019, leads to classifying 28 units in LTO—all considered "in operation" by the IAEA—four fewer than in WNISR2018, of which 24 in Japan, and one each in Canada, China, South Korea and Taiwan. Four reactors restarted from LTO since mid-2018, two in India (Kakrapar-1 and -2) and one each in Argentina (Embalse) and France (Paluel-2). Three reactors, two in Japan (Genkai-2, Onagawa-1) and one in Taiwan (Chinshan-1), moved from LTO to closed.

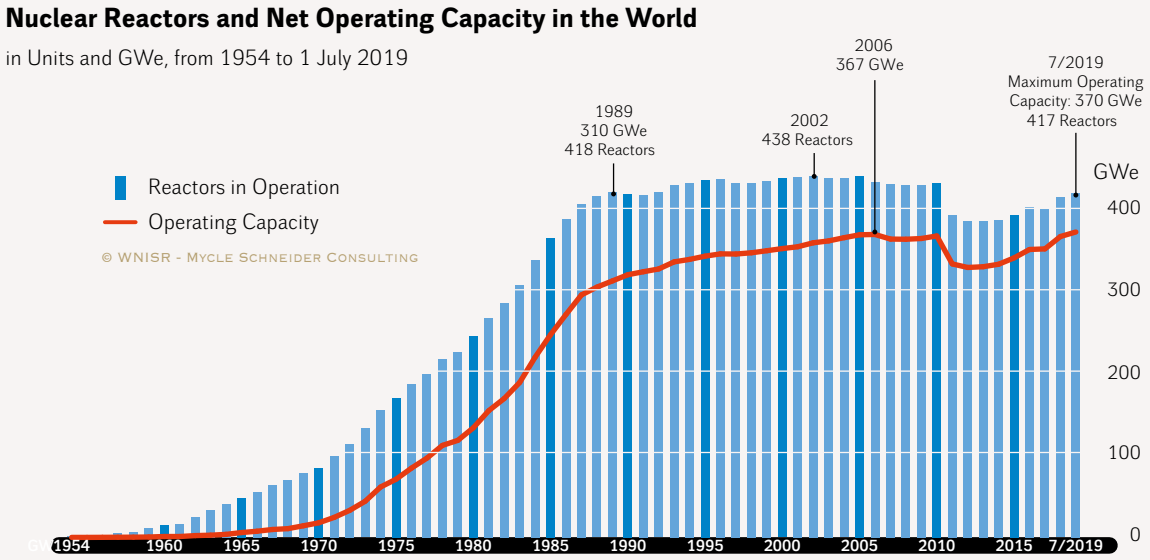
For years, WNISR has considered all ten Fukushima reactors closed. In July 2019, operator Tokyo Electric Power Company (TEPCO) finally officialized the closure and announced plans to decommission the four Fukushima Daini reactors (see **Table 5** and **Annex 3** for a detailed overview of the status of the Japanese nuclear fleet).

As of 1 July 2019, a total of 417 nuclear reactors were operating in 31 countries, up four units from the situation in July 2018[27]. The current world fleet has a total nominal electric net capacity of 370 GW, up by 6.7 GW (+1.9 percent) from one year earlier (see **Figure 7**). While the number of operating reactors remains below the figure reached in 1989 and nuclear electricity generation is still a few percent below the 2006 peak, this is a new historic maximum for operating capacity.

26 - See IAEA Glossary, at www.iaea.org/pris/Glossary.aspx, accessed 1 July 2016.

27 - +8 startups +4 restarts –3 new LTOs –5 closures

Figure 7 | World Nuclear Reactor Fleet, 1954–2019



Sources: WNISR, with IAEA-PRIS, 2019

Note
Changes in the database regarding closing dates of reactors or LTO status slightly change the shape of this graph from previous editions. In particular, the previous "maximum operating capacity" of 2006 (overtaken in July 2019) is now at 367 GW.

For many years, the net installed capacity has continued to increase more than the net number of operating reactors. In 1989, the average size of an operational nuclear reactor was about 740 MW, while that number has increased to almost 890 MW in 2019. This is a result of the combined effects of larger units replacing smaller ones and technical alterations to raise capacity at existing plants resulting in larger electricity output, a process known as uprating.[28] In the United States alone, the Nuclear Regulatory Commission (NRC) has approved 164 uprates since 1977. The cumulative approved uprates in the U.S. total 7.9 GW, the equivalent of eight large reactors.[29] No additional uprates were approved since April 2018 and there are no pending applications as of mid-2019. However, four additional applications are expected during the rest of the year.

A similar trend of uprates and major overhauls in view of lifetime extensions of existing reactors has been seen in Europe. The main incentive for lifetime extensions is economic but this argument is being increasingly challenged as backfitting costs soar and alternatives become cheaper.

28 - Increasing the capacity of nuclear reactors by equipment upgrades e.g. more powerful steam generators or turbines.

29 - U.S.NRC, "Approved Applications for Power Uprates", U.S. Nuclear Regulatory Commission, Updated 2 April 2019, see http://www.nrc.gov/reactors/operating/licensing/power-uprates/status-power-apps/approved-applications.html, accessed 12 August 2019.

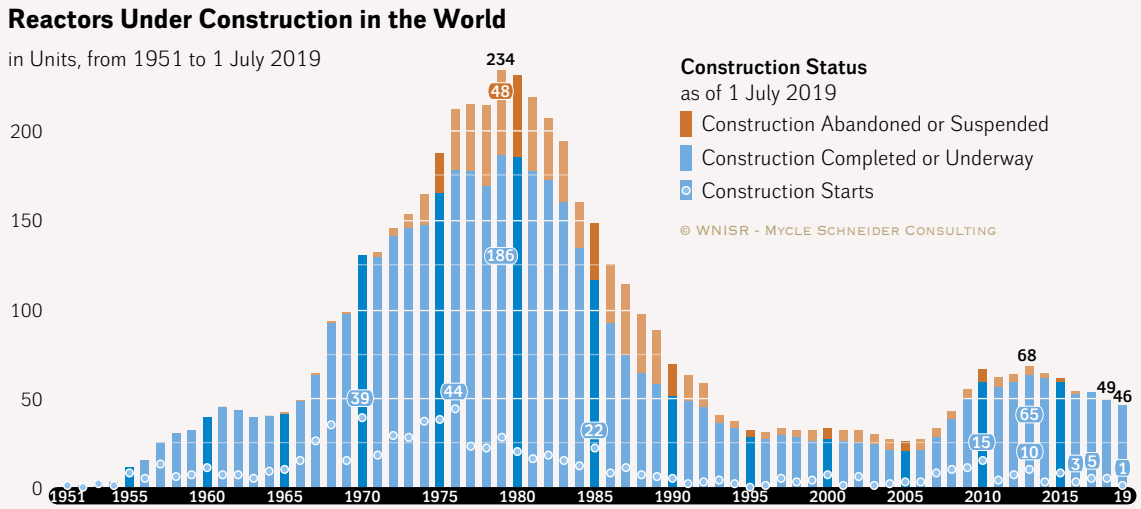
OVERVIEW OF CURRENT NEW-BUILD

As of 1 July 2019, 46 reactors are considered here as under construction, the lowest number in a decade, falling for the sixth year in a row—four fewer than WNISR reported a year ago, and 22 fewer than in 2013 (five of these units have already subsequently been abandoned). Three in four reactors are built in Asia and Eastern Europe. In total, 16 countries are building nuclear plants, one more (U.K.) than reported in WNISR2018 (see **Table 1**).

Five building projects were launched in 2018, one each in Bangladesh, Russia, South Korea, Turkey and the U.K. In the first half of 2019, only one project started construction in the world, in Russia. Russian companies are also building the reactors in Bangladesh and Turkey, Russia is therefore involved in four of these six projects launched since the beginning of 2018.

The figure of 46 reactors listed as under construction by mid-2019 compares poorly with a peak of 234—totaling more than 200 GW—in 1979. However, many (48) of those projects listed in 1979 were never finished (see **Figure 8**). The year 2005, with 26 units under construction, marked a record low since the early nuclear age in the 1950s. Compared to the situation described a year ago, the total capacity of units now under construction in the world dropped again, by 3.9 GW to 44.6 GW, with a rather stable average unit size of 969 MW (see **Annex 7** for details).

Figure 8 | Nuclear Reactors "Under Construction" in the World (as of 1 July 2019)



Sources: WNISR, with IAEA-PRIS, 2019

Table 1 | Nuclear Reactors "Under Construction" (as of 1 July 2019) [30]

Country	Units	Capacity (MW net)	Construction Starts	Grid Connection	Units Behind Schedule
China	10	8 800	2012 - 2017	2020 - 2023	2-3
India	7	4 824	2004 - 2017	2019 - 2023	5
Russia	5	3 379	2007 - 2019	2019 - 2023	3
UAE	4	5 380	2012 - 2015	2020 - 2023	4
South Korea	4	5 360	2012 - 2018	2019 - 2024	4
Belarus	2	2 218	2013 - 2014	2019 - 2020	1-2
Bangladesh	2	2 160	2017 - 2018	2023 - 2024	0
Slovakia	2	880	1985	2020 - 2021	2
USA	2	2 234	2013	2021 - 2022	2
Pakistan	2	2 028	2015 - 2016	2020 - 2021	0
Japan	1	1 325	2007	?	1
Argentina	1	25	2014	2021	1
UK	1	1 630	2018	2025	0
Finland	1	1 600	2005	2020	1
France	1	1 600	2007	2022	1
Turkey	1	1 114	2018	2024	0
Total	**46**	**44 557**	**1985 - 2019**	**2019 - 2025**	**27-29**

Sources: Compiled by WNISR. 2019

Note

This table does not contain suspended or abandoned constructions.

30 - For further details, see Annex 7.

CONSTRUCTION TIMES

CONSTRUCTION TIMES OF REACTORS *CURRENTLY UNDER CONSTRUCTION*

A closer look at projects presently listed as "under construction" illustrates the level of uncertainty and problems associated with many of these projects, especially given that most builders assume a five-year construction period to begin with:

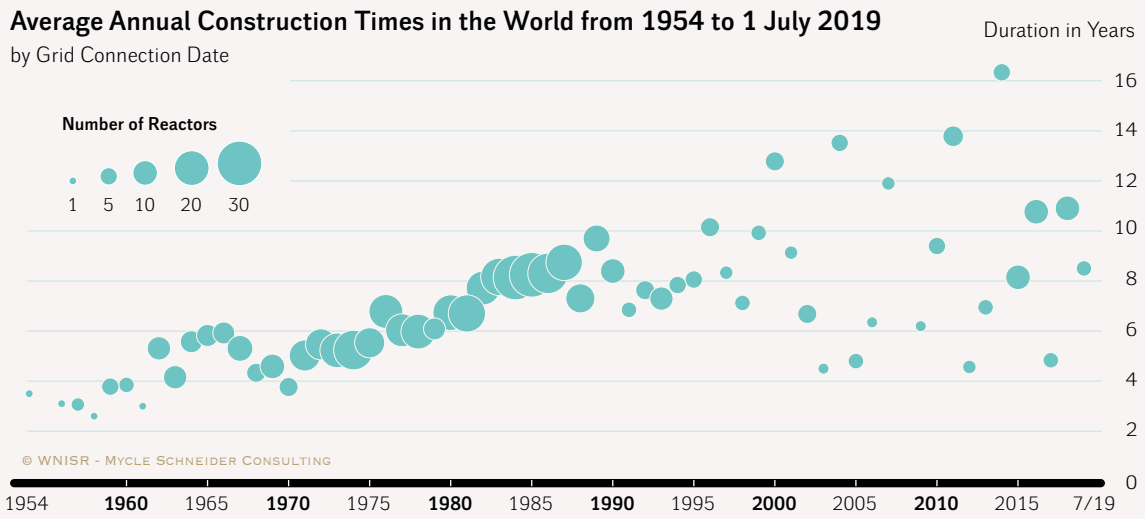
- As of 1 July 2019, the 46 reactors being built have been under construction for an average of 6.7 years, and many remain far from completion.
- *All* reactors under construction in at least half of the 16 countries have experienced mostly year-long delays. At least 27 (59 percent) of the building projects are delayed. Most of the units which are nominally being built on-time were begun within the past three years or have not yet reached projected startup dates, making it difficult to assess whether or not they are on schedule. Particular uncertainty remains over construction sites in Belarus, China and UAE.
- Of the 27 reactors clearly documented as behind schedule, at least eleven have reported *increased* delays and five have reported *new* delays over the past year since WNISR2018.
- WNISR2017 noted a total of 19 reactors scheduled for startup in 2018, one of these started up already in 2017. At the beginning of 2018, 15 reactors were still scheduled for startup during the year, but only nine made it, while the others were delayed at least into 2019.
- Construction on two projects started over 30 years ago, Mochovce-3 and -4 in Slovakia, and their startup has been further delayed, currently to 2020–21.
- Four reactors have been listed as "under construction" for a decade or more: the Prototype Fast Breeder Reactor (PFBR) in India, the Olkiluoto-3 reactor project in Finland, Shimane-3 in Japan and the French Flamanville-3 unit. The Finnish, French and Indian projects have been further delayed this year, and the Japanese one does not even have a provisional startup date.

The actual lead time for nuclear plant projects includes not only the construction itself but also lengthy licensing procedures in most countries, complex financing negotiations, site preparation and other infrastructure development. As the U.K.'s Hinkley Point C project illustrates, a significant share of investment and work was carried out before even entering the official construction phase (see **United Kingdom Focus**).

CONSTRUCTION TIMES OF PAST AND *CURRENTLY OPERATING* REACTORS

There has been a clear global trend towards increasing construction times. National building programs were faster in the early years of nuclear power. As **Figure 9** illustrates, construction times of reactors completed in the 1970s and 1980s were quite homogenous, while in the past two decades they have varied widely.

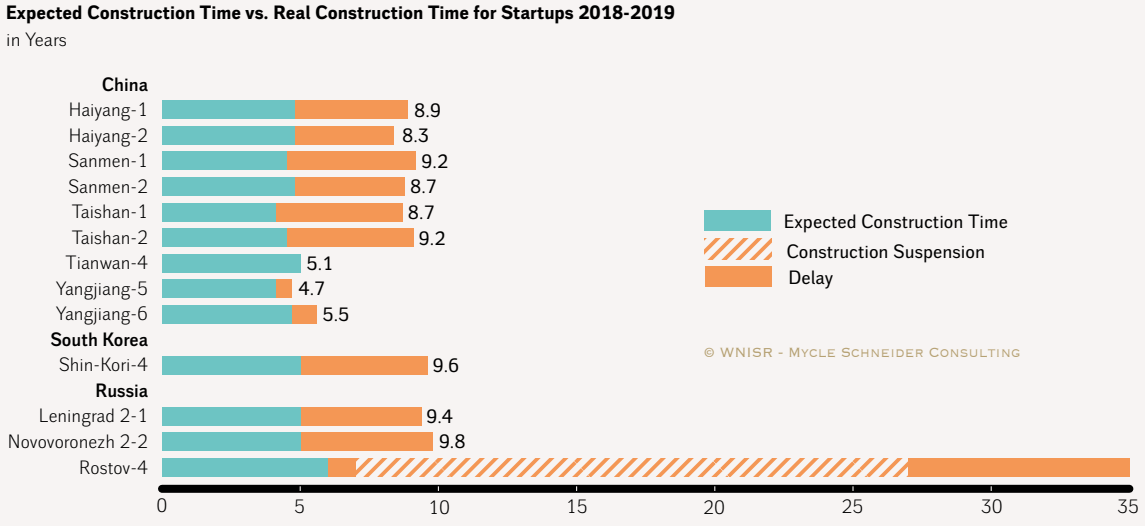
Figure 9 | Average Annual Construction Times in the World



Sources: WNISR, with IAEA-PRIS, 2019

The seven units completed in 2018 by the Chinese nuclear industry averaged 7.7 years of construction time, while the two Russian projects took a mean 22.3 years to connect to the grid, with Rostov-4 taking 35 years to finally generate power (see The Construction Saga of Rostov Reactors 3 and 4) and Leningrad 2-1 close to 10 years. The mean construction time for the nine reactors started up in 2018 was 10.9 years.

Figure 10 | Delays for Units Started Up 2018-2019



Sources: WNISR with IAEA-PRIS, 2019

Note

Expected construction time is based on grid connection data provided at construction start when available; alternatively best estimates are used, based on commercial operation, completion, or commissioning information.

There is only one unit that in the past 18 months started up on time, and that is Tianwan-4 in China, a Russian-designed but mainly Chinese-built VVER-1000 (model V-428M), that

the designers claim to belong to Gen-III, but few details are known. The two Chinese units Yangjiang-5 and -6 were completed with minor delays in 4.7 and 5.5 years respectively. These are ACPR-1000 reactors, designed by China General Nuclear Corp. (CGN) that it claims contain at least ten improvements making them a Gen-III design.[31] Leaving the epic Rostov-4 case aside, the other six units that started up in China (four AP-1000s, two EPRs), the two in Russia and the one in South Korea all experienced years-long delays and roughly doubled their respective planned construction time to 8.3–9.8 years (see **Figure 10**).

The longer-term perspective confirms that short construction times remain the exceptions. Nine countries completed 63 reactors over the past decade—of which 37 in China alone—after an average construction time of 9.8 years (see **Table 2**), a slight improvement over the decade 2008–mid-2018 with 10.1 years.

Table 2 | Reactor Construction Times 2009–mid-2019

Construction Times of 63 Units Started-up 2009–7/2019				
Country	Units	Construction Time (in Years)		
		Mean Time	Minimum	Maximum
China	37	6.0	4.1	11.2
Russia	8	22.2	8.1	35.0
South Korea	6	6.0	4.1	9.6
India	5	9.8	7.2	14.2
Pakistan	3	5.4	5.2	5.6
Argentina	1	33.0	33.0	
Iran	1	36.3	36.3	
Japan	1	5.1	5.1	
USA	1	43.5	43.5	
World	**63**	**9.8**	**4.1**	**43.5**

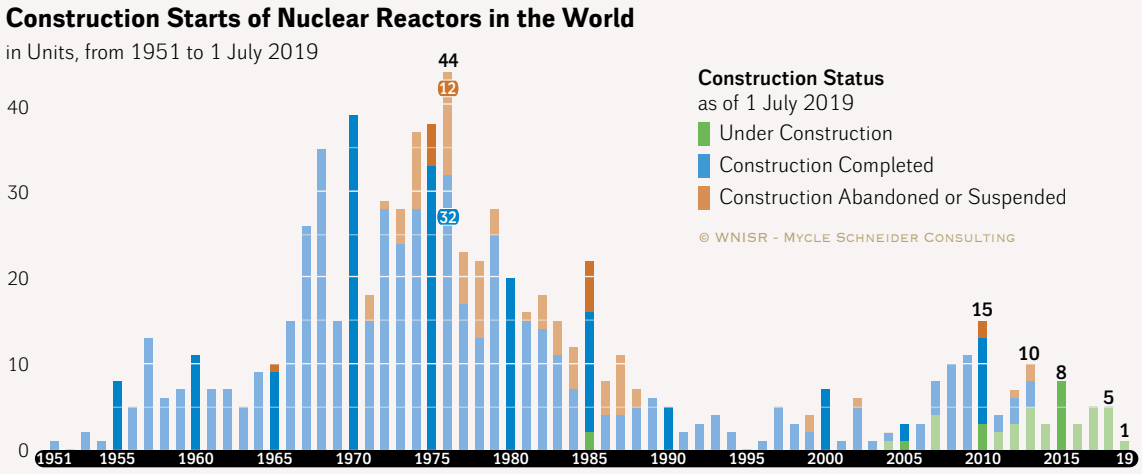
Sources: Compiled by WNISR. 2019

31 - Caroline Peachey, "Chinese reactor design evolution", *Nuclear Engineering International*, 22 May 2014, see https://www.neimagazine.com/features/featurechinese-reactor-design-evolution-4272370/, accessed 14 August 2019.

CONSTRUCTION STARTS AND CANCELLATIONS

The number of annual construction starts[32] in the world peaked in 1976 at 44, of which 12 projects were later abandoned. In 2010, there were 15 construction starts—including 10 in China alone—the highest level since 1985 (see **Figure 11**). That number dropped to five in 2017 and five in 2018. The construction starts in 2018 were unusually diverse as one each took place in Bangladesh, Russia, South Korea, Turkey and U.K. Also, with Bangladesh and Turkey, the list contains two newcomer countries. In both countries, the projects are implemented by the Russian nuclear industry. In Turkey work started at the Akkuyu site, a project that has been proposed since the 1970s. As of mid-2019, only one project got officially underway in the world so far this year, Kursk 2-2 in Russia.

Figure 11 | Construction Starts in the World



Sources: WNISR, with IAEA-PRIS, 2019

Seriously affected by the Fukushima events, China did not start any construction in 2011 and 2014 and began work only on seven units in between. While Chinese utilities started building six more units in 2015, the number shrank to two in 2016, only a demonstration fast reactor in 2017, none in 2018 and none in 2019 as of mid-year (see **Figure 12**). In other words, since December 2016, China has not started building any new commercial reactors. According to media reports, three construction starts got government approval and could take place later in 2019. While this development would mean a restart of commercial reactor building in China, for the time being, the level remains far below expectations. The five-year plan 2016–2020 had fixed a target of 58 GW operating and 30 GW under construction by 2020. As of mid-2019, China had 45.5 GW operating and 9 GW under construction, far from the original target.

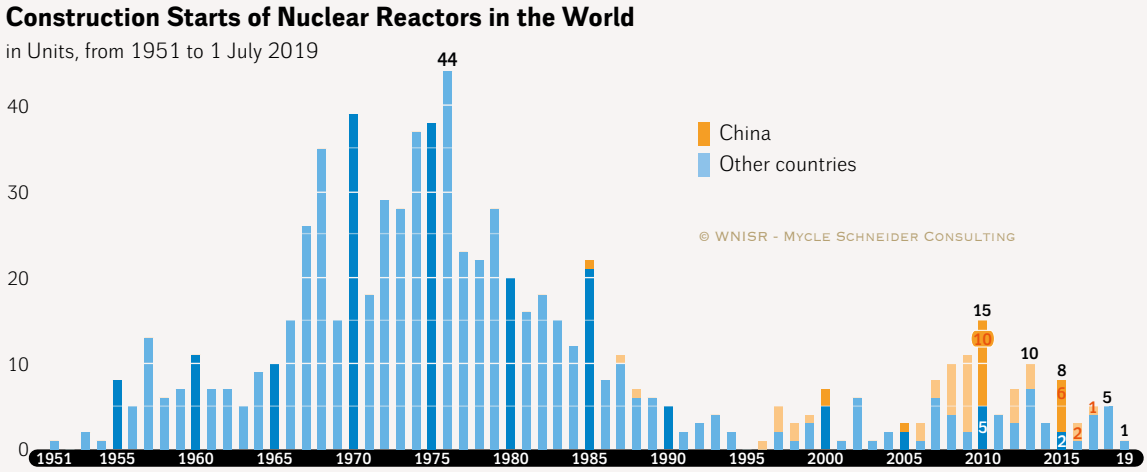
Over the decade 2009–2018, construction began on 71 reactors in the world (of which five have been cancelled). That is more than in the decade 1999–2008, when work started on 45 units

32 - Generally, a reactor is considered under construction when the base slab of the reactor building is being concreted. Site preparation work, excavation and other infrastructure developments are not included.

(of which three have been abandoned). With 49 units China holds the lion's share of the 116 building starts over the past two decades (see **Figure 12**).

In addition, past experience shows that simply having an order for a reactor, or even having a nuclear plant at an advanced stage of construction, is no guarantee of ultimate grid connection and power production. The abandonment of the two V.C. Summer units at the end of July 2017 after four years of construction and following multi-billion-dollar investment is only the latest example in a long list of failed nuclear power plant projects.

Figure 12 | Construction Starts in the World/China



Sources: WNISR, with IAEA-PRIS, 2019

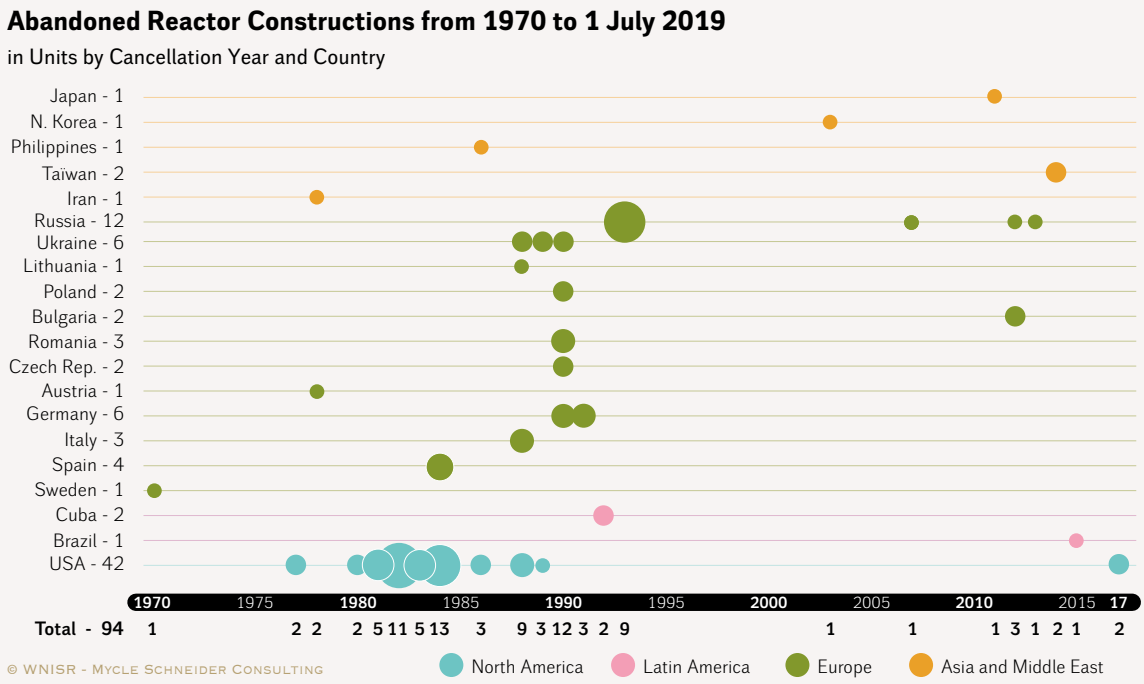
French Alternative Energies & Atomic Energy Commission (CEA) statistics through 2002 indicate 253 "cancelled orders" in 31 countries, many of them at an advanced construction stage. The United States alone accounted for 138 of these order cancellations.[33]

Of the 766 reactor constructions launched since 1951, at least 94 units—12 percent or one in eight—in 20 countries had been abandoned as of 1 July 2019. The past decade shows an abandoning rate of one-in-fourteen—as five in 71 building sites officially started during that period were later given up at various stages of advancement (see also **Figure 13**).

Close to three-quarters (66 units) of all cancelled projects were in four countries alone—the U.S. (42), Russia (12), Germany and Ukraine (six each). Some units were actually 100 percent completed—including Kalkar in Germany and Zwentendorf in Austria—before the decision was taken not to operate them.

33 - CEA, "Elecnuc—Nuclear Power Plants in the World", French Alternatives Energies and Atomic Energy Commission, 2002. The section "cancelled orders" has disappeared after the 2002 edition.

Figure 13 | Cancelled or Suspended Reactor Constructions



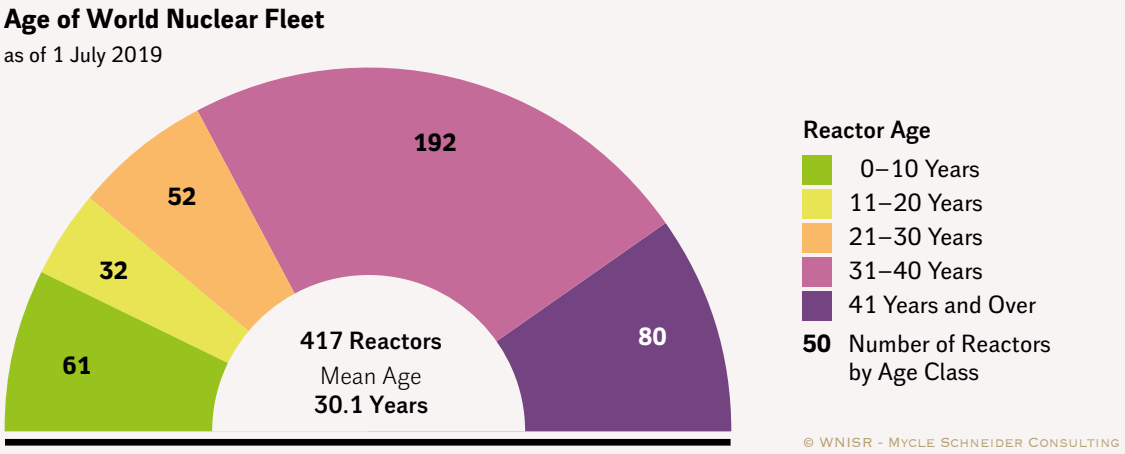
Sources: WNISR, with IAEA-PRIS, 2019

Note: This graph only includes constructions that had officially started with the concreting of the base slab of the reactor building.

OPERATING AGE

In the absence of significant new-build *and* grid connection over many years, the average age (from grid connection) of operating nuclear power plants has been increasing steadily and at mid-2019, for the first time, is exceeding 30 years (30.1 years), up from 29.9 a year ago (see **Figure 14**).[34] A total of 272 reactors, two-thirds of the world fleet, have operated for 31 or more years, including 80 (19 percent) reaching 41 years or more.

Figure 14 | Age Distribution of Operating Reactors in the World



Sources: WNISR, with IAEA-PRIS, 2019

Some nuclear utilities envisage average reactor lifetimes of beyond 40 years up to 60 and even 80 years. In the United States, reactors are initially licensed to operate for 40 years, but nuclear operators can request a license renewal from the Nuclear Regulatory Commission (NRC) for an additional 20 years.

As of 4 May 2018, 85 of the then 99 operating U.S. units had received an extension, with another four applications for five reactors under NRC review. Since WNISR2018, four license renewals for five reactors were granted, one expected submission (Perry-1) was cancelled, two units with renewed licenses were closed, and two additional applications for three reactors are expected in 2021–22.[35]

In the U.S., only four of the 36 units—one in nine—that have been closed had reached 40 years on the grid—Vermont Yankee was closed in December 2014 at the age of 42; Fort Calhoun in October 2016 after 43 years of operation; Oyster Creek, the oldest U.S. reactor, in September 2018 at 49 years; and Pilgrim in May 2019 at 47 years. All four had obtained licenses to operate up to 60 years but were closed mainly for economic reasons. In other words, at least a quarter of the reactors connected to the grid in the U.S. never reached their initial design

34 - WNISR calculates reactor age from grid connection to final disconnection from the grid. In WNISR statistics, "startup" is synonymous with grid connection and "closure" with withdrawal from the grid. In previous editions of the WNISR, the reactor age was automatically rounded to the year. In order to have a better image of the fleet and ease calculations, the age of a reactor is considered to be 1 between the first and second grid connection anniversaries. For some calculations, we also use operating years: the reactor is in its first operating year until the first grid connection anniversary, when it enters the second operating year.

35 - U.S.NRC, "Status of License Renewal Applications and Industry Activities", Updated 13 March 2019, see http://www.nrc.gov/reactors/operating/licensing/renewal/applications.html, accessed 14 August 2019.

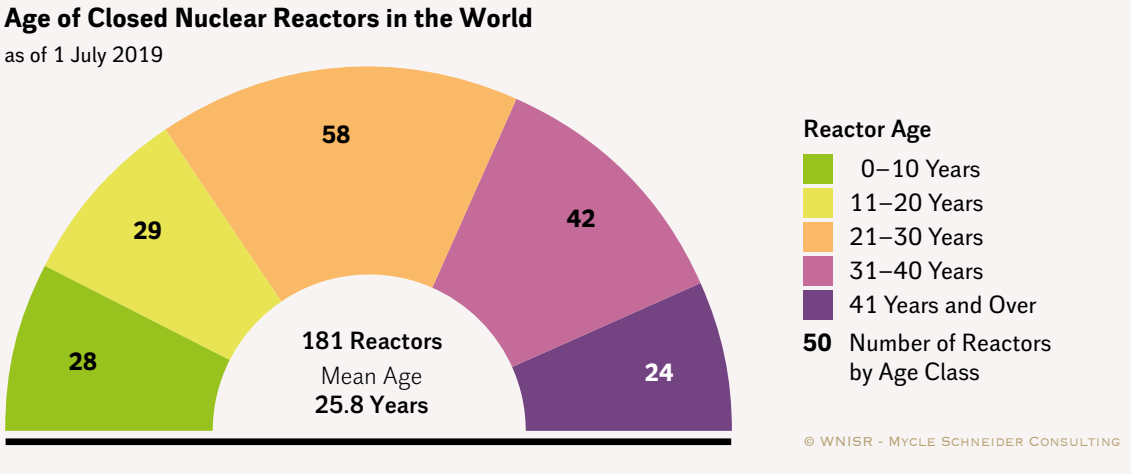
lifetime of 40 years. On the other hand, of the 97 currently operating plants, 46 units have operated for 41 years or more; thus, half of the units with license renewals have already entered the life extension period, and that share is growing rapidly with the mid-2019 mean age of the U.S. operational fleet at 38.9 years (see **United States Focus - Figure 32**).

Many countries have no specific time limits on operating licenses. In France, where the country's first operating Pressurized Water Reactor (PWR) started up in 1977, reactors must undergo in-depth inspection and testing every decade against reinforced safety requirements. The French reactors have operated for 34.4 years on average, and most of them have completed the process with the French Nuclear Safety Authority (ASN) evaluating each reactor allowing them to operate for up to 40 years, which is the limit of their initial design age. However, the ASN assessments are years behind schedule. For economic reasons, the French utility Électricité de France (EDF) clearly prioritizes lifetime extension to 50 years over large-scale new-build. EDF's approach to lifetime extension is still under review by ASN's Technical Support Organization. ASN plans to provide its opinion on the general assessment outline by 2020. This is particularly critical for Tricastin-1, the first unit to undergo the fourth decennial review scheduled to begin in 2019. In addition, lifetime extension beyond 40 years requires site-specific public inquiries in France.

Recently commissioned reactors and the ones under construction in South Korea do or will have a 60-year operating license from the start. EDF will certainly also aim for a 60-year license for its Hinkley Point C units in the U.K.

In assessing the likelihood of reactors being able to operate for 50 or 60 years, it is useful to compare the age distribution of reactors that are currently operating with those that have already closed (see **Figure 14** and **Figure 15**). The age structure of the 181 units already closed (eight more than one year ago) completes the picture. In total, 66 of these units operated for 31 years or more, and of those, 24 reactors operated for 41 years or more. Many units of the first-generation designs only operated for a few years. Considering that the average age of the

Figure 15 | Age Distribution of Closed Nuclear Power Reactors

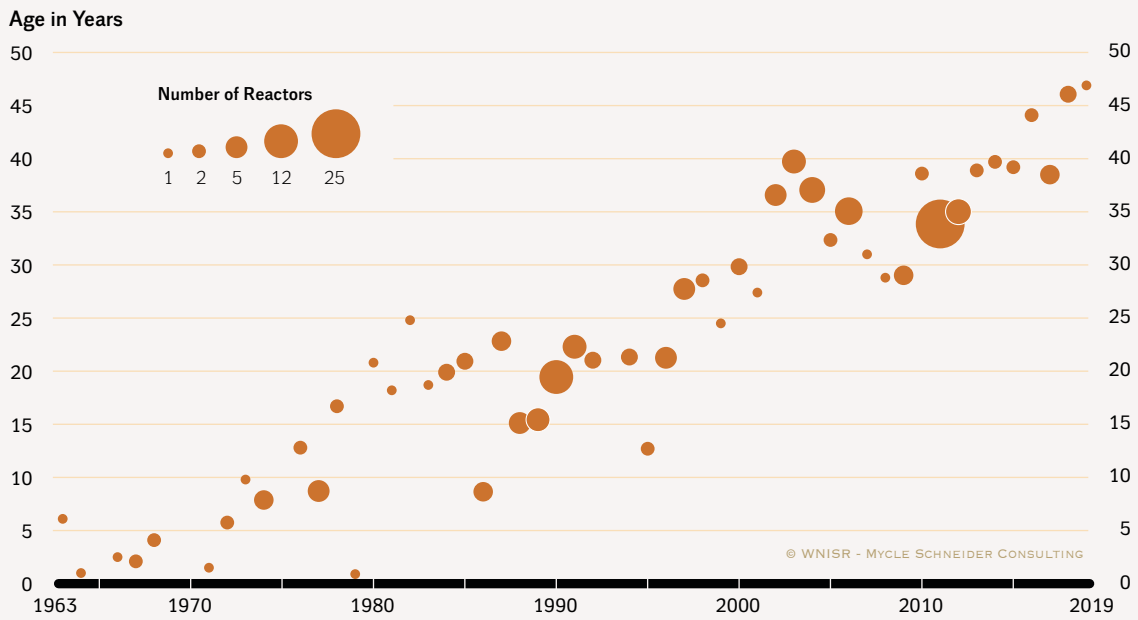


Sources: WNISR, with IAEA-PRIS, 2019

closed units is 25.8 years, plans to stretch the operational lifetime of large numbers of units to 40 years and far beyond seemed rather optimistic.

To be sure, the operating time prior to closure has clearly increased continuously. But while the *average* age of reactors closed in the world in a given year got close to 40 years, it passed it only twice so far: in 2016, with two reactors shutting down at ages 43 (Fort Calhoun, U.S.) and 45 (Novovoronezh, Russia) respectively and in 2018 with Oyster Creek, the oldest U.S. reactor closing at 49 years, as well as Leningrad-1 at 45 and Bilibino at 44 in Russia (see **Figure 16**).

Figure 16 | Nuclear Reactor Closure Age 1963 – 1 July 2019



Sources: WNISR, with IAEA-PRIS, 2019

As a result of the Fukushima nuclear disaster, questions have been raised about the wisdom of operating older reactors. The Fukushima Daiichi units (1 to 4) were connected to the grid between 1971 and 1974. The license for unit 1 had been extended for another 10 years in February 2011, a month before the catastrophe began. Four days after the accidents in Japan, the German government ordered the closure of eight reactors that had started up before 1981, two of which were already closed at the time and never restarted. The sole selection criterion was operational age. Other countries did not adopt the same approach, but it is clear that the 3/11 events had an impact on previously assumed extended lifetimes in other countries as well, including in Belgium, Switzerland and Taiwan. Some of the main nuclear countries closed their respective oldest unit long before age 50, including Germany at age 33, South Korea at 40, Sweden at 46 and the U.S. at 49. France has scheduled to close its two oldest units in spring 2020 at age 43.

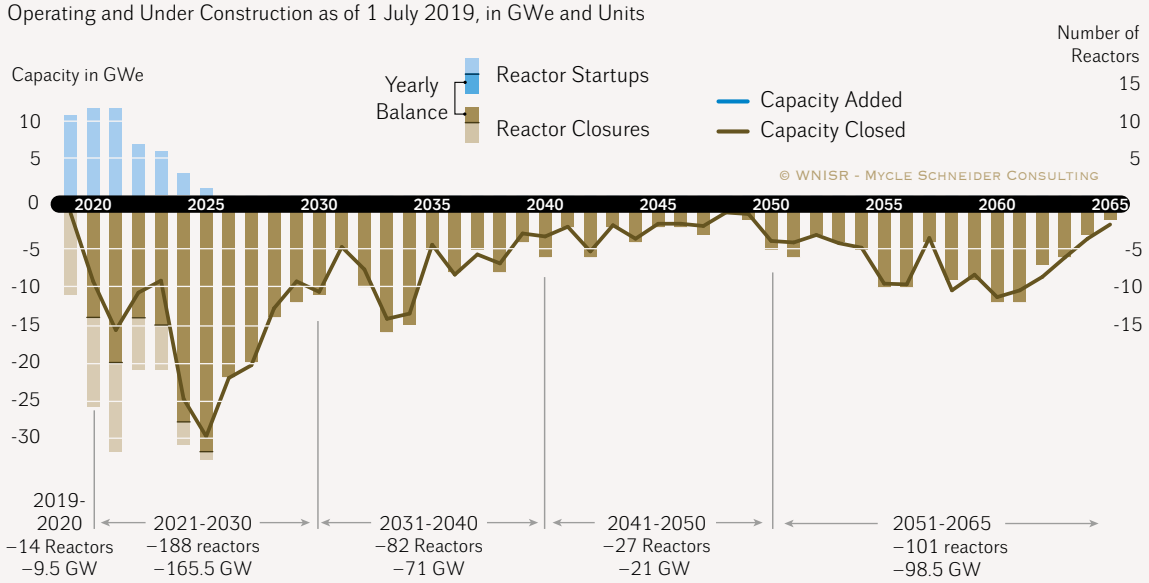
LIFETIME PROJECTIONS

Many countries continue to implement or prepare for lifetime extensions. As in previous years, WNISR has therefore created two lifetime projections. A first scenario (40-Year Lifetime Projection, see **Figure 17**), assumes a general lifetime of 40 years for worldwide operating reactors—not including reactors in Long-Term Outage (LTO). The 40-year number corresponds to the design lifetimes of most operating reactors. Some countries have legislation or policy (Belgium, South Korea, Taiwan) in place that limit operating lifetime to for all or part of the fleet to 40 or 50 years.

For the 85 reactors that have passed the 40-year lifetime, we assume they will operate to the end of their licensed, extended operating time.

A second scenario (Plant Life Extension or PLEX Projection, see **Figure 18**) takes into account all already-authorized lifetime extensions.

Figure 17 | The 40-Year Lifetime Projection (not including LTOs)



Sources: Various sources, compiled by WNISR, 2019

Notes pertaining to Figures 17–19:

The number of startups in 2019 includes two reactors in LTO that were restarted during the first half-year 2019. Restart and closure of 28 reactors in LTO as of 1 July 2019 are not represented here.

The 60-year license for six APR1400 reactors in South Korea, of which two, Shin-Kori-3 & -4, are already in operation, and four under construction, is not represented here. The Figures do not take into account either the expected closure at age 30 of the three remaining Wolsong reactors (see South Korea Focus, Table 6).

The Figures take into account "early retirements" of 10 reactors, while some of them are likely to be cancelled (see United States Focus, Table 8) and others might be added.

In the case of French reactors that have reached 40 years of operation prior to 2019, we use the limit date for their 4th periodic safety review (visite décennale) as closing date in the 40-year projection. For those that will reach 40 years of operation in 2019 or 2020, the date of their 4th periodic safety review is used in the PLEX Projection.

The lifetime projections allow for an evaluation of the number of plants and respective power generating capacity that would have to come online over the next decades to offset closures and simply maintain the same number of operating plants and capacity. With all units under construction scheduled to have started up, installed nuclear capacity would still decrease by 9.5 GW by 2020. In total, 14 additional reactors (compared to the end of 2018 status) would have to be started up or restarted prior to the end of 2020 in order to maintain the status quo of operating units. Compared to the situation in 2014, the number of additional units necessary to break even by 2020 shrank by 16. In fact, construction started on 25 units between 2014 and mid-2019, and Japan restarted nine reactors (none were operating in 2014). The additional capacity needed to maintain the status quo by 2020 increased though by 2 GW.

In the following decade to 2030, 188 additional new reactors (165.5 GW) would have to be connected to the grid to maintain the status quo, 3.2 times the rate achieved over the past decade (59 startups between 2009 and 2018). The situation is identical to 2014, when the corresponding projections for 2021–2030 indicated a need for an equal number of additional reactors, though with a higher total capacity of 178 GW.

The potential stabilization of the situation by 2020 will depend on the number of Japanese and other reactors currently in LTO coming back online, as it is technically impossible to start and complete construction of any additional new plant in a year.

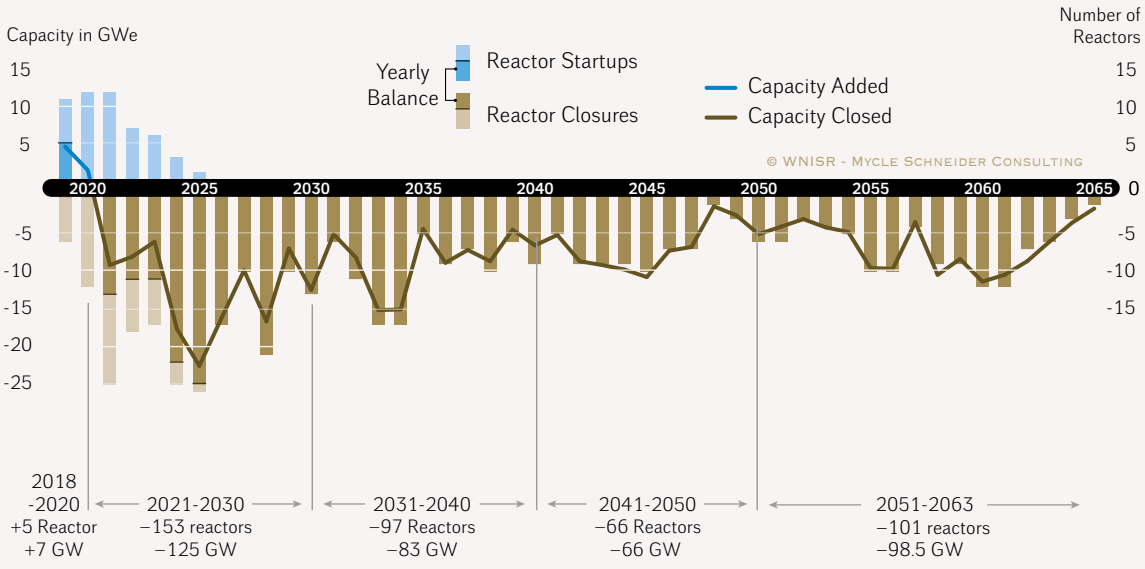
As a result, the number of reactors in operation will probably more or less stagnate at best, unless—beyond restarts—lifetime extensions far beyond 40 years become widespread. Such generalized lifetime extensions are the objective of the nuclear power industry, and, especially in the U.S., there are numerous more or less successful attempts to obtain subsidies for uneconomic nuclear plants (see detailed analysis in **United States Focus**).

Figure 18 | The PLEX Projection (not including LTOs)

Projection 2019-2065 of Nuclear Reactor/Capacity in the World

General assumption of 40-year mean lifetime + Authorized Lifetime Extensions

Operating and Under Construction as of 1 July 2019, in GWe and Units



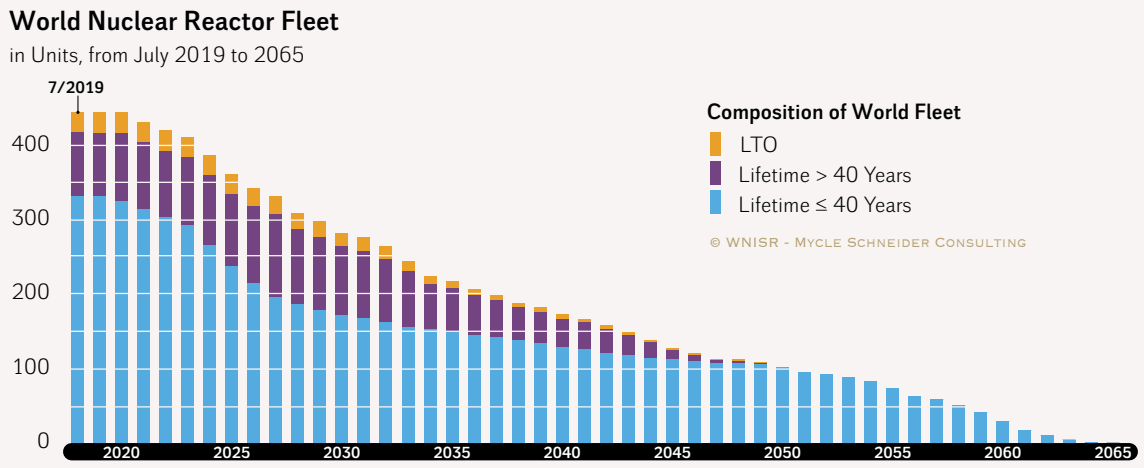
Sources: Various sources, compiled by WNISR, 2019

Developments in Asia, and particularly in China, do not fundamentally change the global picture. Reported figures for China's 2020 target for installed nuclear capacity have fluctuated between 40 GW and 120 GW in the past. The freezes of construction initiation for almost two years and of new siting authorizations for four years have significantly reduced Chinese ambitions.

Every year, we also model a scenario in which all currently licensed lifetime extensions and license renewals (mainly in the United States) are maintained and all construction sites are completed. For all other units, we have maintained a 40-year lifetime projection, unless a firm earlier or later closure date has been announced. By 2020, the net number of operating reactors would increase by five units, and the installed capacity would grow by 7 GW.

In the following decade to 2030, another 153 new reactors (125 GW) would have to start up to replace closures. The PLEX-Projection would still mean, in the coming decade, a need to multiply the number of units built over the past decade by 2.6 (see **Figure 17**, **Figure 18**, and the cumulated effect in **Figure 19**). In the meantime, construction starts have been on a declining trend for a decade.

Figure 19 | Forty-Year Lifetime Projection versus PLEX Projection

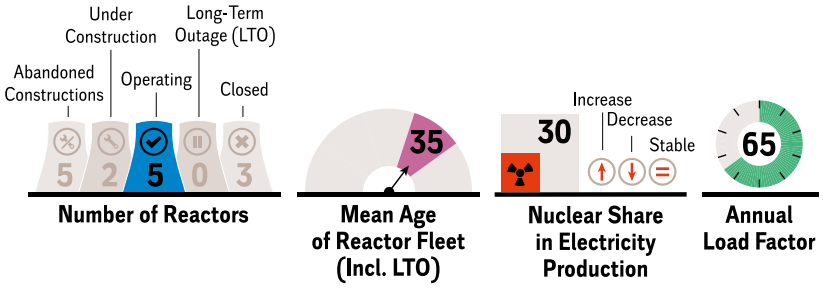


Sources: WNISR, with IAEA-PRIS, 2019

Note: All reactors in LTO are shown until they reach age 40, unless they have a license to operate to 60 years, (see Table 27).

FOCUS COUNTRIES

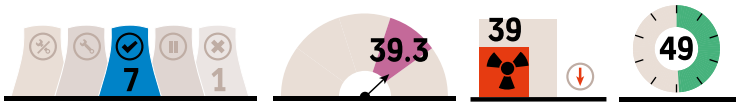
These "quick view" indicators will be used in the country sections throughout the report.



The following chapter provides an in-depth assessment of ten countries: Belgium, China, France, Finland, Germany, Japan, South Korea, Taiwan, United Kingdom (U.K.) and the United States (U.S.). They represent about two thirds of the global reactor fleet (65 percent of the units and 73 percent of the installed capacity) and six of the world's ten largest nuclear power producers. For other countries' details, see **Annex 1**.

Unless otherwise noted, data on the numbers of reactors operating and under construction and their capacity (as of mid-2019) and nuclear's share in electricity generation are from the International Atomic Energy Agency's Power Reactor Information System (PRIS) online database.[36] Historical maximum figures indicate the year that the nuclear share in the power generation of a given country was the highest since 1986, the year of the Chernobyl disaster. Unless otherwise noted, the load factor figures are from *Nuclear Engineering International* (*NEI*).[37]

BELGIUM FOCUS



Belgium operates seven pressurized-water reactors that have generated 27.3 TWh in 2018, almost one-third less than the 40.2 TWh in 2017 and a maximum of 46.7 TWh in 1999. Nuclear power contributed 34 percent of Belgium's electricity in 2018, while the maximum was almost double with 67.2 percent in 1986.

Due to continuous technical issues and extended outages, the average load factor of the Belgian fleet plunged to 48.6 percent in 2018, the second lowest in the world behind Argentina. The average age of the Belgian fleet is 39.3 years. On average, the seven Belgian units were down half of the year (see details hereafter) and in October 2018 power prices reached record levels (€205/MWh or US$231/MWh). The "Belgian nuclear crisis" is the title of an *Argus* White Paper describing that the lack of power from nuclear reactors led not only to the need for coordinated solidarity by neighboring countries to help Belgium with power exports through the winter, but also to strategic reinforcement of energy cooperation, in particular with Germany.[38]

36 - IAEA-PRIS, "Nuclear Share of Electricity Generation in 2018", see https://pris.iaea.org/PRIS/WorldStatistics/NuclearShareofElectricityGeneration.aspx, accessed July 2019.

37 - *NEI*, "Load factors to end December 2018", June 2019, Caroline Peachey, personal communication, email dated 10 June 2019.

38 - Argus, "Argus white paper: Belgian nuclear crisis", October 2018.

Engie-Electrabel, which operates all of the Belgian reactors, stated in January 2019 that 4 GW of nuclear capacity (Doel-3 and -4, Tihange-2 and -3) will be available in winter 2019–20, and thus the situation should be less constrained.[39]

The nuclear capacity constraints in the winter 2018–19 were also seen as a test case, as legally the country is bound to a nuclear phase-out target of 2025. In January 2003, legislation was passed that requires the closure of all of Belgium's nuclear plants after 40 years of operation, so based on their startup dates, plants would be closed progressively between 2015 and 2025 (see **Table 3**). Practically, however, after lifetime extension to 50 years was granted for three reactors, five of the seven reactors would go offline in the single year of 2025. This represents a challenging policy goal.

In November 2017, the Belgian transmission system operator Elia published a study urging the construction of "at least 3.6 GW of new-build adjustable (thermal) capacity" to "cope with the shock of the nuclear exit in 2025"[40]. The Belgian government confirmed the nuclear phase-out date, when, on 30 March 2018, it presented the Federal Energy Strategy.

Table 3 | Belgian Nuclear Fleet (as of 1 July 2019)

Reactor	Net Capacity (MW)	Grid Connection	Operating Age (as of 1 July 2019)	End of License (Latest Closure Date)	Load Factor	
					2018	Lifetime
Doel-1	433	28/08/1974	44.8	10-year lifetime extension to 15 February 2025	30.9	83
Doel-2	433	21/08/1975	43.9	10-year lifetime extension to 1 December 2025	38.9	82.2
Doel-3	1 006	23/06/1982	37.0	1 October 2022	42.6	78.0
Doel-4	1 038	08/04/1985	34.2	1 July 2025	60.6	82.8
Tihange-1	962	07/03/1975	44.3	10-year lifetime extension to 1 October 2025	90.6	81.1
Tihange-2	1 008	13/10/1982	36.7	1 February 2023	62	80.9
Tihange-3	1 038	15/06/1985	34.0	1 September 2025	24.4	86.0

Sources: WNISR, NEI, 2019; Belgian Law of 28 June 2015; Electrabel/GDF-Suez, 2015[41]

39 - ENGIE, "Sécurité d'approvisionnement : Electrabel actualise le planning de maintenance de ses unités nucléaires jusqu'en 2022", 28 January 2019 (in French), see https://corporate.engie-electrabel.be/fr/actualite/securite-dapprovisionnement-electrabel-actualise-le-planning-de-maintenance-de-ses-unites-nucleaires-jusquen-2022/, accessed 27 May 2019.

40 - Elia, "Electricity Scenarios for Belgium Towards 2050–Elia's Quantified Study on the Energy Transition in 2030 and 2040", November 2017, see http://www.elia.be/~/media/files/Elia/About-Elia/Studies/20171114_ELIA_4584_AdequacyScenario.pdf, accessed 1 August 2019.

41 - *Moniteur Belge*, "Loi modifiant la loi du 31 janvier 2003 sur la sortie progressive de l'énergie nucléaire à des fins de production industrielle d'électricité afin de garantir la sécurité d'approvisionnement sur le plan énergétique", N.174, Second Edition, 6 July 2015 (in French and Dutch), see http://www.ejustice.just.fgov.be/mopdf/2015/07/06_2.pdf.
• For Doel-1&-2, see Electrabel, GDF Suez/Engie, "Note de Presse—Sécurité d'approvisionnement et transition énergétique—Accord sur la prolongation de Doel 1 et Doel 2", Press Release, 1 December 2015 (in French), see corporate.engie-electrabel.be/wp-content/uploads/2016/03/note-de-presse-prolongation-doel-1-et-doel-2-securite-dapprovisionnement-en-belgique-fr-def.pdf, and Engie Electrabel, "Doel Nuclear Power Plant—Profile of the 4 units", Updated 7 August 2017, see http://corporate.engie-electrabel.be/local-player/nuclear-3/doel/;
• For Tihange-1, see Engie/Electrabel, "Tihange", Undated, see http://corporate.engie-electrabel.be/local-player/nuclear-3/tihange/;
all accessed 23 June 2019.

Hydrogen Crack Indications and Legal Issues

In summer 2012, the operator identified an unprecedented number of hydrogen-induced crack indications in the pressure vessels of Doel-3 and Tihange-2, with respectively over 8,000 and 2,000—which later increased to over 13,000 and over 3,000 respectively—previously undetected defects. In spite of widespread concerns, and although no failsafe explanation about the negative initial fracture-toughness test results was given, on 17 November 2015, the Federal Agency for Nuclear Control (FANC) authorized the restart of Doel-3 and Tihange-2 for the second time after the original discovery of the defaults (see previous WNISR editions for details).

The Belgian government did not wait for the outcome of the Doel-3/Tihange-2 issue and decided in March 2015 to draft legislation to extend the lifetime of Doel-1 and Doel-2 by ten years to 2025. The law went into effect on 6 July 2015. The government signed an agreement with Electrabel on 30 November 2015 that stipulates that the operator will invest €700 million (US$741.2 million) into upgrading of the two units and an annual fee of €20 million (US$21.2 million), which will be paid into the national Energy Transition Fund, set up by the law of 28 June 2015. On 22 December 2015, FANC authorized the lifetime extension and restart of Doel-1 and -2.

On 6 January 2016, two Belgian NGOs filed a complaint against the 28 June 2015 law with the Belgian Constitutional Court, arguing in particular that the lifetime extension had been authorized without a legally binding public enquiry. In a 22 June 2017 pre-ruling decision, the Court addressed a series of questions to the European Court of Justice (ECJ), in particular concerning the interpretation of the Espoo and Aarhus Conventions, as well as the European legislation. On 29 November 2018, the ECJ's Advocate General presented its advice on the request of the Belgian Constitutional Court concerning the applicability of the EU-Aarhus/Espoo with regards to the Plant Life Extension or PLEX of Doel-1 and -2 and Tihange-1. In her advice, the Advocate General clearly states that

> the definition of 'project' under Article 1(2)(a) of Directive 2011/92 [Environmental Impact Assessment Directive] includes the extension by 10 years of the period of industrial production of electricity by a nuclear power station

and that

> public participation must take place in accordance with Article 6(4) of Directive 2011/92 as early as possible, when all options are open, that is to say, before the decision on the extension is taken.[42]

The ECJ is not bound by, but generally follows, the advice of the Advocate General; however, so far, the ECJ did not send a formal opinion to the Belgian Constitutional Court. Should the ECJ rule in accordance with the Advocate General's recommendations, this could have major implications also for past or planned lifetime extensions in other countries.

42 - Court of Justice of the EU, "Opinion of Advocate General Kokott—Inter-Environnement Wallonie ASBL, Bond Beter Leefmilieu Vlaanderen vzw v. Conseil des ministres, Intervener: Electrabel SA", Request for a preliminary ruling from the Constitutional Court of Belgium, Case C-411/17, *Info Curia*, Provisional text, 29 November 2018, see http://curia.europa.eu/juris/document/document.jsf?docid=208286&text=&dir=&doclang=EN&part=1&occ=first&mode=DOC&pageIndex=0&cid=7984750, accessed 27 June 2019.

Already in November 2015, Greenpeace Belgium had filed a case at the State Council (Conseil d'État) on similar grounds. As of mid 2019, both cases are still pending.

In May 2017, FANC announced that a series of ultrasonic inspections on the pressure vessel of Tihange-2 did not show any evolution of the hydrogen flakes, nor any new defects. On the basis of these results, FANC authorized the restart of the reactor. FANC later admitted that over 300 additional flaw indications at Doel-3 and 70 additional flaw indications at Tihange-2 exceeded the recording threshold for the first time during re-inspections carried out in 2016 and 2017 respectively. However, FANC concluded that the results were due to evolving complex inspection techniques rather than physical changes.

The technical assessment of the safety implications of the flaw indications remains the subject of intense controversy. Several independent safety analysis reports are highly critical of the restart authorizations. In April 2018, the International Nuclear Risk Assessment Group (INRAG) stated on Tihange-2 that "the risk of failure of the reactor pressure vessel is not practically excluded" and requested that "the reactor must therefore be temporarily shut down".[43] INRAG is currently in contact with the German government about the safety assessment of Tihange-2, which will likely turn into an expert opinion exchange in the near future.

A complaint was filed at the Belgian State Council against the restart of Tihange-2 by the City Region (Städteregion) Aachen cities in February 2016, joined by some 80 other Dutch, German and Luxemburg cities. Both cases are still pending. It is unclear when to expect rulings. The legal consequences of a ruling in favor of the plaintiffs are also uncertain.

Serious Flaws in Reinforced Concrete

In October 2017, Electrabel identified serious flaws in the concrete of a building adjacent to the reactor buildings of Doel-3. These bunkered buildings contain backup systems for the safety of the facilities and are supposed to withstand impact from outside like an airplane crash. According to Engie, some of these "anomalies at the reinforcements of the reinforced concrete [were] present since the construction of the building".[44] Doel-3 was originally expected to be off-line for scheduled maintenance for 45 days, however, the outage lasted 302 days.

Similar problems, to varying degrees, have been identified at Tihange-2 and -3, as well as Doel-4. Engie first announced that Tihange-3, which was shut down on 30 March 2018 for planned maintenance and refueling, would restart by 14 May 2018. It suffered subsequent delays, and on 21 September 2018, Engie stated that the Tihange-3 outage was extended to 2 March 2019, and that the restart of Tihange-2—which was shut down on 19 August 2018—would be delayed from 31 October 2018 to 1 June 2019.

However, some work at Tihange-3 has been moved to the next scheduled outage and the unit went back on-line on 1 January 2019, two months earlier than previously announced. The entire

43 - INRAG, "Evaluation of the nuclear risks of the Tihange nuclear power plant 2 — Statement by the international group of experts 'INRAG'", April 2018 (in German and English), see http://www.inrag.org/wp-content/uploads/2018/04/01_INRAG-Statement-Tihange_2018_04_10-ST_ff_final.pdf.

44 - Engie/Electrabel, "Révision en cours dans les centrales de Doel 3 et Tihange 3: réaction d'ENGIE Electrabel à propos de l'article dans *Le Soir*", 5 July 2018.

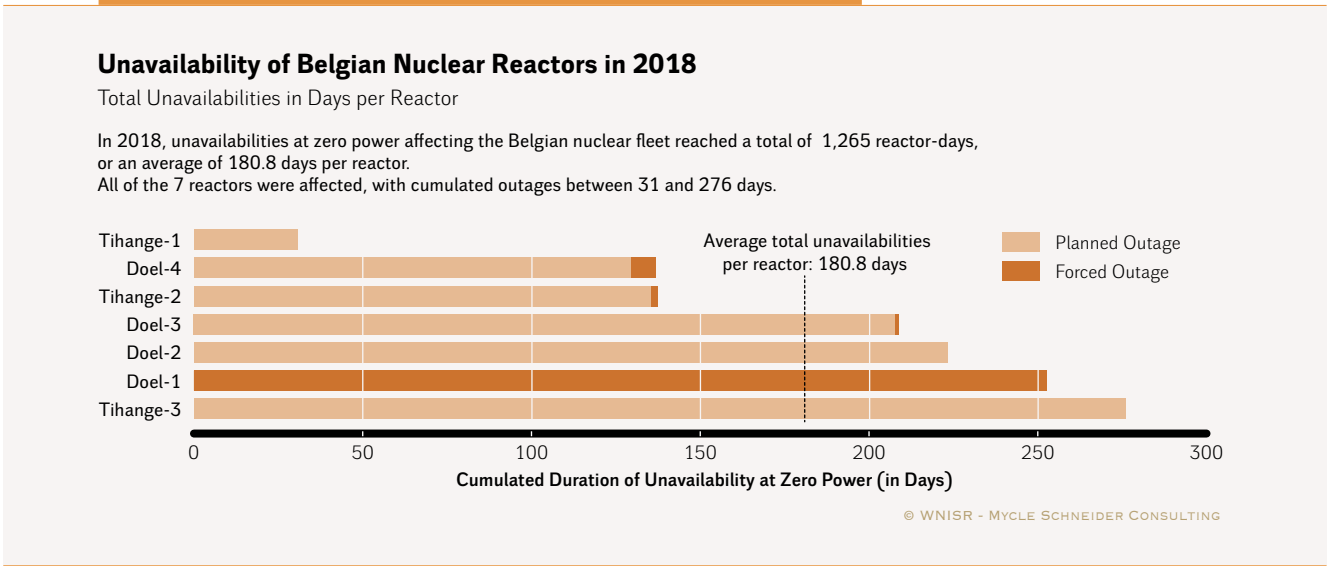
roof of the bunkered building is now scheduled to be replaced during the outage planned for summer 2020, which will significantly extend the shutdown.

On the other hand, while the regulator gave the green light on 11 June 2019[45], the restart of Tihange-2 was delayed and had been rescheduled several times before finally taking place on 3 July 2019.[46]

Performance Assessment

The cumulation of planned outages that were extended repeatedly, plus unexpected outages, led to an unprecedented annual record. In 2018, the seven Belgian nuclear reactors cumulated a total of 1,265 outage days, representing an average of six months (181 days) per reactor (see **Figure 20**), or twice as many as France over the same period (see **France Focus**). All of the seven units were offline at some point, with cumulated outages reaching between 31 days (Tihange-1) and 276 days (Tihange-3) per reactor.

Figure 20 | Unavailability of Belgian Nuclear Reactors in 2018 (Cumulated)



Sources: ENTSO-E and Engie Transparency Platforms, 2019

Notes

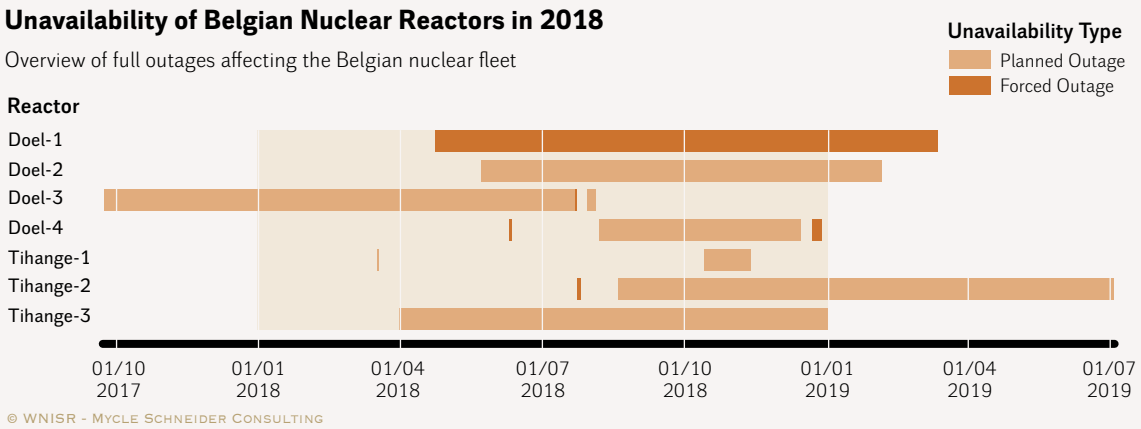
This graph only compiles outages at zero power, thus excluding all other operational periods with reduced capacity >0 MW. Impact of unavailability on power production is therefore significantly larger.

"Planned" and "Forced" unavailability as published by ENTSO-E. The Doel-1 unavailability, presented here as forced (according to ENTSO-E) during its whole duration, is listed as "planned" by ENGIE for 248 days in 2018. See Figure 21 and Figure 22.

45 - AFCN, "L'AFCN approuve le redémarrage de Tihange 2", Press Release, 11 June 2019 (in French), see https://afcn.fgov.be/fr/actualites/lafcn-approuve-le-redemarrage-de-tihange-2, accessed 11 June 2019.

46 - ENTSO-E, "Unavailability of Production and Generation Units", 7 July 2019.

Figure 21 | Unavailability of Belgian Nuclear Reactors in 2018 (by Outage Period)



Sources: ENTSO-E and Engie Transparency Platforms, 2019

Notes

This graph only compiles outages at zero power, thus excluding all other operational periods with reduced capacity >0 MW. Impact of unavailability on power production is therefore significantly larger.

"Planned" and "Forced" unavailability as published by ENTSO-E. The Doel-1 unavailability, presented here as forced (according to ENTSO-E) during its whole duration, is listed as "planned" by ENGIE for 248 days in 2018. See Figure 22.

Lifetime Extensions = Extended Outages?

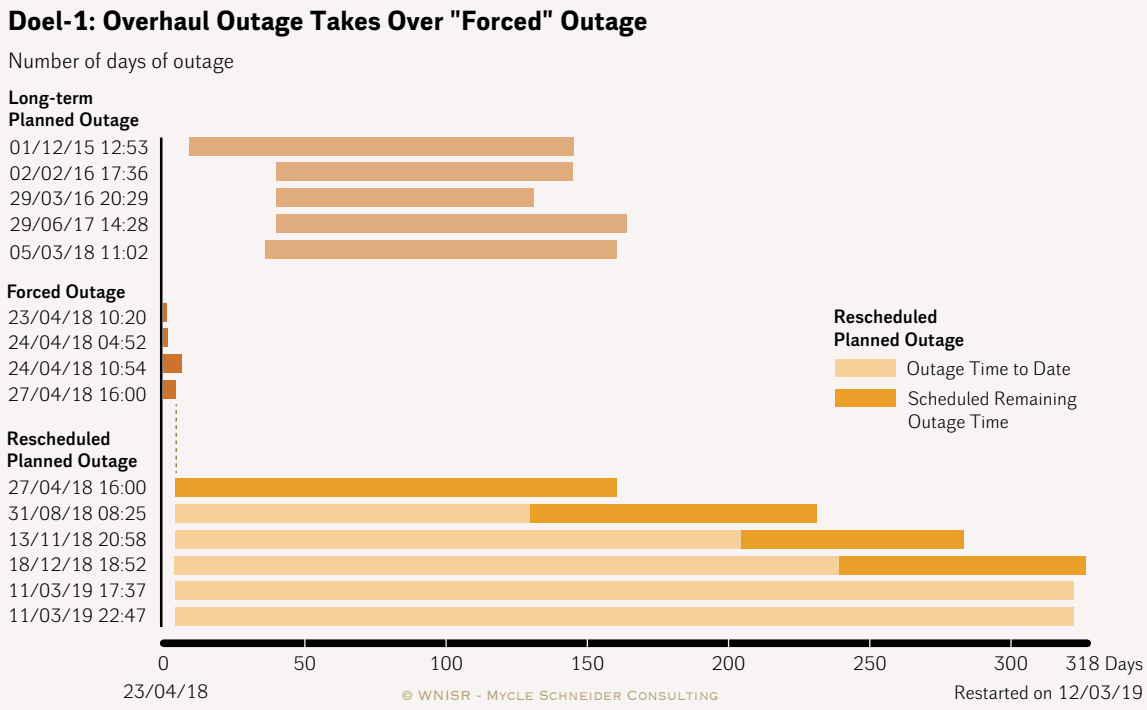
The Federal Agency for Nuclear Control (FANC) notes in its March 2019 national progress report on the stress tests of nuclear power plants that review and assessment "progresses slightly slower than expected". The reasons indicated are workload related, for both licensee and regulator, triggered by the "safety events that occurred in 2018" and "by other safety projects (Long Term Operation of Tihange-1 or Doel-1 and -2) that are resource-intensive for both organizations."[47] While only three of 365 upgrading actions by the operator were still outstanding by the end of 2018, the regulator still had to approve and confirm one quarter of the global action plan.

On 23 April 2018, **Doel-1** was closed following a leak in a back-up pipe on its primary cooling circuit. This unplanned outage was at first expected to last around 1.5 days, then 6.5 days. But the damage was worse than anticipated and on 27 April 2018, it was decided to bring forward an outage originally scheduled to start at the end of May 2018. The outage was to last 154 days, to 1 October 2018, one month longer than initially predicted. In August 2018, Engie declared that "Doel-1 and -2 are currently in a planned overhaul. This long overhaul was planned in order to extend the exploitation of the units for ten more years."[48] The Doel-1 outage turned from "unplanned" to "planned" and was extended progressively to 318 days (see **Figure 22**).

47 - FANC, "Belgian Stress Tests—National progress report on the stress tests of nuclear power plants", March 2019.

48 - Engie, "Adjustment of the revision agenda of the nuclear units—Message to Belga", Press Release, 31 August 2018, see https://corporate.engie-electrabel.be/news/press-releases/adjustment-of-the-revision-agenda-of-the-nuclear-units/, accessed 2 August 2019.

Figure 22 | The Doel-1 Case



Source: Engie Transparency Platform, 2019

Notes
Overview of subsequent versions of unavailability messages for the Doel-1 "Unplanned Outage" after the discovery of a leak in the emergency cooling water circuit and the following "Overhaul Outage". "Planned" and "Forced" outages as declared by ENGIE.

Doel-2 was shut down on 22 May 2018 for backfitting/upgrading for lifetime extension with a planned restart on 8 October 2018. In reality, the unit went back on-line only on 4 February 2019.

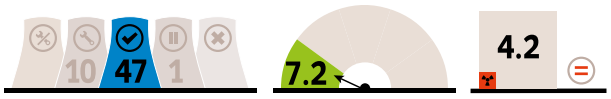
In most cases it is virtually impossible to identify the precise reasons for extended outages, as unexpected events interact with regular maintenance, post-3/11 upgrading and measures aimed at lifetime extensions. Beyond the repair work, additional monitoring is requested by the regulator on parts that have turned out to be damaged beyond expectation (in both recent cases, the concrete flaws and emergency cooling circuit leaks).

Compliance Issue Solved

As reported in WNISR2018, on 7 June 2018, the European Commission had decided to send a reasoned opinion to Belgium "for not having notified transposition measures required under the Nuclear Safety Directive (Council Directive 2014/87/Euratom)".[49] Belgium was given two months' time to reply to the reasoned opinion, as well as to adopt and communicate all the necessary measures to ensure full and correct transposition of the Directive into national law. As the Commission considered the elements communicated by Belgium satisfactory, it closed the case on 7 March 2019.

49 - European Commission, "June infringements package: key decisions. Nuclear safety: Commission calls on Belgium, Poland and Spain to completely transpose EU nuclear safety rules", 7 June 2018, see https://ec.europa.eu/info/news/june-infringements-package-key-decisions-nuclear-safety-commission-calls-belgium-poland-and-spain-completely-transpose-eu-nuclear-safety-rules-2018-jun-07_en, accessed 2 August 2019.

CHINA FOCUS

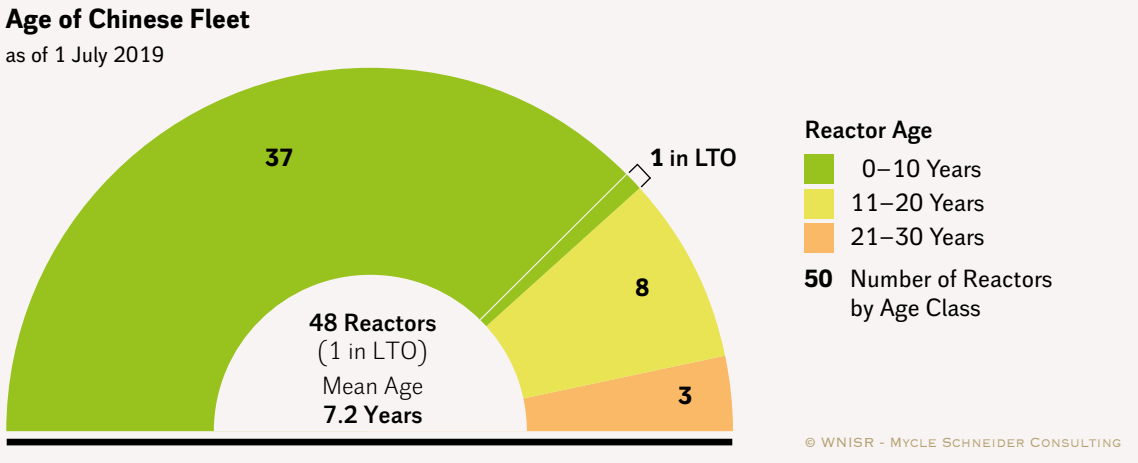


China continues to expand its nuclear power sector and now operates the third largest reactor fleet, behind the United States and France. As of 1 July 2019, China had 47 operating reactors with a total net capacity of 44.5 GW, and one reactor in Long-Term Outage or LTO. The Chinese nuclear fleet is very young with an average age of 7.2 years (see **Figure 23** and **Table 23**). In 2018, nuclear power contributed 277 TWh, which constituted 4.2 percent of all electricity generated in China, a slight increase from 3.9 percent in 2017. This compares with wind power that injected 366 TWh and solar 177.5 TWh into the grid respectively.[50] In other words, electricity generated by wind energy alone continues to exceed the nuclear contribution, and solar energy is rapidly catching up. Wind and solar combined now outproduce nuclear by almost a factor of two. (For more details, see the **Nuclear Power vs. Renewable Energy** chapter).

In general, the outlook for nuclear power in China appears to be significantly dimmer than it was just a few years ago. *Nuclear Intelligence Weekly* (*NIW*) reports that since 2015,

> capital investment in the nuclear sector has been in steady decline and last year [2018] registered a total of 43.7 billion yuan (US$6.5 billion), down 3.8% from 2017. Investment in nuclear has been less than in most other power sectors due to the lack of newbuilds.[51]

Figure 23 | Age Distribution of Chinese Nuclear Fleet



Sources: WNISR, with IAEA-PRIS, 2019

A key reason is the high costs. A former head of the Energy Research Institute (ERI) of the National Development and Reform Commission (NDRC), the key state planning agency, explains that nuclear power "has begun to face price competition, and will certainly face more competition in the future".[52]

50 - BP, "Statistical Review of World Energy–Workbook", Statistics Work Book, June 2019, see https://www.bp.com/content/dam/bp/business-sites/en/global/corporate/xlsx/energy-economics/statistical-review/bp-stats-review-2019-all-data.xlsx, accessed 11 June 2019.

51 - C. F. Yu, "State Council Close to Approving Hualong-One Projects", *NIW*, 1 February 2019.

52 - Peter Fairley, "China's losing its taste for nuclear power. That's bad news.", *MIT Technology Review*, 12 December 2018, see https://www.technologyreview.com/s/612564/chinas-losing-its-taste-for-nuclear-power-thats-bad-news/, accessed 12 December 2018.

Despite this decline, China continues to be the country with the largest number of nuclear reactors under construction. There are 10 units totaling 8.8 GW under construction, nearly one quarter of a global total of 46 reactors underway as of mid-2019 (see **Annex 7**, **Table 27**). The International Atomic Energy Agency (IAEA) still does not list the CFR-600 fast neutron reactor as being under construction. However, media reports suggest that the first pour of concrete for this project occurred in December 2017, with commercial operation expected in 2023.[53] Thus, WNISR considers the unit as under construction.

The figure of 10 reactors under construction is significantly below the figure of 16 one year earlier, and of 20 two years before. This new-build decline is a clear demonstration of the slowdown of the Chinese nuclear power program.

At least three of the 10 reactors under construction are delayed: the first two Hualong One (HPR-1000) reactors being built at Fuqing, and the High Temperature Gas Cooled Reactor at Shidaowan (more on the latter in the chapter on **Small Modular Reactors**). Progress on the HPR-1000 design is especially interesting, because its timely completion will have a bearing on the attractiveness of China as a source of nuclear reactors, since it is this specific design that China is planning to export to other countries.

When pouring of concrete commenced for the second HPR-1000 at Fuqing (Fuqing-6) in December 2015, China National Nuclear Corporation (CNNC) stated that Fuqing-5 and -6 were "scheduled to be completed in 2019 and 2020, respectively".[54] Even last year, one article on nuclear power in China reported "CNNC says it will have one reactor operating in 2019, ahead of schedule".[55] The "ahead of schedule" claim has been repeated, including by CNNC in April 2019 when it began cold hydrostatic testing of Unit 5 of the Fuqing nuclear power plant.[56] However, if one looks at past examples, the time it has taken to go from cold testing to grid connection ranges from 16 months (Hongyanhe-1) to 10 months (Ningde-3), suggesting that it is unlikely that Fuqing-5 will be connected to the grid before 2020.

China connected seven reactors to the grid in five months (between May and October 2018), and two in June 2019. These included two EPRs (Taishan-1 and -2), four AP-1000s (Sanmen-1 and -2, and Haiyang-1 and -2) and one ACPR-1000 (Yangjiang-6). The EPRs and the AP-1000s were both high-profile flagship projects for these two designs and much rested on the success of these projects. The Sanmen project was touted as "the biggest energy cooperation project between China and the United States" by the head of the National Energy Administration in 2009.[57]

As previous issues of the WNISR have documented in detail, eight of those nine reactors were delayed, and for most of them completion took about twice as long as predicted at the time of

53 - *WNN*, "China begins building pilot fast reactor", *World Nuclear News*, 29 December 2017, see http://www.world-nuclear-news.org/NN-China-begins-building-pilot-fast-reactor-2912174.html, accessed 16 June 2019.

54 - *WNN*, "First concrete for sixth Fuqing unit", 22 December 2015, see http://www.world-nuclear-news.org/NN-First-concrete-for-sixth-Fuqing-unit-2212154.html, accessed 16 June 2019.

55 - Peter Fairley, "China's losing its taste for nuclear power. That's bad news.", *MIT Technology Review*, 12 December 2018, op. cit.

56 - *WNN*, "Cold testing under way at Chinese Hualong One unit", 29 April 2019, see http://world-nuclear-news.org/Articles/Cold-testing-underway-at-Chinese-Hualong-One-unit, accessed 17 June 2019.

57 - *Xinhua*, "China starts building 3rd-generation nuclear power reactors using Westinghouse technologies", *People's Daily Online*, 20 April 2009, see http://en.people.cn/90001/90778/90857/90860/6640730.html, accessed 13 May 2018.

construction start (see **Figure 10**). The delays were largely a result of the designs not being finalized, quality problems during constructions and safety concerns.

Whatever those causes, the net result is that the market for AP-1000 reactors and EPRs in China has all but evaporated. An example is the Zhagzhou site in Fujian, which some news sources have identified as having been earmarked for AP-1000 reactors earlier,[58] but is now likely to be the next site for the construction of another Hualong power plant.[59] CNNC's decision to construct a Hualong reactor there was explained by the dean of the College of Energy at Xiamen University: "The problem with AP1000—the delays, the design changes, the supply chain issues and then the trade problems—has forced their hand, and it has become Hualong".[60]

The problems with imported reactor construction have also affected the prospects for the domestically designed Hualong. While the latter is clearly the preferred choice for new construction, the Chinese government has not been granting the requisite permissions for a rapid buildup. In February 2017, China's National Energy Administration (NEA) reportedly approved the construction start of eight new reactors.[61] But more than two years later, none of those have actually started construction. Again, in February 2019, the State Council was reportedly "close to formally approving two twin-unit Hualong-One projects, in Zhangzhou and Huizhou".[62] As of the time of writing, none of them had come through. This is not to say that no new projects will be approved. But it is clear that nuclear power construction has slowed down and at this point, there is no sign that this will not stay that way.

The repeated delays have finally led Chinese officials to admit to what previous issues of the WNISR had already established—that is China will not meet its declared target of an installed capacity of 58 GW of nuclear power by 2020. In April 2019, China Electricity Council Vice Chairman Wei Shaofeng told the China Nuclear Energy Sustainable Development Forum in Beijing that "total nuclear capacity is expected to reach 53 GW next year".[63] The other, less often talked about, target of having 30 GW of nuclear power capacity under construction as of 2020 is also virtually impossible at this point.

China continues to be on the lookout for opportunities to export the HPR-1000. The only reactors of the design under construction outside China are at the Karachi Nuclear Power Plant (KANUPP) in Pakistan, and those are reportedly still on schedule for commercial

58 - Hideo Kubota, "China's Nuclear Industry at a Turning Point", Research Institute of Tepia Corporation, *E-Journal of Advanced Maintenance*, Vol.1, No.3, November 2010, see http://www.jsm.or.jp/ejam/Vol.1.No.3/GA/6/article.html; and Elaine Li, "The clash for Zhangzhou nuclear power plant", *NBN*, 18 October 2016, see https://nbn.media/clash-zangzhou-nuclear-power-plant-2/, accessed 18 June 2019.

59 - Earlier in the decade, many reports suggested that Zhanghou was earmarked for the AP-100, the small modular reactor design promoted by CNNC. See Li Jinying, "Market Analysis of Chinese SNRs (small nuclear reactors)", presented at the 2nd Annual Small Modular Reactor Conference, 24 April 2012; and *WNN*, "Small reactors planned for Zhangzhou", 17 November 2011. One report says that for the Zhangzhou site, plans (in 2011) "called for AP1000s, but the technology was switched to the Hualong-One in 2015 amid prolonged delays and equipment problems at the inaugural AP1000 project at Sanmen". See C.F. Yu, "State Council Close to Approving Hualong-One Projects", *NIW*, 2019, op. cit.

60 - David Stanway, "China goes all-in on home grown tech in push for nuclear dominance", *Reuters*, 17 April 2019, see https://af.reuters.com/article/africaTech/idAFL3N21R1X9, accessed 20 April 2019.

61 - *WNN*, "China sets out nuclear plans for 2017", March 2017, see http://www.world-nuclear-news.org/NP-China-sets-out-nuclear-plans-for-2017-0203174.html, accessed 15 May 2018.

62 - C.F. Yu, "State Council Close to Approving Hualong-One Projects", *NIW*, 2019, op. cit.

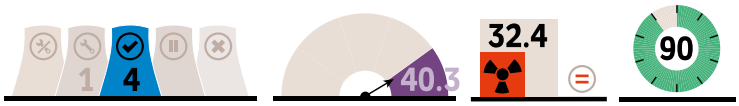
63 - David Stanway, "China to fall short of 2020 nuclear capacity target", *Reuters*, 2 April 2019, see https://www.reuters.com/article/us-china-nuclearpower-idUSKCN1RE04S, accessed 2 April 2019.

operation in 2021 and 2022.[64] Over "80 percent of the estimated project cost is being financed through a loan from China's state-owned Export-Import (Exim) Bank".[65]

There are reports of China being close to signing a deal with Argentina to export one HPR-1000 reactor, which has been valued at US$8 billion[66] to US$10 billion.[67] The two countries have been exploring reactor construction for many years now, but as of mid-2019, a final agreement had not been reached. A key reason for the progress of the deal appears to be China's willingness to offer a "loan from the Industrial and Commercial Bank of China (ICBC), which will cover 85% of the plant's construction costs".[68]

Finally, the other major hope of exports for China is in the U.K., where China's strategy has revolved around first getting a toehold in the market by collaborating with EDF on its Hinkley Point project, and then, if that project proceeds, a significant role in the Sizewell C nuclear power station project.[69] The Hualong reactor design is being assessed by the regulatory authority with proposals to build it at Bradwell (see **U.K. Focus** for more information).

FINLAND FOCUS



Finland operates four units that in 2018 supplied 21.9 TWh of electricity, compared to 21.6 TWh in 2017 and the maximum of 22.7 TWh in 2013. The nuclear share represented 32.4 percent of the nation's electricity in 2018, compared to 33.2 percent in 2017 and the highest share of 38.4 percent in 1986. On 7 March 2019, the Cabinet approved the operating license for Finland's fifth reactor, the 1.6 GW EPR at Olkiluoto (OL3), which has been under construction since August 2005.[70] The reactor has had multiple revised startup dates; in March 2019, the target date for grid connection was April 2020, 15 years after construction start and 11 years later than originally planned.[71]

Finland has already adopted different nuclear technologies and suppliers, as two of its operating reactors are VVERs (Vodo-Vodianoï Energuetitcheski Reaktor) V213 built by Russian contractors at Loviisa, while two are AAIII, BWR-2500 built by Asea Brown Boveri (ABB) at Olkiluoto. The OL3 EPR contractor is AREVA. The average age of the four operating reactors is 40.3 years. In January 2017, operator TVO (Teollisuuden Voima's) filed an application for

64 - *WNN*, "Karachi 2 reactor internals in place", 31 January 2019, see http://world-nuclear-news.org/Articles/Karachi-2-reactor-internals-in-place, accessed 14 June 2019.

65 - Power Technology, "Karachi Nuclear Power Plant (KANUPP) Expansion, Pakistan", Undated, see https://www.power-technology.com/projects/karachi-nuclear-power-plant-expansion/, accessed 18 June 2019.

66 - David Stanway, "Argentina, China still discussing nuclear power project: undersecretary", *Reuters*, 2 April 2019, see https://www.reuters.com/article/us-china-nuclearpower-argentina/argentina-china-still-discussing-nuclear-power-project-undersecretary-idUSKCN1RE0O5, accessed 19 June 2019.

67 - Fermín Koop, Lili Pike, "China eyes Argentina in global nuclear roll out", *Diálogo Chino*, 23 May 2019, see https://dialogochino.net/27282-china-eyes-argentina-in-global-nuclear-roll-out/, accessed 4 June 2019.

68 - Ibidem.

69 - *WNN*, "EDF Energy expects 20% cost saving for Sizewell C", 18 January 2018, see https://www.world-nuclear-news.org/Articles/EDF-Energy-expects-20-cost-saving-for-Sizewell-C, accessed 19 June 2019.

70 - YLE, "Third Olkiluoto nuclear reactor granted operating license", 8 March 2019, see https://yle.fi/uutiset/osasto/news/third_olkiluoto_nuclear_reactor_granted_operating_license/10680697, accessed 9 June 2019.

71 - TVO, "OL3 EPR's regular electricity generation starts in July 2020", 17 July 2019, see https://www.tvo.fi/news/, accessed 17 July 2019.

a 20-year license extension for the respectively 39 and 37-year old units Olkiluoto-1 and -2.[72] On 20 September 2018, the Cabinet approved the lifetime extension for Teollisuuden Voima's (TVO) Olkiluoto1 and 2 to operate until 2038.[73]

There are improved prospects for additional lifetime extension of nuclear reactors in Finland following the announcement on 4 June 2019 of the coalition government's carbon neutral 2035 objective. The government program states: "We view extended permits for existing nuclear power plants positively, provided that the Radiation and Nuclear Safety Authority is in favour of them".[74] Analysis of the scenario of a fossil free energy system is predicated on 36 TWh of nuclear generation, 64 percent higher than in 2018.[75] While the operation of OL3 could make up part of this added generation, lifetime extensions would be required also for the Soviet designed Loviisa1 and 2. The Loviisa reactors began operation in February 1977 and November 1980 and are licensed to operate until 2027 and 2030, respectively. Alternatively, the production goal would mean the completion and operation of the 1200 MW AES-2006 Hanhikivi-1, not yet under construction, but scheduled to begin operation in 2028.

Olkiluoto-3 (OL3)

In December 2003, Finland became the first country to order a new nuclear reactor in Western Europe since 1988. AREVA NP, then a joint venture owned 66 percent by AREVA and 34 percent by Siemens,[76] was contracted to build the EPR at Olkiluoto (OL3) under a fixedprice turnkey contract with the utility TVO. After the 2015 technical bankruptcy of AREVA Group, in which the cost overruns of Olkiluoto had played a large part, the majority shareholder, the French government, decided to integrate the reactor-building division under new-old name Framatome into a subsidiary majorityowned by state utility EDF. However, EDF made it clear that it will not take over the billions of euros' liabilities linked to the costly Finnish AREVA adventure.[77] Thus, it was decided that the financial liability for OL3 and associated risks stay with AREVA S.A. after the sale of AREVA NP and the creation of a new company AREVA Holding, now named Orano, that will focus on nuclear fuel and waste management services, very similar to the old COGEMA. In July 2017, the French government confirmed that it had completed its €2 billion (US$2.3 billion) capital increase, most of which was to cover the costs to AREVA of the OL3 project.[78]

72 - TVO, "New operating license applied for Olkiluoto 1 and 2 plant units", 26 January 2017, see http://tvo.fi/news/1830, accessed 9 June 2019.

73 - TVO, "Finnish Government Approves Extension Of Operating Licences For OL1 And OL2 Plant Units", 20 September 2018, see https://www.tvo.fi/news/2043, accessed 9 June 2019.

74 - Finnish Government, "Programme of Prime Minister Antti Rinne's Government 6 June 2019—Inclusive and competent Finland – a socially, economically and ecologically sustainable society", June 2019, see http://julkaisut.valtioneuvosto.fi/bitstream/handle/10024/161664/Inclusive%20and%20competent%20Finland_2019.pdf?sequence=9&isAllowed=y, accessed 15 June 2019.

75 - Smart Energy Transition, "Finnish energy system can be made 100% fossil free", 4 December 2018, see http://smartenergytransition.fi/en/finnish-energy-system-can-be-made-100-fossil-fuel-free/, accessed 13 June 2019.

76 - Siemens quit the consortium in March 2011 and announced in September 2011 that it was abandoning the nuclear sector entirely; see *WNN*, "Siemens quits the nuclear game", 19 September 2011, see http://www.world-nuclear-news.org/C_Siemens_ quits_the_nuclear_game_1909111.html, accessed 4 June 2018.

77 - Jean-Michel Bezat, "EDF pose ses conditions au rachat des réacteurs d'Areva", *Le Monde*, 19 May 2015 (in French), see http://www.lemonde.fr/economie/article/2015/05/19/edf-pose-ses-conditions-au-rachat-des-reacteurs-d-are-va_4636164_3234.html, accessed 9 June 2019.

78 - Jean-Michel Belot, Richard Lough, "Areva says French state completes two billion-euro capital increase", *Reuters*, 12 July 2017, see https://www.reuters.com/article/us-arevasa-capital-idUSKBN19X2S9, accessed 9 June 2019.

The OL3 project was financed essentially on the balance sheets of the Finland's leading firms and heavy energy users as well as a number of municipalities under a unique arrangement that makes them liable for the plant's indefinite capital costs for an indefinite period, whether or not they get the electricity—a capex "takeorpay contract", in addition to the additional billions incurred by AREVA under the fixed price contract.

OL3 construction started in August 2005, with operations planned from 2009. However, as that date—and other dates—passed, in its 2015 Annual Report, TVO stated: "According to the schedule updated by the Supplier, regular electricity production at OL3 will commence at the end of 2018".[79]

From the beginning, the OL3 project was plagued with countless management and quality-control issues. Not only did it prove difficult to carry out concreting and welding to technical specifications, but the use of sub-contractors and workers from over 50 nationalities made communication and oversight extremely complex (see previous WNISR editions).

After further multiple delays, TVO announced in October 2017 that it had again delayed planned commercial operation from November 2018 to May 2019, with grid connection planned for December 2018.[80] TVO then announced in April 2018 that fuel loading was delayed until autumn 2018 (prior to this it had been scheduled for April 2018).[81] A further delay was announced in June 2018, with grid connection planned for May 2019, and "regular electricity generation" in September 2019.[82] That target has now been missed as well. In April 2019 fuel loading was pushed further to August 2019. However, given the need to verify the effectiveness of the measures implemented by TVO to counter vibration in the pressurizer surge line (see hereunder), it is likely that fuel loading will be further delayed.

TVO's claims of grid connection in October 2019 and electricity generation by January 2020 were considered by WNISR as highly optimistic.[83] On 17 July 2019, TVO confirmed further delays to OL3. The revised schedule provided by plant supplier AREVA/Siemens to TVO reported that nuclear fuel loading is now planned from January 2020, with grid connection in April 2020 and commercial operation from July 2020. TVO Director of the OL3 project, Jouni Silvennoinen, stated that "Although, the completion of the plant unit will be further delayed, we are currently working to reach the fuel loading phase and to take over the OL3 EPR unit."[84]

OL3 was cited by the nuclear industry as a showcase for next-generation reactor technology with TVO and AREVA predicting 56 months to completion. However, WNISR predicted nearly

79 - TVO, "Report of the Board of Directors and Financial Statements 2015", February 2016, see http://www.tvo.fi/news/1692, accessed 9 June 2019.

80 - Jussi Rosendahl, Tuomas Forsell, "Areva's Finland reactor to start in 2019 after another delay", *Reuters*, 9 October 2017, see https://www.reuters.com/article/us-finland-nuclear-olkiluoto/arevas-finland-reactor-to-start-in-2019-after-another-delay-idUSKBN1CE1ND, accessed 9 June 2019.

81 - AREVA, "2016 Reference Document", May 2017.

82 - TVO, "OL3 EPR's regular electricity generation starts in September 2019", Press Release, 13 June 2018, see https://www.tvo.fi/news/2000, accessed 9 June 2019.

83 - *WNN*, "TVO starts work to resolve Olkiluoto 3 vibration issue", 23 May 2019, see https://www.world-nuclear-news.org/Articles/TVO-starts-work-to-resolve-Olkiluoto-3-vibration-i, accessed 10 June 2019.

84 - TVO, "OL3 EPR's regular electricity generation starts in July 2020", 17 July 2019, see https://www.tvo.fi/news/, accessed 17 July 2019.

a decade ago that the project would lead to a crisis,[85] which has turned out to be correct as its total construction time to operation on the current schedule of January 2020, will be 188 months, and operation more than ten years behind schedule.

OL3 Pressurizer Vibration

A major factor that has contributed to the delays in the OL3 project during the past 12 months has been a significant technical safety issue. During hot functional testing (HFT) of OL3, which was completed in May 2018,[86] excessive vibration was detected in the pressurizer surge-line which contains high temperature and radioactive reactor coolant under high pressure. The vibrations were outside the permitted safety margin.[87]

The pressurizer surge-line is a Category 1 component (nuclear class I) and seismic category I. It is one of the most important components in maintaining the integrity of the primary pressure boundary. The pressurizer controls the Reactor Coolant System (RCS) pressure by maintaining the temperature of the pressurizer liquid at the saturation temperature corresponding to the desired system pressure with heaters and spray. TVO, at completion of HFT, reported in June 2018 that "the pressurizer surge line vibrations that delayed the hot functional tests will be corrected before fuel loading."[88]

Vibration outside operational license and design base conditions can be considered a major safety issue, since it could lead, in the worst case, to significant internal pipe damage, including the break of the pressurizer surge-line. A likely cause of the vibration is thermal stratification in the surge line which is greatest during heat-up and cooldown because the temperature difference between the pressurizer and hot leg is then the largest.[89]

The Finnish safety regulator STUK, while reporting to the Government in February 2019 that operation of the OL3 would be safe, noted that before fuel loading could be authorized, technical solutions needed to be applied to suppress the pressurizer surge-line vibration of the primary circuit. STUK would "supervise the work and verify before the loading of fuel that the alteration works have been performed and the operability of the solution has been tested."[90]

On 23 May 2019, TVO announced that it had "resolved" the surge-line vibrations.[91] In practice, TVO has begun the installation of viscous bitumen liquid absorbers with the aim of dampening

85 - Steve Thomas, "The EPR in Crisis", Public Services International Research Unit, Business School, University of Greenwich, London, November 2010, see https://gala.gre.ac.uk/id/eprint/4699/3/(ITEM_4699)_THOMAS_2010-11-E-EPR.pdf, accessed 4 June 2018; and WNISR, "The World Nuclear Industry Status Report 2009", see https://www.worldnuclearreport.org/The-World-Nuclear-Industry-Status-52.html, accessed 9 June 2019.

86 - TVO, "OL3 EPR's regular electricity generation starts in September 2019", Press Release, 13 June 2018.

87 - Lefteris Karagiannopoulos, "Exclusive: Safety problem found at Areva's Finnish reactor before start-up – regulator", *Reuters*, 23 February 2019, see https://www.reuters.com/article/us-finland-nuclear-safety-exclusive/exclusive-safety-problem-found-at-arevas-finnish-reactor-before-start-up-regulator-idUSKCN1QB27O, accessed 9 June 2019.

88 - TVO, "OL3 EPR's regular electricity generation starts in September 2019", Press Release, 13 June 2018.

89 - B. Liang, "Periodic Remaining Life Evaluation Program Of PWR Presurizer Surge Line Accounting For Thermal Stratification Effect", Shanghai Nuclear Engineering Research and Design Institute, China, IAEA-CN-155-041, see https://www-pub.iaea.org/MTCD/Publications/PDF/P1362_CD/htm/pdf/Session3/041.pdf, accessed 30 August 2019.

90 - STUK, "Radiation and Nuclear Safety Authority (STUK): Operating licence can be granted to Olkiluoto 3", Press Release, 25 February 2019, see https://www.stuk.fi/web/en/-/radiation-and-nuclear-safety-authority-stuk-operating-licence-can-be-granted-to-olkiluoto-3, accessed 12 June 2019.

91 - TVO, "Olkiluoto 3 Surge Line Vibration Is Resolved", 23 May 2019, see https://www.tvo.fi/news/2114, accessed 12 June 2019.

the vibration effects, with a target of completing installation in late spring. As of 1 July 2019, work was ongoing. Interestingly, a vibration problem has been confirmed also in the Taishan1 EPR in China, where a "muffler" system has been installed. TVO chose the bitumen/viscous system "because there is more vibration at Olkiluoto-3 than at Taishan and the viscous system seemed to work better."[92]

OL3 Costs

As WNISR has documented over the years, the EPR has been a financial disaster. In March 2018, TVO and AREVA announced that they had reached agreement on the completion of OL3, settling all related disputes.[93] In relation to costs and losses caused by the delays, financial compensation of €450 million was to be paid by AREVA to TVO in two installments. There was also a commitment by AREVA that there were sufficient funds for completion of OL3 and that they will cover all applicable guarantee periods, including setting up a trust mechanism funded by AREVA to secure the financing of the costs of completion of the project. The settlement agreement also stipulated that in the event that AREVA fails to complete the project by the end of 2019, they will pay a penalty to TVO that may not exceed €400 million (US$450 million).

With the confirmation of the settlement and TVO disclosing its total investment, it is possible to indicate the cost of the Finnish EPR. TVO's current capital expenditure assumptions and the effect of the settlement agreement estimates its total investment to be around €5.5 billion (US$6.42 billion); on top of this AREVA had losses of €5.5 billion, for a total of €11 billion (US$12.4 billion) compared with the initial estimate cost in 2003 of "around €3 billion".

Rather prematurely, the International Atomic Energy Agency (IAEA) in 2005 proclaimed that "The EPR becomes reality at Finland's Olkiluoto3".[94] Fifteen years later, it is possible that by the time of WNISR2020 the OL3 reactor will be operating. But the multiple failures and enormous cost overruns during the past 14 years of construction have had a major impact on the prospects for nuclear power in Europe and beyond. Touted as spearheading a nuclear renaissance,[95] it has instead exposed the implementation difficulties of even a single reactor project.

In Finland there is no more talk of a second EPR as OL4, as originally planned. Nearly a decade ago, Steve Thomas, energy economist and past contributing author to the WNISR, wrote:

> The promise for Generation III+ plants that they would: 'have the advantage of combining technology familiar to operators of current plants with vastly improved safety features and significant simplification is expected to result in lower and more predictable construction and operating costs' has clearly not been fulfilled... As early as 1995 and again in 1997, there were concerns about the cost of the EPR then expected to be US$2000/kW.... At US$6000/kW or more, it seems unlikely that the EPR will be affordable except where huge public

92 - *NW*, "Vibration damping system being installed at Olkiluoto-3 in Finland", 21 March 2019.

93 - TVO, "TVO confirms a settlement agreement signed on OL3 EPR project completion and related disputes", 11 March 2018, see https://www.tvo.fi/news/1966, accessed 19 July 2019.

94 - U. Giese, R. Leverenz, "The EPR becomes reality at Finland's Olkiluoto 3", Framatome ANP GmBH, IAEA, 2005, see https://inis.iaea.org/search/search.aspx?orig_q=RN:37052975, accessed 12 June 2019.

95 - Zoran V. Stosic, "The Nuclear Renaissance and AREVA's Reactor Designs for the 21st Century: EPR and SWR-1000", AREVA NP, Proceedings of the International Conference Nuclear Energy for New Europe 2007, Portorož (Slovenia), 10–13 September 2007, see http://www.djs.si/proc/port2007/htm/pdf/014.pdf, accessed 12 June 2019.

> subsidies are offered and/or there is a strong likelihood of full cost recovery from consumers, no matter what the cost is.[96]

And as WNISR reported already in 2009: "The flagship EPR project at Olkiluoto in Finland, managed by the largest nuclear builder in the world, AREVA NP, has turned into a financial fiasco."[97]

In the ten years since then, the experience of the OL3 project has only further confirmed these analyses.

Hanhikivi-1

In addition to OL3, in January 2009, the company Fennovoima Oy applied to the Ministry of Employment and the Economy for a decision-in-principle on a new nuclear plant at one of three locations—Ruotsinpyhtää, Simo, or Pyhäjoki. This was narrowed down to the latter site. Fennovoima Oy was established by a consortium of Finnish power and industrial companies. As with OL3, there was an unrealistic startup date given for 2020. In March 2014, Rosatom, through a subsidiary company RAOS Voima Oy, completed the purchase of 34 percent of Fennovoima for an undisclosed price,[98] and then in April 2014 a "binding decision to construct" a 1200 MW AES2006 reactor was announced.

In December 2014, the Finnish Parliament voted in favor of a supplement to the decision-in-principle to include Rosatom's reactor design.[99] A construction license application was submitted at the end of June 2015. In September 2015, the Finnish Nuclear Safety Authority STUK began assessing the project called Hanhikivi1, which at the time was reported would take until the end of 2017.[100]

However, site-preparation work and rock blasting reportedly already began in January 2016.[101] Actual construction was scheduled to start some time in 2018, with completion expected in 2024.[102] However, as WNISR2018 reported, the schedule was not credible—just like in many other Rosatom projects—as the "first batch of documentation" for the construction license application was only transmitted to the Finnish safety authorities on 1 November 2016.[103] Subsequently, in November 2017, Fennovoima Oy was instructed by STUK to "improve their

96 - Steve Thomas, "The EPR in Crisis", November 2010, University of Greenwich, London, see https://gala.gre.ac.uk/id/eprint/4699/3/(ITEM_4699)_THOMAS_2010-11-E-EPR.pdf, accessed 12 June 2019.

97 - Mycle Schneider, Antony Froggatt, et al., "The World Nuclear Industry Status Report 2009—With Particular Emphasis on Economic Issues", 11 June 2012, see https://www.worldnuclearreport.org/The-World-Nuclear-Industry-Status-52.html, accessed 12 June 2019.

98 - Fennovoima, "Rosatom acquired 34% of Fennovoima", Press Release, 27 March 2014.

99 - *WNN*, "Parliament approves Fennovoima's amendment", 5 December 2014, see http://www.world-nuclear-news.org/NN-parliament-approves-Fennovoimas-amendment-5121401.html, accessed 12 June 2019.

100 - STUK, "STUK will start the Construction License safety review and assessment of Fennovoima's project", Press Release, 8 September 2015, see https://www.stuk.fi/web/en/-/stuk-will-start-the-construction-license-safety-review-and-assessment-of-fennovoima-s-project, accessed 12 June 2019.

101 - *PIE*, "PIE's New Power Plant Project Tracker", February 2016.

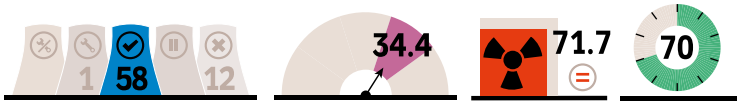
102 - *WNN*, "Daily", 21 March and 8 June 2017.

103 - *WNN*, "Daily", 2 November 2016.

operations before they are in a position to start the construction work."[104] STUK warned that "among other things, Fennovoima must improve the supervision of the organizations involved in the planning and construction of the nuclear power plant. The safety culture of RAOS Project, which is the plant supplier, and the main contractor Titan 2 currently does not fulfill the Finnish expectations".[105]

A 2013 assessment of the AES-2006 reactor concluded that a "long list of safety issues shows that a sufficient level of protection against external and internal impacts as well as the functionally [functionality] of the safety systems had not been demonstrated in a sufficient manner to allow STUK to conclude a positive review. Up to now, a severe accident cannot be excluded due to the design of the AES2006."[106] The STUK review process is ongoing. In December 2018, Fennovoima Oy announced that they had a received a new revised schedule from the plant supplier RAOS Project.[107] This projected that a construction license would be secured in 2021 and construction begun in the same year, with operation of the plant pushed back to 2028. With construction not yet started, the Hanhikivi1 project is already eight years behind the original schedule.

FRANCE FOCUS



Multi Annual Energy Plan and The Energy Bill

In April 2019, the French Government tabled a bill at the National Assembly on the basis of the draft Multi Annual Energy Plan (PPE). The PPE is a planning tool introduced in the 2015 Energy Transition Law that will define the framework of the French energy landscape to 2023 and beyond. The PPE sets the priorities of action for public authorities concerning all forms of energy generation as well as energy efficiency. It will also determine the near-term future of nuclear power in setting targets for installed capacity and therefore the potential closure of a number of reactors. The bill has passed both chambers in the first reading and on 19 July 2019 a mixed commission was appointed to elaborate compromise solutions to outstanding issues under an accelerated procedure.[108]

WNISR2018 stated:

> The state-controlled utility Électricité de France (EDF) seems to live in a different world and stated in its contribution to the PPE consultation that it "envisages certain closures"

104 - STUK, "STUK demands a better safety culture from the Fennovoima nuclear power plant project", 9 November 2017, see http://www.stuk.fi/web/en/-/stuk-demands-a-better-safety-culture-from-the-fennovoima-nuclear-power-plant-project, accessed 12 June 2019.

105 - Ibidem.

106 - Oda Becker, "NPP Fennovoima (Hanhikivi 1)", Report REP-0447, Expert Statement to the EIA Program, commissioned by the Austrian Federal Ministry for Agriculture, Forestry, Environment and Water Management, Project Management Department V/6 "Nuclear Coordination" and the Government of Lower Austria, 2013, see https://www.umweltbundesamt.at/fileadmin/site/publikationen/REP0447.pdf, accessed 13 June 2019.

107 - Fennovoima, "The Hanhikivi 1 project schedule to be re-evaluated", 21 December 2018, see https://www.fennovoima.fi/en/news/hanhikivi-1-project-schedule-be-re-evaluated, accessed 12 June 2019.

108 - For the status of the legislative procedure see Assemblée Nationale, "Projet de Loi–Energie et climat", introduced 30 April 2019 (in French), see http://www.assemblee-nationale.fr/dyn/15/dossiers/alt/energie_climat, accessed 24 July 2019.

> of nuclear reactors "starting 2029".[109] The startling suggestion simply ignores the current legislation that stipulates a reduction of the nuclear share in the French power mix to 50 percent by 2025 and the context of the entire debate.

In fact, EDF got its way to some extent, and the government's draft bill, while maintaining the 50percent target, moves it from 2025 to 2035. According to the government, maintaining the 2025 deadline would have meant the construction of new gas-fired power plants, "in contradiction with our climate objectives"[110], a position contested by its own Energy Management Agency ADEME.[111] At the same time, it raises the stakes on the phase-out of fossil fuels, increasing the 2030 target from –30 percent to –40 percent (baseline 1990) and thus reducing the overall 2050-greenhouse-gas emissions by a factor of more than six rather than four. The last coal-fired power plant is to be closed by 2022. However, this could be delayed as the Flamanville3 EPR will not be in operation until then (see hereunder).

According to the government model, achieving a reduction to 50 percent of the nuclear share in the electricity mix would lead to the closure of 14 reactors by 2035, including the two oldest units at Fessenheim in spring 2020, and two to four additional units by 2028. Achieving the 2025 target would have meant the closure of 24 reactors over a shorter time span.

The draft law does not mention spent fuel management, but the PPE—citing jobs, reduction in natural uranium use and spent fuel generation, as well as "a better containment for the final waste"—stipulates that the "spent fuel-reprocessing and -recycling policy must be maintained".[112]

French Nuclear Power Performance Remains Poor

In 2018, 58 operating reactors[113] in France produced 395.91 TWh, a significant improvement (+14.1 TWh or +3.7 percent) over the previous year. However, it is the third year in a row that generation remained below 400 TWh. In 2005, nuclear generation peaked at 431.2 TWh.

Nuclear plants provided 71.7 percent of the country's electricity, only 0.1 percentage point better than in 2017, which was the lowest share since 1988. The share stabilized after declining four years in a row at almost 7 percentage points below the peak year of 2005 (78.5 percent).

France's load factor at 69.6 percent was still poor in 2018 but improved since a record low of 55.6 percent in 2016, then second lowest in the world behind Argentina. The lifetime load factor remains constant below 70 percent (69.3 percent). According to operator EDF:

> In 2018, generation performance was affected by exceptional damages and large generation incidents (costing around 12.5 TWh), longer-than-expected outages (costing around 5 TWh) and environmental constraints (costing around 2 TWh). The outage extensions

109 - EDF, "Cahier d'acteur n°43", Débat Public PPE, May 2018.

110 - Assemblée Nationale, "Projet de loi relatif à l'énergie et au climat", tabled by Prime Minister Édouard Philippe and then-Minister of Ecology François de Rugy, 30 April 2019.

111 - ADEME = Agence de l'Environnement et de la Maîtrise de l'Énergie; the French Environment & Energy Management Agency.

112 - Ministry for Ecology, "French Strategy for Energy and Climate—Multi Annual Energy Plan—2019-2023—2024-2028, April 2019. The plutonium separation and use strategy is highly controversial but its discussion would be outside the scope of the WNISR. For information on reprocessing and plutonium, see work by the International Panel on Fissile Materials (IPFM) at fissilematerials.org.

113 - All Pressurized Water Reactors (PWRs), 34 x 900 MW, 20 x 1300 MW, and 4 x 1400 MW.

> experienced in 2018 were caused in equal measure by maintenance and operational quality issues, technical failures and project management deficiencies. Performance losses related to unplanned outages rose from a rate of 3.26% in 2017 to 3.7% in 2018 because of several exceptional incidents.[114]

Environmental constraints refer to operating restrictions for several nuclear plants because of lack of cooling water or excess water temperatures. The heat wave in the summer of 2019 led again to the closure or output reduction of several reactors, including the two Golfech units and the two SaintAlban units.

Power Trade

For many years, France was Europe's largest electricity exporter, but in 2016, net exports dropped by 36.6 percent to 39.1 TWh, while Germany's net power exports hit a new record at 53.7 TWh. For the first time, Germany overtook France and became the biggest net power exporter in Europe.[115] In 2017, this trend was reinforced, with France's net exports shrinking again to 38 TWh net,[116] while Germany's net exports increased again to some 55 TWh,[117] with France being the second largest net *importer* from Germany with 13.7 TWh.[118] In January 2018, France imported just under 1 TWh net, "a level that had never been reached", according to RTE.[119] However, over the year 2018 with particularly high output of its hydro plants due to favorable climatic conditions, France exported 60.2 TWh net and recovered its position as the largest net exporter in the EU,[120] with Germany exporting 51.2 TWh net. At the same time, France fell back to the third largest net importer from Germany with 8.9 TWh, but keeps importing from Germany more than from any other country. [121]

Nuclear Unavailability Review 2018

The analysis of the unavailability of French nuclear reactors in 2018 shows:

- A minimum of four French reactors have been down (zero capacity) at the same time.
- A maximum of 27 of the 58 units were down at the same time.
- On 38 occasions, 18 units were down during the same day.
- One 50 occasions, 16 units were down during the same day.

The total number of zero output days of the French reactor fleet exceeded 5,000 days in 2018, an average of 87.6 days per reactor or an outage ratio of a quarter of the time, not including load

114 - EDF, "Reference Document 2018", April 2019.

115 - AGEB, "Bruttostromerzeugung in Deutschland ab 1990 nach Energieträgern", Working Group on Energy Balances, German Institute for Economic Research (DIW), March 2019 (in German), see http://www.ag-energiebilanzen.de/index.php?article_id=29&fileName=20170207_brd_stromerzeugung1990-2016.pdf, accessed 23 June 2017.

116 - RTE, "Mon bilan électrique 2017", 2018.

117 - Updated figure according to AGEB, "Bruttostromerzeugung in Deutschland ab 1990 nach Energieträgern", March 2019, op. cit.

118 - Agora Energiewende, "Die Energiewende im Stromsektor: Stand der Dinge 2017", January 2018.

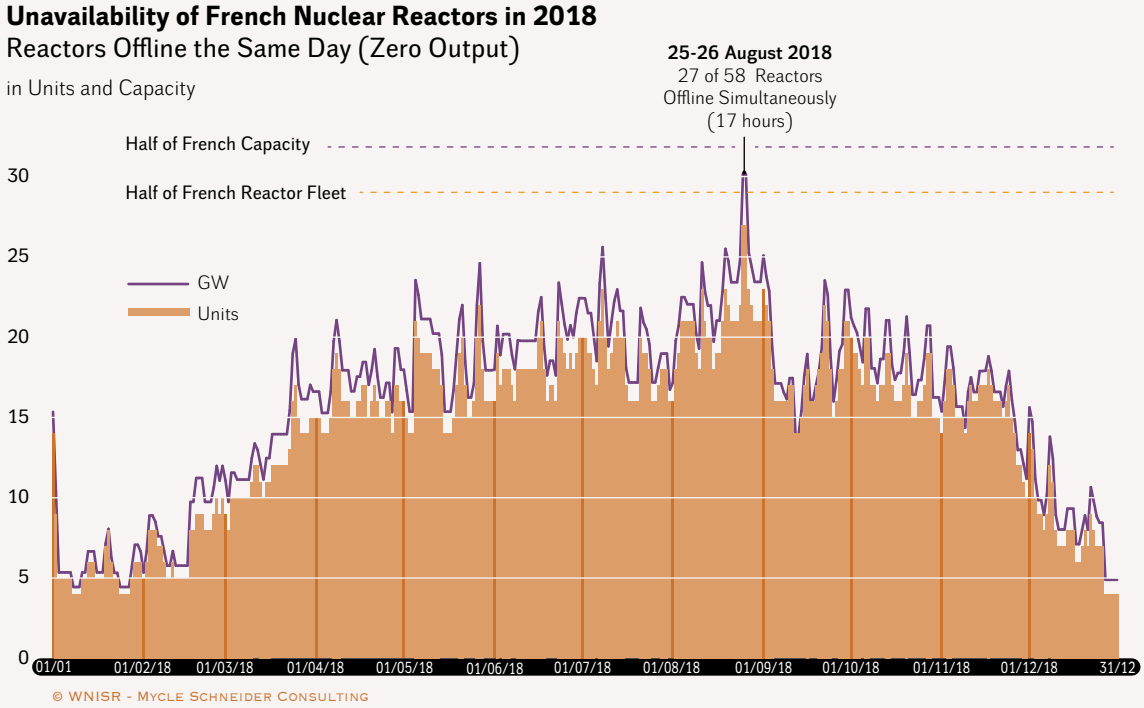
119 - RTE, "Bilan électrique 2017", 2018.

120 - RTE, "Bilan électrique 2018", 2019.

121 - Agora Energiewende, "Die Energiewende im Stromsektor: Stand der Dinge 2018", January 2019.

following or other operational situations with reduced but above-zero output e.g. as during the heat wave (see Figure 24 and Figure 25).

Figure 24 | Reactor Outages in France in 2018 (in number of units and GWe)



Sources: RTE and EDF, "List of outages", 2019[122]

Note

For each day in the year, this graph shows the total number of reactors offline, not necessarily simultaneously as all unavailabilities do not overlap, but on the same day.

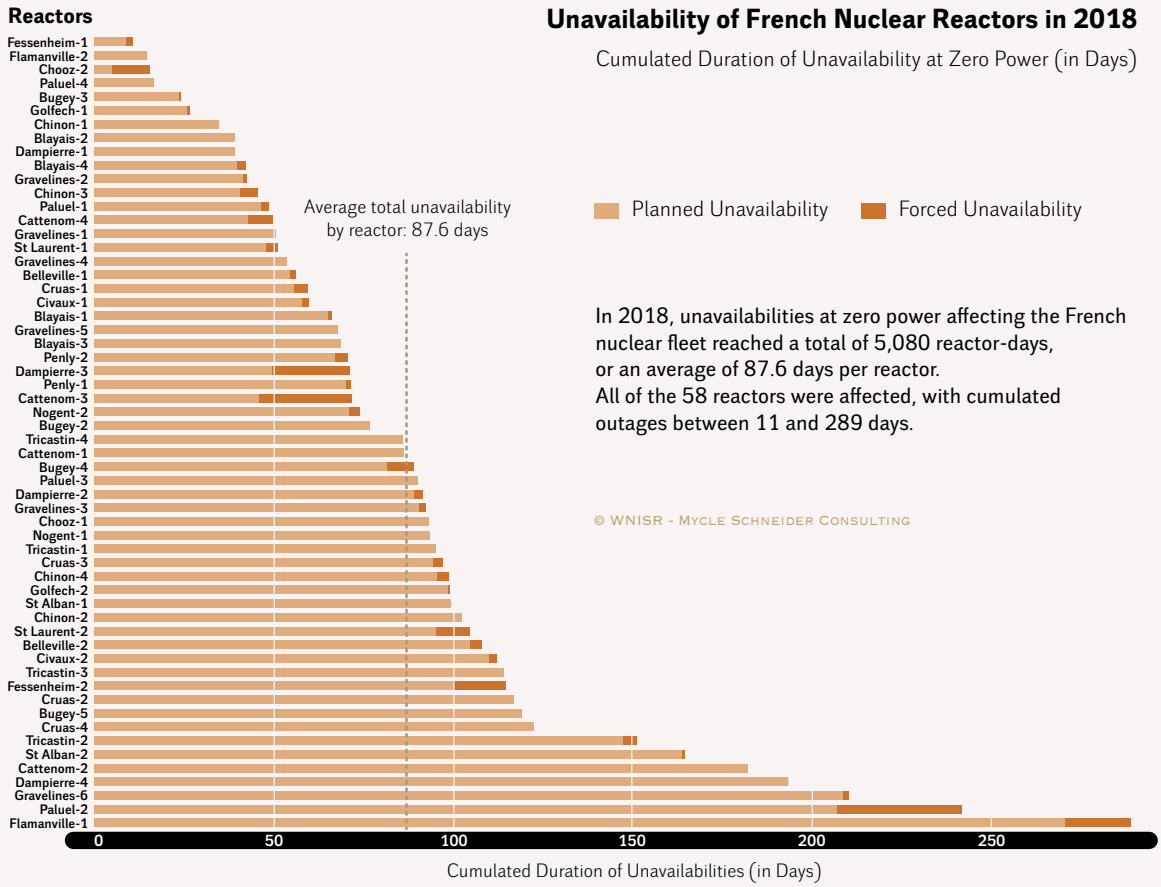
Some of the longest outages include:

- Cattenom-2 (182 days): The unavailability included 141 days for the third decennial review (VD3)[123], preceded by 41 days for "maintenance" work.
- Dampierre-4 (193 days in 2018): The outage was mainly due to the VD3 that progressively increased from an expected 50 days to 191 days.
- Gravelines-6 (210 days in 2018): The shutdown was essentially due to the VD3 that was progressively extended from a scheduled 164 days, when it started, to 208 days. This is even more remarkable as the VD3 was originally to include the replacement of the reactor's three steam generators, an operation delayed to 2020 because the Nuclear Safety Authority (ASN) did not deliver the necessary quality certificates for the new equipment. This means another long outage is to be expected for 2020.

122 - See EDF, "List of Outages", 2019, see https://www.edf.fr/en/the-edf-group/who-we-are/activities/optimisation-and-trading/list-of-outages-and-messages/list-of-outages, last accessed July and August 2019.

123 - The decennial reviews (visite décennale) are time-consuming in-depth nuclear safety related inspections, backfitting and upgrading.

Figure 25 | Forced and Planned Unavailability of Nuclear Reactors in France in 2018



Sources: Compilation from RTE, 2019

Notes

This graph only compiles outages at zero power, thus excluding all other operational periods with reduced capacity >0 MW. Impact of unavailabilities on power production is therefore significantly larger.

"Planned" and "Forced" unavailabilities as declared by EDF.

Lifetime Extension, ASN and the Fourth Decennial Reviews

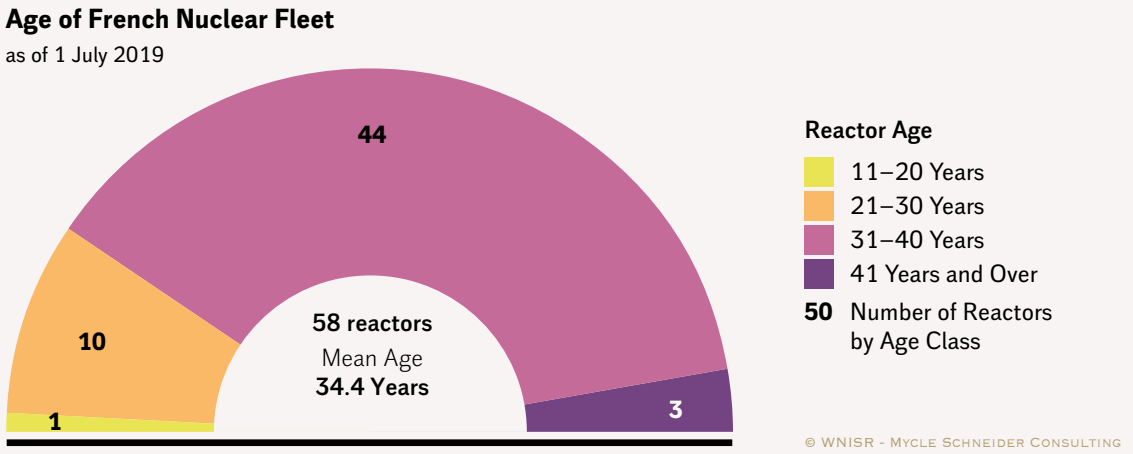
The average age of France's 58 power reactors was 34.4 years by mid-2019 (see Figure 26). In the absence of new reactor commissioning and any closure, the fleet is aging by one year every year.

Lifetime extension beyond 40 years of some reactors—47 operating units are now over 31 years old—would require significant additional upgrades. Also, relicensing will be subject to public inquiries reactor by reactor.

Operating costs have increased substantially over the past years. Investments for lifetime extensions will need to be balanced against the already excessive nuclear share in the power mix, the stagnating or decreasing electricity consumption in France—it has been roughly stable for the past decade—and in the European Union (EU) as a whole, the shrinking client base, successful competitors, and the energy efficiency and renewable energy production targets set at both the EU and the French levels. EDF claims that the power generating costs for existing reactors would be €32/MWh (US$38/MWh), including nuclear operating and maintenance

costs (€22/MWh including fuel at €5/MWh) and all anticipated upgrading costs for plant life extension to 50 years (10 €/MWh) remain more economic than "any new alternative".[124] However, there are serious questions about these numbers. Michèle Pappalardo, former Ecology Minister Nicolas Hulot's Chief of Staff and former senior representative of the Court of Accounts, remarked during the hearings of the Inquiry Committee that EDF's calculation stopped mid-way in 2025, and recalled that the Court had calculated a total cost of €100 billion (US$117 billion) for the period 2014–2030.[125]

Figure 26 | Age Distribution of French Nuclear Fleet (by Decade)



Sources: WNISR, with IAEA-PRIS, 2019

Apart from the two oldest French reactors at Fessenheim, now planned to be definitively closed in spring 2020, EDF will seek lifetime extension beyond the 4th Decennial Safety Review (VD4) for most if not all of its remaining reactors. This is in line with the Government's Multi Annual Energy Plan, which plans for no further reactor closures until 2023 (the end of the current presidential term) and only a limited number in the following years. This program will be limited to 900 MWe reactors, the oldest segment of the French nuclear fleet. The first reactors to undergo the VD4 are scheduled to include Tricastin1 in 2019, Bugey-2 and -4 in 2020, and Tricastin-2, Dampierre-1, Bugey-5 and Gravelines-1 in 2021.

EDF expects these VD4 outages to last six months, longer than the average of three to four months experienced through VD2 and VD3 outages. However, as illustrated by the recent outage history, many factors could lead to significantly longer outages.

Detailed generic requirements for plant life extension have not been issued yet by the Nuclear Safety Authority (ASN). Originally, these requirements were to be issued in 2016 but their release has been postponed a number of times, due to the need for extended and often unprecedented technical discussions. The general objective of ASN has been to bring the reactors "as close as possible" to the safety level required in new reactor designs, such as the

124 - EDF, "Le parc nucléaire en exploitation en France : Exploitation, maintenance et Grand Carénage", 11 January 2018.

125 - Barbara Pompili, "Rapport d'enquête sur la sûreté et la sécurité des installations nucléaires", Commission d'Enquête sur la Sûreté et la Sécurité des Installation Nucléaires, French National Assembly, N°1122, tome II, 28 June 2018 (in French), see http://www.assemblee-nationale.fr/15/rap-enq/r1122-tII.asp, accessed 19 July 2018.

EPR under construction in Flamanville. This is strikingly different from other countries, and notably the U.S., where safety authorities merely request to maintain a given safety level.

ASN now plans to issue its generic order by 2020, which is particularly critical for Tricastin-1, the first unit scheduled to undergo the VD4, *starting in 2019*. The case will be particularly sensitive to unexpected difficulties. For example, the requirement to introduce a kind of core-catcher[126] would be a first in an existing reactor.

It is clearly expected that the amount of work to be completed as part of the VD4 will be much more important than for VD3, and EDF might have underestimated the resulting workload, or overestimated its capacity to deliver on it. EDF, in fact, has already started negotiating with ASN for the workload to be split in two packages, with the supposedly smaller second one to be postponed four years after the VD4.[127]

The timely delivery of this work is likely to stretch the industrial capacity of EDF and its subcontractors beyond its current limits. ASN has recently pointed to the need for the operator to restore its level of industrial control as a top priority for nuclear safety.[128]

The Ongoing Flamanville-3 EPR Saga

At this stage, commissioning cannot be expected before end of 2022.

EDF, 25 July 2019[129]

The 2005 construction decision of Flamanville-3 (FL3) was mainly motivated by the industry's attempt to confront the serious problem of maintaining nuclear competence. In December 2007, EDF started construction on FL3 with a scheduled startup date of 2012. The project has been plagued with detailed-design issues and quality-control problems, including basic concrete and welding similar to those at the Olkiluoto (OL3) project in Finland, which started two-and-a-half years earlier. These problems never stopped and in April 2018, it was discovered that the main welds in the secondary steam system did not conform with the technical specifications; so by the end of May 2018 EDF stated that repair work might again cause "a delay of several months to the start-up of the Flamanville 3 European Pressurized Water Reactor (EPR) reactor."[130] In fact, the delay will be several years, and the startup of FL3 is now not expected before the end of 2022.

126 - In a core-melt accident (like at Fukushima Daiichi 1, 2, and 3), the core-catcher is supposed to avoid molten-fuel interaction with concrete and make sure that it does not burn through the concrete and get into the ground.

127 - ASN, "Réexamen périodique associé aux quatrièmes visites décennales des réacteurs du palier 900 MWe", Presentation at a meeting of the local information committee on the major energy facilities at Tricastin, Commission locale d'information des grands équipements énergétiques du Tricastin (CLIGEET), 4 July 2018 (in French), see https://www.ladrome.fr/sites/default/files/5.2_presentation_asn_vd4.pdf, accessed 23 March 2019.

128 - ASN, "L'ASN formule trois attentes à l'occasion de ses vœux à la presse", Notice of Information and video, 29 January 2019 (in French), see https://www.asn.fr/Informer/Actualites/L-ASN-formule-ses-attentes-a-l-occasion-des-voeux-a-la-presse, accessed 25 March 2019.

129 - EDF, "Half-Year Results 2019", 25 July 2019.

130 - EDF, "Quality deviations on certain welds of the secondary circuit at the Flamanville EPR: the investigation continues", 31 May 2018, see https://www.edf.fr/en/the-edf-group/dedicated-sections/journalists/all-press-releases/quality-deviations-on-certain-welds-of-the-secondary-circuit-at-the-flamanville-epr-the-investigation-continues, accessed 7 June 2018.

In a letter of 19 June 2019, ASN informed EDF that "in the light of the numerous deviations in the production of the Flamanville EPR penetration welds, they would have to be repaired"[131]. ASN pointed out in the letter, signed by the Chairman:

> **ASN considers that, given the number and nature of the deviations affecting these welds, their break can no longer be considered as highly improbable and that a break preclusion approach can no longer be applied to them**. [Bold font in the original.][132]

ASN explains on its website:

> In 2018, EDF had proposed an approach aiming to justify maintaining these welds as they were. ASN then considered that the outcome of such an approach was uncertain and had asked EDF to begin preparatory operations prior to repair of the welds located between the two walls of the reactor containment [consult information notice published on 03/10/2018].
>
> EDF's approach was reviewed by ASN, with technical support from IRSN [French Institute for Radiation Protection and Nuclear Safety], including consultation of the Advisory Committee for Nuclear Pressure Equipment (GP ESPN) [consult information notice published on 11/04/2019].

Until the latest discovery, FL3 was expected to start generating power in May 2019, reaching full capacity in November 2019. [133] The official cost estimate for FL3 stood at €10.5 billion (US$12.3 billion) as of 2015[134]. After a series of additional mishaps and delays, in July 2018, the owner-builder stated: "The EDF group has therefore adjusted the Flamanville EPR schedule and construction costs accordingly. The loading of nuclear fuel is now scheduled for the 4th quarter in 2019 and the target construction costs have been revised from €10.5 billion [US$12.3 billion] to €10.9 billion [US$12.7 billion]".[135] EDF revised its position in July 2019 and announced that, concerning the FL3 steam line repair work, it "expects to communicate the schedule and cost implications of the selected scenario in the next few months", already certain that "commissioning cannot be expected before the end of 2022".[136]

This latest delay raises another legal problem. The construction license, which had already been extended in 2017, will run out on 10 April 2020.[137] On 23 July 2019, EDF filed a new application to amend the construction license.[138] This time, it will likely entail a new public enquiry.

FL3 is now at least a decade behind schedule.

131 - ASN, "Deviations on the Flamanville EPR steam lines: the eight penetration welds will have to be repaired", Information Notice, 20 June 2019, see http://www.french-nuclear-safety.fr/Information/News-releases/Deviations-on-the-Flamanville-EPR-steam-lines-the-eight-penetration-welds-will-have-to-be-repaired, accessed 20 June 2019.

132 - ASN, "Letter to the Chairman of EDF", 19 June 2019, see http://www.french-nuclear-safety.fr/Media/Files/letter-CODEP-CLG-2019-027253-UK-ASN-EDF-VVP-EPR, accessed 28 July 2019.

133 - Bate Felix, Benjamin Mallet, "L'EPR de Flamanville attendu à pleine puissance en novembre 2019", *Reuters*, 11 July 2017.

134 - EDF, "2015 Management Report—Group Results", 13 May 2016.

135 - EDF, "Welds in the main secondary system of the Flamanville EPR: EDF sets up corrective actions and adjusts schedule and target construction costs", 25 July 2018, see https://www.edf.fr/en/edf/welds-in-the-main-secondary-system-of-the-flamanville-epr-edf-sets-up-corrective-actions-and-adjusts-schedule-and-target-construction-costs, accessed 25 July 2018.

136 - EDF, "Half-Year Results 2019", 25 July 2019.

137 - Ministry of the Environment, Energy and the Sea, in charge of International Relations on Climate, "Décret n° 2017-379 du 23 mars 2017 modifiant le décret n° 2007-534 du 10 avril 2007 autorisant la création de l'installation nucléaire de base dénommée Flamanville 3, comportant un réacteur nucléaire de type EPR, sur le site de Flamanville (Manche)", 24 March 2017 (in French), see https://www.legifrance.gouv.fr/affichTexte.do;jsessionid=0385C6ECDD66D0F6D6896702526A28A5.tpdila22v_2?cidTexte=JORFTEXT000034264985&dateTexte=&oldAction=rechJO&categorieLien=id&idJO=JORFCONT000034264920, accessed 28 July 2019.

138 - EDF, "Half-Year Results 2019", 25 July 2019.

Other Ongoing Quality Issues

In April 2015, the French Nuclear Safety Authority (ASN) revealed that the bottom piece and the lid of the FL3 pressure vessel had "very serious" defects.[139] Chemical and mechanical tests "revealed the presence of a zone in which there was a high carbon concentration, leading to lower than expected mechanical toughness values".[140] Both pieces were fabricated and assembled by AREVA in France, while the center piece was forged by Japan Steel Works (JSW) in Japan. ASN stated then that the same fabrication procedure by AREVA's Creusot Forge was applied to "certain calottes" (also called bottom heads and closure heads) of the two pressure vessels made for the two EPRs under construction at Taishan in China, while the EPR under construction in Finland was entirely manufactured in Japan. AREVA's challenge was to prove that, although clearly below technical specifications, the EPR pressure vessels could withstand any major transient. After a lengthy and controversial re-qualification procedure (see WNISR2017 for details), ASN released its official judgement on the issue considering the "mechanical characteristics" of vessel cover and bottom "adequate". However, ASN "considers that the use of the closure head must be limited in time" and as a new closure head could be available by 2024, the current piece "shall not be operated beyond that date".[141]

In a more recent development, ASN investigations at the Framatome subcontractor JSW's factory in Muroran, Japan, that manufactures the replacement vessel head for FL3 and components for replacement steam generators for French 1300 MW reactors, revealed some serious flaws, including:

- The incapacity to prove a constant temperature during the forging process;
- The use of pencils in process documentation;
- Hand-written, unsigned, undated corrections on quality documentation.[142]

Ongoing Fallout from Creusot Forge Affair

Meanwhile, the finding of carbon segregations in the pressure vessel of FL3 had raised concerns about the possibility that other components could have been fabricated below technical specifications due to poor quality processes at Creusot Forge.[143] On 25 April 2016, AREVA informed ASN that "irregularities in the manufacturing checks", the quality-control procedures, were detected at about 400 pieces fabricated since 1969, about 50 of which would be installed in the French currently operating reactor fleet. The "irregularities" included "inconsistencies, modifications or omissions in the production files, concerning manufacturing

139 - Ludovic Dupin, "Le cri d'alarme de l'ASN sur le nucléaire français", *Usine Nouvelle*, 20 January 2016 (in French), see http://www.usinenouvelle.com/article/le-cri-d-alarme-de-l-asn-sur-le-nucleaire-francais.N374729, accessed 11 June 2016.

140 - ASN, "Flamanville EPR reactor vessel manufacturing anomalies", Press Release, 7 April 2015, see http://www.french-nuclear-safety.fr/Information/News-releases/Flamanville-EPR-reactor-vessel-manufacturing-anomalies, accessed 14 August 2017.

141 - ASN, "ASN presents its position regarding the Flamanville EPR reactor vessel anomaly", Press Release, 28 June 2017, see http://www.french-nuclear-safety.fr/Information/News-releases/ASN-presents-its-position-regarding-the-Flamanville-EPR-reactor-vessel-anomaly, accessed 31 July 2017.

142 - ASN, "Lettre au Président de Framatome", 4 January 2019.

143 - The regulation on pressurized components of nuclear facilities changed in 2005. In particular, it now requires that mechanical properties should be verified in every area of the components, instead of limiting it to the most sensitive areas as it previously was the norm.

parameters or test results".[144] The most serious regulatory violation led ASN to withdraw the certificate of a replacement steam generator introduced in Fessenheim-2 in 2012, because the forging process of its central part did not comply with qualified methods, and this was covered in the documentation submitted to ASN and EDF, leaving the reactor shut down between June 2016[145] and April 2018. According to EDF, in total, it has detected 1,775 "anomalies" in parts that were integrated into 46 reactors.[146] According to EDF, as of the end of January 2019, 54 reactors had obtained ASN's green light for restart "confirming the operational safety of the concerned components".[147] This means that in the case of the remaining four units ASN still has not confirmed the safety of the respective incriminated parts.

The Ongoing Tricastin Canal Embankment Case

The Tricastin Nuclear Power Plant

Photo: www.asn.fr

On 27 September 2017, ASN required that "EDF temporarily shut down the four reactors of the Tricastin nuclear power plant as rapidly as possible", because of the "risk of failure of a part of the embankment of the Donzère-Mondragon canal with regard to the most severe earthquakes

144 - ASN, "AREVA has informed ASN of irregularities concerning components manufactured in its Creusot Forge plant", 4 May 2016, see http://www.french-nuclear-safety.fr/Information/News-releases/Irregularities-concerning-components-manufactured-in-its-Creusot-Forge-plant, accessed 14 August 2017.

145 - Pierre-Franck Chevet, "Décision n° CODEP-CLG-2016-02945 du 18 juillet 2016 du Président de l'Autorité de sûreté nucléaire suspendant le certificat d'épreuve du générateur de vapeur n° 335 fabriqué par AREVA NP", ASN, République Française, 18 July 2016 (in French), see https://www.asn.fr/content/download/105596/795168/version/1/file/Décision n° CODEP-CLG-2016-02945 du 18 juillet 2016.pdf, accessed 10 August 2017.

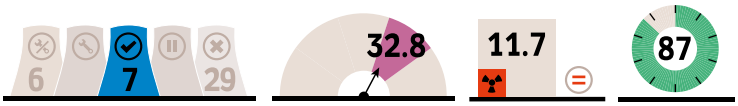
146 - These numbers and the following three paragraphs from EDF, "Dossiers de fabrication", 17 July 2018 (in French), see https://www.edf.fr/groupe-edf/nos-energies/nucleaire/segregation-carbone-et-dossiers-de-fabrication-creusot-forge/dossiers-de-fabrication, accessed 20 July 2018.

147 - EDF, "Reference Document 2018", April 2019.

studied in the nuclear safety case."[148] ASN's technical backup Institute for Radiation Protection and Nuclear Safety (IRSN) released a briefing that stated that the plant had not been designed to withstand flooding from the canal. Such an event would "lead to the total loss of cooling of the fuel in the core and in the spent fuel pool of every reactor leading to the meltdown of that fuel".[149]

On 5 December 2017, ASN validated the embankment repair work carried out by EDF and granted permission for restart of the Tricastin reactors.[150] On 25 June 2019, ASN requested additional work to reinforce the embankment to be carried out by the end of 2022 at the latest. Until then, the ASN requests EDF to implement increased embankment surveillance and guarantee the availability of human and material means to repair potential damage stemming from an earthquake.[151]

GERMANY FOCUS



Germany's remaining seven nuclear reactors generated 71.9 TWh net in 2018, almost matching the 72.2 TWh of 2017, but less than half of the generation of 162.4 TWh in record year 2001. Nuclear plants provided a stable 11.7 percent of Germany's electricity generation, representing little more than one-third of the historic maximum of 30.8 percent in 1997. One more reactor (Philippsburg-2) will be closed at the end of 2019, according to the nuclear phase-out legislation that will see all reactors closed by the end of 2022 (see **Table 4** for details). The average load factor remained stable at 86.7 percent, allowing Germany to keep its third rank in the world (behind Romania and Finland). Three German reactors are still among the ten best lifetime load factors. All seven units that generated power in 2018 are in the Top Ten lifetime electricity generators in the world, five of which are holding positions one to five. (Only three U.S. reactors made it into the Top Ten alongside the German units).[152]

> *"Renewables cover 16.7% of final energy in Germany, nuclear covers 17.4% of final energy in France."*

Germany decided immediately after 3/11 to close eight of the oldest[153] of its 17 operating reactors and to phase out the remaining nine until 2022, effectively reactivating a "consensus agreement" negotiated a decade earlier. This choice was implemented by a conservative, pro-

148 - ASN, "Insufficient seismic resistance of a part of the Donzère-Mondragon canal embankment: ASN imposes temporary shutdown of the Tricastin nuclear power plant", Press Release, 28 September 2017, see http://www.french-nuclear-safety.fr/Information/News-releases/ASN-imposes-temporary-shutdown-of-the-Tricastin-nuclear-power-plant, accessed 15 July 2018.

149 - IRSN, "Protection du site du Tricastin contre les risques d'inondation—Comportement des digues du canal de Donzère-Mondragon en cas de séisme", 28 September 2017 (in French), see http://www.irsn.fr/FR/Actualites_presse/Actualites/Documents/IRSN_NI-Tricastin-Digues-canal-donzere-seisme_20170928.pdf, accessed 15 July 2018.

150 - ASN, "ASN allows restart of the reactors of the Tricastin nuclear power plant (NPP)", 5 December 2017, see http://www.french-nuclear-safety.fr/Information/News-releases/ASN-allows-restart-of-the-reactors-of-the-Tricastin-nuclear-power-plant-NPP, accessed 22 June 2018.

151 - ASN, "Décison n°2019-DC-0674 de l'ASN du 25 juin 2019", 10 July 2019 (in French), see https://www.asn.fr/Reglementer/Bulletin-officiel-de-l-ASN/Installations-nucleaires/Decisions-individuelles/Decison-n-2019-DC-0674-de-l-ASN-du-25-juin-2019, accessed 27 July 2019.

152 - *NEI*, "Load factors to end December 2018", June 2019, Caroline Peachey, personal communication, email dated 10 June 2019.

153 - Including the Krümmel and Brunsbüttel reactors that by then had not generated power for two almost two and four years respectively.

business, and, until the Fukushima disaster, very pro-nuclear Government, led by physicist Chancellor Angela Merkel, with no political party dissenting, which makes it virtually irreversible under any political constellation. On 6 June 2011, the Bundestag passed a seven-part energy transition legislation almost by consensus and it came into force on 6 August 2011 (see earlier WNISR editions for details).

Table 4 | Legal Closure Dates for German Nuclear Reactors 2011–2022

Reactor Name (Type, Net Capacity)	Owner/Operator	First Grid Connection	End of License (latest closure date)
Biblis-A (PWR, 1167 MW)	RWE	1974	6 August 2011
Biblis-B (PWR, 1240 MW)	RWE	1976	
Brunsbüttel (BWR, 771 MW)	KKW Brunsbüttel[a]	1976	
Isar-1 (BWR, 878 MW)	PreussenElektra	1977	
Krümmel (BWR, 1346 MW)	KKW Krümmel[b]	1983	
Neckarwestheim-1 (PWR, 785 MW)	EnBW	1976	
Philippsburg-1 (BWR, 890 MW)	EnBW	1979	
Unterweser (BWR, 1345 MW)	PreussenElektra	1978	
Grafenrheinfeld (PWR, 1275 MW)	PreussenElektra	1981	31 December 2015 (closed 27 June 2015)
Gundremmingen-B (BWR, 1284 MW)	KKW Gundremmingen[c]	1984	31 December 2017
Philippsburg-2 (PWR, 1402 MW)	EnBW	1984	31 December 2019
Brokdorf (PWR, 1410 MW)	PreussenElektra/Vattenfall[d]	1986	31 December 2021
Grohnde (PWR, 1360 MW)	PreussenElektra	1984	
Gundremmingen-C (BWR, 1288 MW)	KKW Gundremmingen	1984	
Isar-2 (PWR, 1410 MW)	PreussenElektra	1988	31 December 2022
Emsland (PWR, 1329 MW)	KKW Lippe-Ems[e]	1988	
Neckarwestheim-2 (PWR, 1310 MW)	EnBW	1989	

Sources: Atomgesetz, 31 July 2011, Atomforum Kernenergie May 2011; IAEA-PRIS 2012

Notes

Krümmel and Brunsbüttel were officially closed in 2011 but had not been providing electricity to the grid since 2009 and 2007 respectively

PWR=Pressurized Water Reactor; **BWR**=Boiling Water Reactor; **RWE**= Rheinisch-Westfälisches Elektrizitätswerk Power AG

a - Vattenfall 66.67%, E.ON 33.33% **b** - Vattenfall 50%, E.ON 50%. **c** - RWE 75%, E.ON 25%.

d - E.ON 80%, Vattenfall 20%. **e** - RWE 87.5%, E.ON 12.5%.

Renewables generated 226 TWh representing 35 percent of gross national electricity generation or 38 percent of gross national power consumption in 2018, about half of it from onshore/offshore wind power, which alone, since 2017, by far outgenerates nuclear power. In 2017, renewables covered 15.9 percent of Germany's total final energy consumption.[154] To put this into perspective, in France, nuclear power covered 17 percent of final energy in 2017.[155] Provisional figures for 2018 show respective shares of 16.7 percent for German renewables[156] and 17.4 percent for French nuclear.[157] As renewables accelerate their expansion beyond the power sector throughout the German economy, their share in final energy has increased by

154 - Federal Ministry for Economic Affairs and Energy, "Development of Renewable Energy Sources in Germany 2018", February 2019.

155 - General Commission for Sustainable Development, "Bilan énergétique de la France pour 2017", French Ministry for the Ecological and Inclusive Transition, February 2019.

156 - Federal Ministry for Economic Affairs and Energy, "Renewable Energy Sources in Germany 2018—Key information of the year 2018 at a glance", February 2019.

157 - General Commission for Sustainable Development, "Bilan énergétique de la France en 2018–Données provisoires", French Ministry for the Ecological and Inclusive Transition, April 2019.

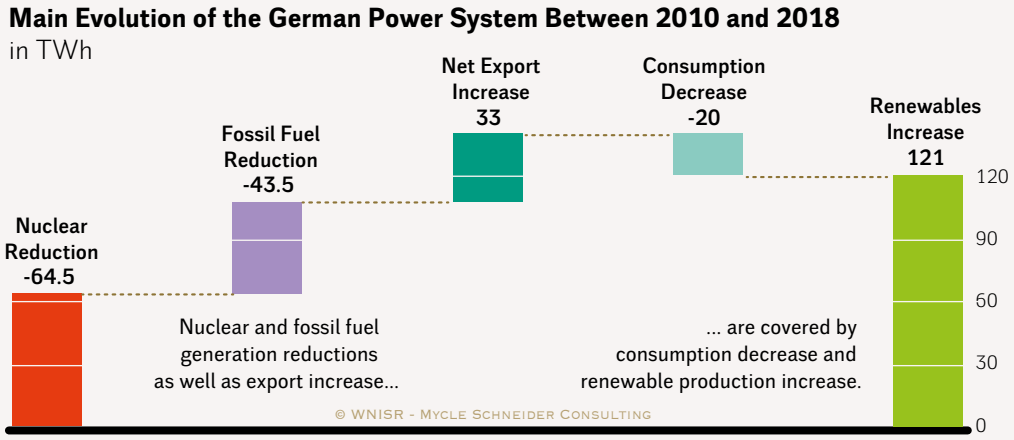
more than 5 percentage points since 2010, while the French nuclear share remained about stable (16.9 percent in 2010).

Fossil-fuel-based generation in Germany continued to drop in 2018—hard coal by 10.4 percent, lignite by 2 percent and natural gas by 3.8 percent. Renewables were again by far the largest contributor to the power mix (gross) and supplied more than lignite (22.5 percent) and hard coal (12.9 percent) together, while natural gas also contributed 12.9 percent.[158]

In 2017, Germany's net power exports hit a new record at 55 TWh. In 2018, the net exports stood at 51.2 TWh, the fourth year in a row that the trade surplus exceeded 50 TWh.

Figure 27 summarizes the main developments of the German power system between 2010—the last year prior to the post-3/11 closure of the eight oldest nuclear reactors—and 2018.

Figure 27 | Main Developments of the German Power System Between 2010 and 2018



Source: WNISR based on AGEB, 2019[159]

It shows that the remarkable increase of renewable electricity generation (+120.9 TWh) and the reduction in domestic consumption (–20.3 TWh) were far more than sufficient to compensate for the reduction of nuclear generation (64.6 TWh), enabling also a reduction in power generation from fossil fuels (–43.5 TWh) and a threefold increase in net exports (+33.5 TWh) (without which the fossil-fueled generation would have been even lower). Within the fossil-fuel generating segment, for the first time in 2018, all primary fuel-uses decreased compared to the previous year *and* remained below the 2010 level:

- Lignite peaked in 2013 and then declined to just below the 2010 level (–0.4 TWh);
- Hard coal also peaked in 2013 then dropped significantly (–33.8 TWh or –28.9 percent below 2010);

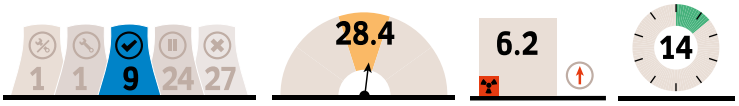
158 - AGEB, "Energieverbrauch in Deutschland im Jahr 2018", Working Group on Energy Balances, German Institute for Economic Research (DIW), February 2019, op. cit.

159 - AGEB, "Bruttostromerzeugung in Deutschland ab 1990 nach Energieträgern", Working Group on Energy Balances, German Institute for Economic Research (DIW), 6 March 2019 (in German), see https://ag-energiebilanzen.de/index.php?article_id=29&fileName=20181214_brd_stromerzeugung1990-2018.pdf, accessed 24 July 2019.

- Natural gas peaked in 2010 and then fluctuated to remain on the lower end (–5.9 TWh or 6.6 percent below 2010)
- Oil was relatively insignificant and dropped further (–3.5 TWh or 40.2 percent since 2010).

Greenhouse gas emissions from the power sector dropped again by 3.7 percent in 2018, while carbon intensity decreased from 489 gCO_2/kWh to 472 gCO_2/kWh.[160]

JAPAN FOCUS



A total of nine reactors are currently operating in Japan. No additional reactors restarted since WNISR2018 under the revised Nuclear Regulatory Authority's (NRA) safety guidelines, whereas four had done so in the year to May 2018.

One reactor, PWR Ikata-3, which restarted in 2016 and had been in operation until October 2017, was shut down for nearly one year following a first of its kind high court ruling in December 2017 (see WNISR2018). Scheduled to return to operation in January 2018, the Hiroshima High Court issued a citizens-sought injunction against the operation of the reactor on the grounds of seismic and volcano risks. The plant is at risk from the massive Nankai Trough and the Median Tectonic Line fault belt—Japan's largest-class and longest fault zone, which runs near the Ikata plant site. On 25 September 2018, the Hiroshima High Court reversed its decision,[161] lifted the injunction, and permitted the Ikata plant to resume operation on 27 October 2018.[162]

Two reactors were announced for permanent closure since WNISR2018. Tohoku Electric Power Company announced on 25 October 2018 that the BWR Onagawa-1, that had not produced power since 2011, was to remain permanently off grid.[163] Kyushu Electric Power Company on 9 April 2019 issued a formal notification of the closure of its Pressurized Water Reactor (PWR) Genkai-2.[164] The Ikata-2 PWR moved to formal closure in October 2018 when the utility, Shikoku Electric Power Company, notified the NRA.[165] In March 2018, the utility had announced the Board of Directors' decision for the permanent closure of the 36-year-old unit.[166]

160 - Agora Energiewende, "Die Energiewende im Stromsektor: Stand der Dinge 2018—Rückblick auf die wesentlichen Entwicklungen sowie Ausblick auf 2019", January 2019 (in German), see https://www.agora-energiewende.de/fileadmin2/Projekte/2018/Jahresauswertung_2018/125_Agora-JAW-2018_WEB.pdf , accessed 24 July 2019.

161 - *Bloomberg*, "Japan Court Allows Nuclear Reactor to Reopen in Boost to Abe's Energy Push", 25 September 2019, see https://www.bloomberg.com/news/articles/2018-09-25/japan-court-rules-shikoku-electric-can-restart-nuclear-reactor, accessed 25 April 2019.

162 - The plaintiffs to the Hiroshima High Court contended that the risks from volcanic eruption had not been fully addressed by Shikoku Electric. *Japan Times*, "Shikoku Electric restarts Ikata nuclear reactor following failed court challenges", 27 October 2018, see https://www.japantimes.co.jp/news/2018/10/27/national/shikoku-electric-restarts-ikata-nuclear-reactor-following-failed-court-challenges/#.XN1oHJNKjOQ, accessed 26 April 2019.

163 - *Japan Times*, "Tohoku Electric to scrap aging No. 1 unit at Onagawa nuclear plant", 25 October 2018, see https://www.japantimes.co.jp/news/2018/10/25/national/tohoku-electric-scrap-aging-no-1-unit-onagawa-nuclear-plant/#.XNLolZNKjOQ, accessed 3 August 2019.

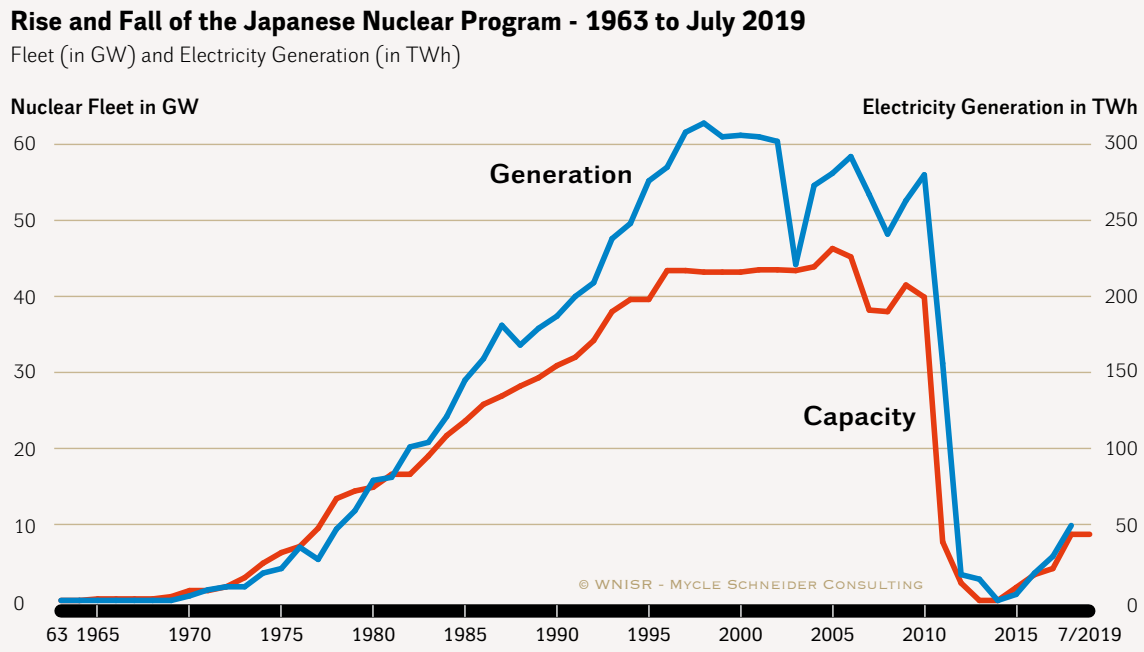
164 - Kyushu Electric Power Company, "Notification on the abolition of Genkai Nuclear Power Station Unit No. 2", 9 April 2019 (in Japanese), see http://www.kyuden.co.jp/press_190409-1.html.

165 - WNA, "Shikoku outlines plans for decommissioning Ikata 2", 17 October 2018, see http://www.world-nuclear-news.org/Articles/Shikoku-outlines-plans-for-decommissioning-Ikata-2, accessed 3 August 2019.

166 - WNISR, "Permanent Closure of Ikata-2 Brings Total Shutdowns to One Third of Pre-Fukushima Capacity in Japan", 27 March 2018, see https://www.worldnuclearreport.org/Permanent-Closure-of-Ikata-2-Brings-Total-Shutdowns-to-One-Third-of-Pre.html, accessed 10 May 2019.

As of 1 July 2019, utilities have declared 17 commercial reactors to be decommissioned since the Fukushima Daiichi accident began in March 2011, together with the Prototype Monju Fast Breeder Reactor (FBR). This means that as of 1 July 2019, 24 reactors remain in Long-Term Outage (LTO) since none of these have generated electricity during recent years. WNISR has considered for years that the four reactors at Fukushima Daini will never restart. (See **Figure 30** and **Annex 3** for a detailed overview of the Japanese Reactor Program).

Figure 28 | Rise and Fall of the Japanese Nuclear Program



Sources: WNISR, with IAEA-PRIS, 2019

Note

This Figure takes into account LTO status for Kashiwazaki Kariwa Units 1, 5, 6 and 7 in the wake of the Niigata Earthquake, not shown in previous versions of this graph.

In 2018, nuclear power produced 49.3 TWh, contributing 6.2 percent of the nation's annual output compared to 29.3 TWh and 3.6 percent electricity share in 2017, and 17.5 TWh and 2.2 percent respectively in 2016 (see **Figure 28**). This is by far the largest share of nuclear generated electricity in Japan since 2011 (18 percent), compared with 29 percent in 2010 and the historic high of 36 percent in 1998.

As WNISR 2018 reported, restart of additional reactors was not expected in the year to July 2019 and there are now further delays in the restart program. Reactors that were planned for restart in the second quarter of 2019, specifically Takahama-1 and -2, have now been delayed into 2020 and 2021 respectively, while upgrading work at Mihama-3 will not be completed until July 2020, with restart now slated for August 2020, though further delays to all these are possible.[167]

167 - KEPCO, "About the state of implementation of safety improvement measures construction of Takahama power plant 1 and 2 and Mihama power plant 3", 4 February 2019 (in Japanese), see https://www.kepco.co.jp/corporate/pr/2019/0204_2j.html; and KEPCO, "State of Implemetation of safety improvement measures construction—Takahama Units 1 and 2, and Mihama Unit 3", 4 February 2019, see https://www.kepco.co.jp/corporate/pr/2019/pdf/0204_2j_01.pdf, both accessed July 2019.

The industry during the past year has been making important progress in creating favorable electricity market conditions that if implemented will provide significant financial incentives for extending reactor operations beyond 40 years. Specifically, a capacity market will operate in Japan from 2020. The principal beneficiaries of this will be the utilities operating nuclear power plants and coal generation plants.[168] At the same time, an unexpected development arose in April 2019 when the Nuclear Regulatory Authority (NRA) voted to impose a strict operational condition on reactors that could lead to the closure of multiple reactors starting in 2020.[169] The decision was due to utilities notifying the NRA that they would not meet the deadline for completion of anti-terrorist measures created post-Fukushima. Thus, while Japanese reactors are currently generating the most electricity since 2011, the industry faces the prospect of extended shutdown of these reactors from 2020. As in previous years, a consistent majority of Japanese citizens, when polled, continue to oppose the sustained reliance on nuclear power, support its early phase-out, and remain opposed to the restart of reactors.[170]

With retail market liberalization, there has been a noticeable loss of market share by nuclear utilities. The alternative to shutting down this capacity (reactor closures) was to create the capacity market where they will sell the surplus kilowatts to the wholesale electricity market. It is expected that a separate capacity market will be created in each of the regions where nine nuclear utilities plus Okinawa operate.[171] With longterm contracts and payments, the effect will be to provide additional long-term revenue and incentivize continued reactor operation, including lifetime extensions.[172] On the other hand, economic headwind from renewable energy competition and efficient uses of electricity could increase (see **Climate Change and Nuclear Power**).

Reactor Closures

The 11 commercial Japanese reactors now confirmed to be decommissioned (not including the Monju Fast Breeder Reactor (FBR) or the ten Fukushima reactors) had a total generating capacity of 6.4 GW, representing 14.7 percent of Japan's operating nuclear capacity as of March 2011.[173] Together with the ten Fukushima units, the total rises to 21 reactors and 15.2 GW or 34.8 percent of operating nuclear capacity prior to 3/11 that has now been permanently removed from operations (see **Table 5**).

168 - Matsukubo Hajime, "The Capacity Market: An overview and issues", Citizen's Nuclear Information Center, 3 June 2019, see http://www.cnic.jp/english/?p=4435, accessed 8 July 2019.

169 - Noriaki Koshikawa, Kazunari Hanawa, "Japan nuclear plants face shutdown over delayed anti-terror steps", *Nikkei Asian Review*, 25 April 2019, see https://asia.nikkei.com/Politics/Japan-nuclear-plants-face-shutdown-over-delayed-anti-terror-steps, accessed 3 August 2019.

170 - Simon Denyer, "As Japan's leader, Junichiro Koizumi backed nuclear power. Now he's a major foe.", *Washington Post*, 10 March 2019, see https://www.washingtonpost.com/world/asia_pacific/as-japans-leader-junichiro-koizumi-backed-nuclear-power-now-hes-a-major-foe/2019/03/09/d1106ee8-4037-11e9-85ad-779ef05fd9d8_story.html?utm_term=.5c32633bfb75, accessed 3 August 2019.

171 - Edward Kee, "Japan - Nuclear Power and Electricity Reform", Nuclear Economics Consulting Group, NEGC Commentary 26, 26 February 2019, see https://nuclear-economics.com/wp-content/uploads/2019/02/26-Japan-nuclear-power-and-electricity-reform-update.pdf, accessed 8 July 2019.

172 - Nakanishi Kiyotaka, "Power generation sector protection system is strengthened", *Nikkei Energy Next*, 18 April 2019 (in Japanese), see https://tech.nikkeibp.co.jp/dm/atcl/feature/15/031400070/041600096/?P=1, accessed 8 July 2019.

173 - Based on a total installed capacity of 43.6 GW (not including the 246 MW Monju FBR and Kashiwazaki Kariwa 2–4) which were in LTO in March 2011.

Table 5 | Official Reactor Closures Post-3/11 in Japan

Operator	Reactor	Capacity MW	Startup Year	Closure Announcement[a] dd/mm/yy	Official Closure Date[b] dd/mm/yy	Last Production	Age[c]
TEPCO	Fukushima Daiichi-1 (BWR)	439	1970	-	19/04/12	2011	40
	Fukushima Daiichi-2 (BWR)	760	1973	-	19/04/12	2011	37
	Fukushima Daiichi-3 (BWR)	760	1974	-	19/04/12	2011	36
	Fukushima Daiichi-4 (BWR)	760	1978	-	19/04/12	2011	33
	Fukushima Daiichi-5 (BWR)	760	1977	19/12/13	31/01/14	2011	34
	Fukushima Daiichi-6 (BWR)	1 067	1979	19/12/13	31/01/14	2011	32
KEPCO	Mihama-1 (PWR)	320	1970	17/03/15	27/04/15	2010	40
	Mihama-2 (PWR)	470	1972	17/03/15	27/04/15	2011	40
	Ohi-1 (PWR)	1 120	1977	22/12/17	01/03/18	2011	34
	Ohi-2 (PWR)	1 120	1978	22/12/17	01/03/18	2011	33
KYUSHU	Genkai-1 (PWR)	529	1975	18/03/15	27/04/15	2011	37
	Genkai-2 (PWR)	529	1980	13/02/19	13/02/13	2011	31
SHIKOKU	Ikata-1 (PWR)	538	1977	25/03/16	10/05/16	2011	35
	Ikata- 2 (PWR)	538	1981	27/03/18[d]	27/03/18	2012	30
JAEA	Monju (FBR)	246	1995	12/2016[e]	05/12/17	LTS[f] since 1995	-
JAPC	Tsuruga -1 (BWR)	340	1969	17/03/15	27/04/15	2011	41
CHUGOKU	Shimane-1 (PWR)	439	1974	18/03/15	30/04/15	2010	37
TOHOKU	Onagawa-1 (BWR)	498	1983	25/10/18	21/12/18[g]	2011	27
TOTAL: 18 Reactors /11.2 GWe							

Sources: JAIF, Japan Nuclear Safety Institute, compiled by WNISR, 2019

Notes

a - Unless otherwise specified, all announcement dates from Japan Nuclear Safety Institute, "Licensing status for the Japanese nuclear facilities", 12 February 2019, see http://www.genanshin.jp/english/facility/map/, accessed 30 May 2019.

b – Unless otherwise specified, all closure dates from individual reactors' page via JAIF, "NPPs in Japan", Japan Atomic Industrial Forum, see http://www.jaif.or.jp/en/npps-in-japan/, as of 30 May 2019.

c - Note that WNISR considers the age from first grid connection to last production day.

d - *WNN*, "Shikoku decides to retire Ikata 2", 27 April 2018, see http://www.world-nuclear-news.org/C-Shikoku-decides-to-retire-Ikata-2-2703184.html, accessed 22 July 2018.

e - *The Mainichi*, "Japan decides to scrap trouble-plagued Monju prototype reactor", 21 December 2016, see http://mainichi.jp/english/articles/20161221/p2g/00m/0dm/050000c, accessed 21 December 2016.

f - The Monju reactor was officially in Long-Term Shutdown or LTS (IAEA-Category Long Term Shutdown) since December 1995.

g – The decision to close the reactor was announced in October 2018, but not followed by an official closure announcement. However, IAEA-PRIS lists the reactors as closed on 21 December 2018. The JAIF website does not provide a closure date for the reactor.

The revision opened the way for utilities to calculate their decommissioning costs in installments over a period of ten years.

In October 2017, the Federation of Electric Power Companies (FEPC) reported a year-on-year increase of ¥500 billion (US$4.4 billion) to a total of ¥4 trillion ($US35 billion) spent or assigned by nuclear utilities to cover the costs of safety retrofits to their reactor fleet.[174]

WNISR 2018 projected that the 38-year-old 529 MW Genkai-2 and the 35-year-old 498 MW Onagawa-1 units would be likely next candidates for decommissioning.

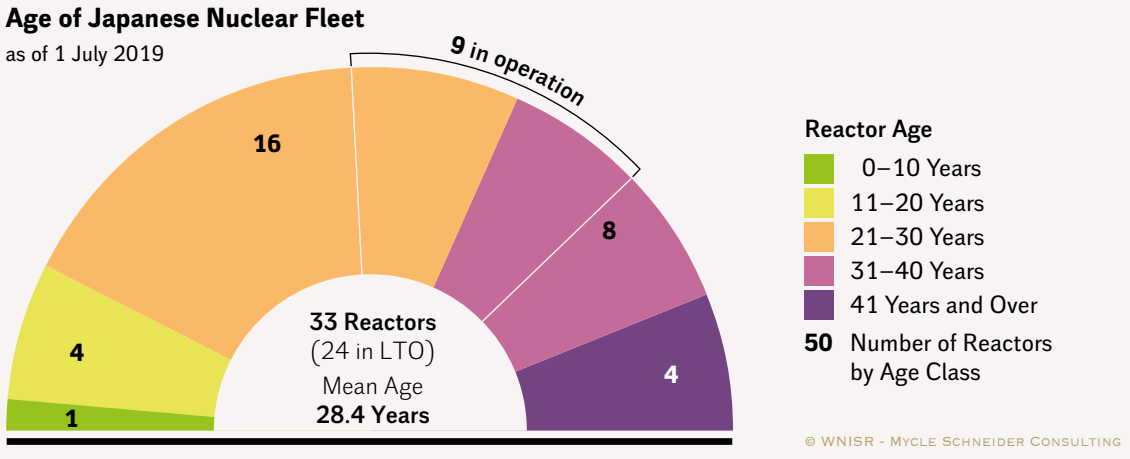
A senior manager for **Genkai-2** owner Kyushu Electric stated in February 2019 that they were "now considering whether to restart or decommission the reactor from an economic

174 - *NW*, "Safety costs might lead to more Japan nuclear units being retired: analysts", 16 November 2017.

and technical view point".[175] This was followed in April 2019 by the decision for permanent closure.[176] The utility had not submitted the reactor for review by the NRA, concentrating on approval and restart of its two newer and larger units Genkai-3 and -4, as well as Sendai-1 and -2. While the host prefecture for the Genkai plant has been generally supportive of nuclear power, an official for Saga Prefecture was cited by *Platts* as stating that "Kyushu Electric should recognize our policy", which was "reduce reliance on nuclear power generation as much as possible," in line with the central government plan for the power mix.[177]

In the case of **Onagawa-1**, Tohoku Electric officials had stated in 2017, that they "intend to restart it" but "haven't reached a conclusion, whether we can do so, because we have to evaluate safety costs and a return from that investment."[178] The utility cited the costs of post-Fukushima safety measures and the relatively small output of the reactor that made a decision to restart unprofitable. On 25 October 2018, Tohoku Electric President Hiroya Harada informed the Miyagi Prefecture Governor Yoshihiro Murai of their decision to close Onagawa-1, which was based on "consideration [of] technical restrictions associated with additional safety measures, output and the years in use."[179]

Figure 29 | Age Distribution of Japanese Fleet



Sources: WNISR, with IAEA-PRIS, 2019

Future announcements on formal decommissioning are expected in 2019. In mid-June 2018, more than seven years after the triple reactor meltdown at the Fukushima Daiichi (1) nuclear plant, Tokyo Electric Power Company Holdings Inc (TEPCO) finally bowed to the inevitable and announced it was considering the decommissioning of the four reactors at Fukushima

175 - *NW*, "Japan's Kyushu electric likely to retire 559-Mw Genkai-2, analysts say", 7 February 2019.

176 - Kyushu Electric Power, "Decision of decommissioning of the Genkai Nuclear Power Unit No.2", Press Release, 13 February 2019, see http://www.kyuden.co.jp/en_press_190213-1.html, accessed 13 February 2019.

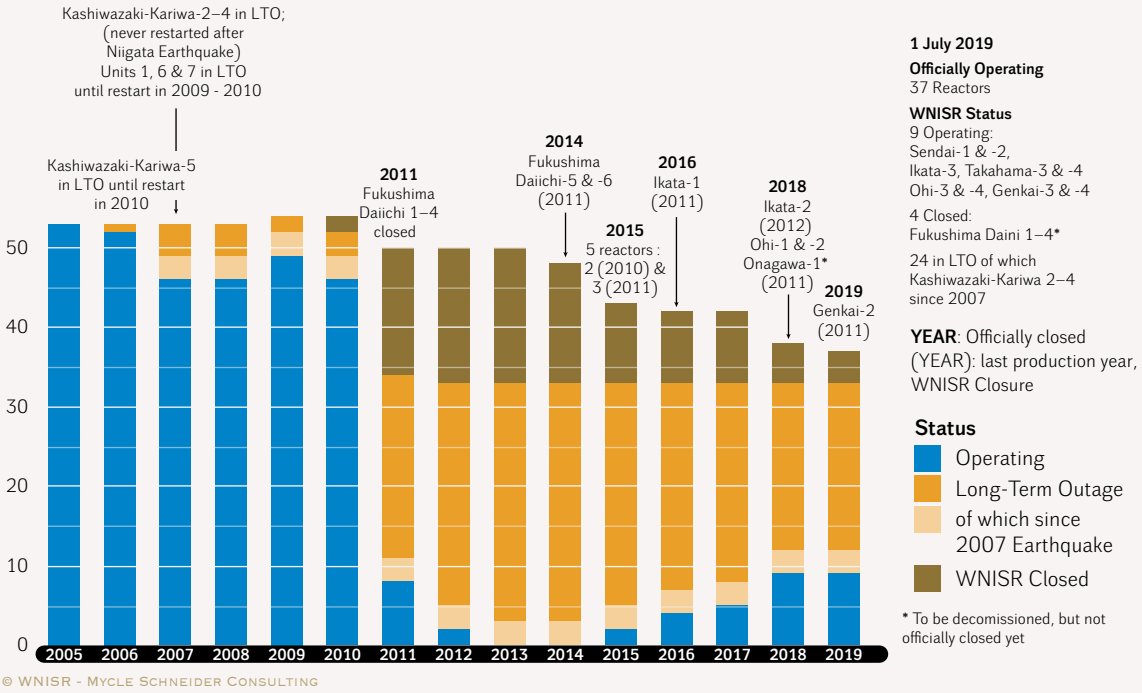
177 - *NW*, "Japan's Kyushu electric likely to retire 559-Mw Genkai-2, analysts say", 7 February 2019.

178 - *Platts*, "Nuclear News Flashes", 26 April 2018.

179 - *The Japan Times*, "Tohoku Electric to scrap aging No. 1 unit at Onagawa nuclear plant", 25 October 2018, see https://www.japantimes.co.jp/news/2018/10/25/national/tohoku-electric-scrap-aging-no-1-unit-onagawa-nuclear-plant/#.XNLolZNKjOQ, accessed 25 April 2019.

Daini (2).[180] While WNISR over the past years has classified the four reactors as closed, it is only on 31 July 2019 that TEPCO formally announced the final decision to decommission the plant.[181]

Figure 30 | Status of Japanese Reactor Fleet



Sources: Various, Compiled by WNISR, 2019

In the case of TEPCO's last remaining nuclear plant at **Kashiwazaki Kariwa** in Niigata Prefecture, it is expected that a decision on the future and possible decommissioning of one or more of the seven reactors will be made in 2019. On 1 January 2017, Mayor Masahiro Sakurai of Kashiwazaki City announced that as a condition for allowing restart of Units 6 and 7, TEPCO must propose a decommissioning plan by 2019 for at least one reactor from Units 1–5 (with no upward limit on the number of these reactors to be permanently shuttered).[182] The mayor suggested it is inevitable to scale down the plant: "Considering the Fukushima nuclear accident, seven reactors are too many."[183] The mayor extended his position dramatically when on 25 July 2017 he agreed to the restart of Kashiwazaki Kariwa Units 6 and 7 reactors but on the condition that TEPCO "presents a plan to decommission the remaining five in two

180 - Darrell Proctor, "TEPCO Exec: Daini Plant Will Be Decommissioned", *POWER*, 14 June 2018, see http://www.powermag.com/tepco-exec-daini-plant-will-be-decommissioned/, accessed 25 April 2019.

181 - TEPCO, "Fukushima Daini Nuclear Power Station to be Decommissioned", 31 July 2019, Press Release, see https://www7.tepco.co.jp/newsroom/press/archives/2019/hd_190731_01-e.html, accessed 2 August 2019.

182 - Niigata-Nippo, "Mayor Kashiwazaki asks TEPCO for decommissioning one of Units 1 to 5", 6 January 2017 (in Japanese) see http://www.niigata-nippo.co.jp/news/national/20170601327254.html, accessed 25 May 2018.

183 - *The Mainichi*, "Mayor to link reactor decommissioning to restarting 2 others at same TEPCO plant", 2 June 2017, see https://mainichi.jp/english/articles/20170602/p2a/00m/0na/002000c, accessed 25 April 2019.

years."[184] The demand was made in the mayor's first meeting with TEPCO's new president, Tomoaki Kobayakawa, where June 2019 was set as a date when TEPCO would provide a plan. In response, TEPCO's President Kobayakawa said: "We should exchange opinions further."[185] In July 2018, President Kobayakawa noted that he was "aware that this is a problem in which some kind of reply is needed."[186] And without clarifying, according to *Nikkei,* he stated that "he understands that Sakurai is not asking to decommission every reactor or scrap them immediately."[187] In March 2019, TEPCO reported that they were still aiming for a June 2019 date to submit a report on decommissioning but were struggling with the "complexity".[188] In early June 2019, TEPCO informed Sakurai that they were aiming for a plan to be presented in "early July".[189] On 1 July 2019, however, the mayor cancelled his meeting with TEPCO following a miscommunication by TEPCO during the night of 17 June 2019 when a 6.7 magnitude earthquake occurred off the coast of Niigata.[190] TEPCO staff faxed local government office, including Kashiwazaki, with incorrect information indicating that there were safety problems with the electric supply to the spent fuel pools at all seven of the Kashiwazaki Kariwa's reactors. As of 1 July 2019, it remains unclear when TEPCO will present its plans to the mayor.

There has been no clear indication from TEPCO on the number of reactors that will be offered up for decommissioning. Analysis of the reactors, including from TEPCO, suggests at least two reactors and possibly up to four might be proposed. Leading candidates for closure are Kashiwazaki-2, -3 and -4 which have not operated since 2007 when they were shut down by the Niigata Chuetsu-oki earthquake.

Other reactors that remain highly vulnerable to closure include the two **Shika** BWR units owned by Hokuriku Electric. The utility and the Nuclear Regulatory Authority (NRA) are in dispute over the status of three seismic fault lines at the site, with the NRA concluding in 2015 and 2016 that these may be active under the reactor of Unit 1 and just below safety-related equipment of Unit 2, which would preclude operation.[191] There are no immediate prospects of the utility giving up restart plans for Unit 2, which is an Advanced Boiling Water Reator (ABWR), and has been under NRA review since 2014. The reactor was only connected to the grid in 2005, and during the past 14 years has only operated for just over five years. Hokuriku officials have stated their intention to submit Shika-1 for NRA review,[192] but there are no prospects for restart.[193]

184 - *Asahi Shimbun*, "Mayor: TEPCO's Niigata plant must close 5 reactors", 26 July 2017 (in Japanese), see http://www.asahi.com/ajw/articles/AJ201707260037.html, accessed 25 April 2019.

185 - Ibidem.

186 - Jun Iiyama, Yuki Fukumoto, "Tepco seeks overseas partners in renewable energy pivot", *Nikkei Asian Review*, 24 July 2018, see https://asia.nikkei.com/Business/Companies/Tepco-seeks-overseas-partners-in-renewable-energy-pivot, accessed 25 April 2019.

187 - Ibidem.

188 - *Nikkei*, "Tokyo Electric Niigata representative, Amagasaki 1-5 units 'decommissioning plan, within the deadline'", 20 March 2019 (in Japanese), see https://www.nikkei.com/article/DGXMZO42720200Q9A320C1L21000/?fbclid=IwAR25VptCy64t7WkUJe5-9Bq18Oe_YJ9vz2anY3vIACIh8-T-Q4vpZgskfLo.

189 - *Denki Shimbun*, "TEPCO Kashiwazaki Kariwa, whereabouts of decommissioning plan... Submission time is coming / Business will be affected, affecting management", 7 June 2019 (in Japanese) see https://www.denkishimbun.com/archives/41117, accessed 8 July 2019.

190 - *NW*, "Mayor cancels Kashiwazaki meeting after erroneous TEPCO report sent", 4 July 2019.

191 - *The Mainichi*, "Fault under Shika nuclear reactor likely to be active: NRA expert panel", 3 March 2016, see https://mainichi.jp/english/articles/20160303/p2a/00m/0na/015000c, accessed 30 April 2019.

192 - *NW*, "Japan's Hokuriku to seek Shika-1 review after Shika-2 restart approval", 21 March 2019.

193 - *Nikkei*, "Recurring profit, average 35 billion yen", 26 April 2019 (in Japanese), see https://www.nikkei.com/article/DGXMZO44216150V20C19A4LB0000/, accessed 30 April 2019.

The Japanese nuclear fleet's mean age now stands at 28.4 years, with 12 units over 31 years (see **Figure 29**).

Restart Prospects

As stated, no reactors are planned to be restarted through the remainder of FY 2019. Thereafter, planned reactor restarts in 2020 and beyond remain uncertain. All currently operating reactors in Japan are Pressurized Water Reactors (PWRs)—the destroyed Fukushima Daiichi units were BWRs. As of 1 July 2019, not counting two reactors "under construction", 16 reactors remain under NRA safety review (out of a total of 25 that have applied since July 2013); 24 reactors remain in Long-Term Outage (LTO). Not all will restart, with many questions and disagreements over seismic issues, and many plants far back in the review and screening queue. There are officially two reactors under construction (Shimane-3 and Ohma).

Reactors most advanced in the restart process, and therefore with a possible restart in the coming 12 to 24 months, include Kansai Electric's (KEPCO) PWR **Takahama-1 and -2**, and PWR **Mihama-3**, which have passed NRA review for their respective upgrading plans. These three reactors, which are 45, 44 and 43 years old respectively, were granted lifetime operation approval to 60 years by the NRA in 2016.[194] Restart schedules of these three reactors have all been revised. In delaying restart of Takahama-1 from September 2019, Kansai Electric announced a revised date of June 2020, both for completion of engineering work and a restart date.[195] It is likely that this date will slip further. In the case of Takahama-2, restart has been pushed back from April 2020 to February 2021. As for Mihama-3, restart has been postponed from February to August 2020. Again, there is a high likelihood of further delay for restart of Mihama-3. The uncertainties are such that in 2020 there could be three additional reactors operating in Japan, or—possibly more likely—one or none.

The restart delays for Takahama-1 and -2, and Mihama-3 are due to longer planned timescales for multiple engineering retrofits to safety systems that are being applied. These include emergency water injection equipment, Primary Containment Vessel (PCV) overpressure damage prevention and measures to reduce risks from hydrogen explosion.[196] Assuming that all three reactors will be operating by mid-2021, Kansai Electric would have in total seven reactors in operation, with an installed capacity of 6.25 GW.

The most advanced in the NRA restart review process is the Tohoku Electric's BWR **Onagawa-2**, which applied for NRA review in December 2013.[197] However, the utility postponed

194 - Noriyuki Ishii, "NRA Approves Extensions of Operating Periods to 60 Years for Takahama-1 and -2, the First for Aging Reactors", JAIF, 22 June 2016, see https://www.jaif.or.jp/en/nra-approves-extensions-of-operating-periods-to-60-years-for-takahama-1-and-2-the-first-for-aging-reactors/; and Noriyuki Ishii, "NRA Approves Extension of Operating Lifetime for Mihama-3 through 2036", JAIF, 17 November 2019, see https://www.jaif.or.jp/en/nra-approves-extension-of-operating-lifetime-for-mihama-3-through-2036/, both accessed 26 April 2019.

195 - *NW*, "Kansai Electric's reactor restart delay to increase company's LNG procurement", 21 February 2019; and *NW*, "One reactor expected to restart in Japan in 2019", 11 October 2018.

196 - Kansai Electric, "Construction plan for a particular serious accidents, such as dealing facility of Takahama Nuclear Power Plant Units 1 and 2 Approval overview of the application (3rd)", 15 March 2019 (in Japanese), see https://www.kepco.co.jp/corporate/pr/2019/pdf/0315_1j_01.pdf; and Kansai Electric, "About reactor setting change permission application of Mihama power plant (setting of measures such as specific serious accident of Mihama power plant No. 3)", 20 April 2018 (in Japanese), see https://www.kepco.co.jp/corporate/pr/2018/pdf/0420_3j_01.pdf, both accessed April 2019.

197 - *WNN*, "Tohoku seeks Onagawa 2 restart", 30 December 2013, see http://www.world-nuclear-news.org/Articles/Tohoku-seeks-Onagawa-2-restart, accessed 26 April 2019.

its restart schedule several times and could do so again. In 2015, Tokhoku Electric had stated that it would complete safety related work on the reactor by April 2017.[198] In January 2017, the utility disclosed to the NRA that the reactor building had sustained 1,130 cracks in the walls and "lost an estimated 70 percent of structural rigidity" in the 3/11 earthquake.[199] The disclosures led Tohoku to push back restart schedule from 2018 to 2019 and then beyond 2020. The disclosures to the NRA followed an architectural investigation which identified that structural rigidity, the ability to withstand earthquakes and other stresses from outside without being distorted, was concentrated in the upper third of the reactor building with the third floor only retaining 30 percent of its integrity compared with July 1995 when the reactor began operation. It also confirmed a 25 percent loss of structural integrity in the two above-ground floors and three basement levels.

Significantly, the disclosure contrasts starkly with the assessment and conclusions of a high-profile International Atomic Energy Agency (IAEA) mission to the plant in 2012.[200] The IAEA mission included a "structures team" assigned to observe and collect information on the performance of the structural elements of buildings, with different design criteria. They reported that, as far as cracks in Unit 2 are concerned, they were "less than 0.3 mm, although at some locations there were cracks of approximately 0.8 mm. These minor cracks do not affect the overall integrity of the structure." The IAEA concluded: "The lack of any serious damage to all classes of seismically designed facilities attests to the robustness of these facilities under severe seismic ground shaking", and that "the structural elements of the NPS [Nuclear Power Station] were remarkably undamaged given the magnitude and duration of ground motion experienced during this great earthquake."[201]

The Onagawa plant is located 125 km from the source of the 3/11 earthquake, the nuclear reactor site closest to the hypocenter (Fukushima Daiichi was 180 km from the hypocenter). As such, the lack of apparent damage to the plant since 2011 has been hailed by the IAEA and others as evidence of the robustness of nuclear power plants in general. The Onagawa-2 reactor was in its startup sequence and not critical on 11 March 2011, whereas Units 1 and 3 were in operation. As of 1 July 2019, the utility had not applied for NRA review of Unit 3 which began operation in May 2001. Tokoku Electric's President stated in November 2018 that they were in preparation for submitting a safety review application to the NRA for the reactor, without specifying a date.[202] There are suspicions that damage sustained at Unit 3 is more significant than reported. On 28 March 2019, the utility announced that total projected costs for retrofits at Onagawa-2 were ¥340 billion (US$3.1 billion).[203]

198 - JAIF, "Tohoku Electric Power Says Work on Safety Measures at Onagawa-2 and Higashidori-1 to End by April 2017", 17 June 2015, see https://www.jaif.or.jp/en/tohoku-electric-power-says-work-on-safety-measures-at-onagawa-2-and-higashidor-1-to-end-by-april-2017/, accessed 26 April 2019.

199 - *Asahi Shimbun*, "1,130 cracks, 70% rigidity lost at Onagawa reactor building", 18 January 2017.

200 - IAEA, "Mission To Onagawa Nuclear Power Station To Examine The Performance Of Systems, Structures And Components Following The Great East Japanese Earthquake And Tsunami", Mission Report to the Government of Japan, 30 July–11 August 2012, Onagawa and Tokyo (Japan), IAEA Department Of Nuclear Safety And Security, Department Of Nuclear Energy, see https://www.iaea.org/sites/default/files/iaeamissiononagawa.pdf, accessed 26 April 2019.

201 - Ibidem.

202 - *NW*, "Tohoku Electric preparing to apply to NRA for Onagawa-3 safety review", 1 November 2018.

203 - *Kahoku Shimpo*, "Onagawa Nuclear Power Plant No. 2—Safety Measures ¥ 340 Billion", 29 March 2019 (in Japanese), see https://www.kahoku.co.jp/tohokunews/201903/20190329_11016.html, accessed 26 April 2019.

In polling conducted in 2018 in Miyagi Prefecture, 70 percent of the public are reported to be opposed to the restart of the Onagawa plant.[204] In March 2019, the Miyagi assembly voted down legislation for a prefecture-wide referendum on whether Onagawa should restart.[205] The draft legislation followed the submission of a petition with 111,743 signatures from prefectural residents. Tohoku Electric is aiming to complete its NRA safety review for Unit 2 in July 2019 and thereafter seek local approval for restart.[206]

Tohoku Electric's other reactor, **Higashidori-1** in Aomori Prefecture, remains under investigation seven years after the NRA concluded in December 2012 that two seismic fault lines are active.[207] Tohoku initiated further seismic surveys in March 2019 carried out through September with the aim of convincing the NRA that the faults are not active.[208] Under Japanese regulations, a reactor is not permitted to operate or be constructed if an active fault exists at a nuclear site. One of Japan's leading seismologists, who resigned from the government panel that drafted the revised Japan's seismic guidelines, has warned that "a strong earthquake of up to about 7.3 magnitude could directly hit an area where even perfect seismic research could not discover an active fault line".[209]

The utility Chugoku Electric is moving forward with NRA approval for restart of its Shimane unit 2 BWR. In May 2019, the NRA summarized the status of review for the reactor, with seismic "design basis ground motion and design basis tsunami design policy substantially complete".[210] However, there remain substantial issues still under review, including overall seismic and tsunami design policy, safety assessment for hydrogen countermeasures and containment vessel cooling, pressure overload and water injection. In March 2019 Chugoku was not able to inform investors of a target date for restart.[211] At the same time, on 10 August 2018 Chugoku submitted its application to the NRA for review of its Shimane-3 Advanced Boiling Water Reactor (ABWR).[212] Construction began on Shimane-3 on 12 October 2007. According to the Japan Atomic Industrial Forum (JAIF), the reactor was 93.6 percent complete as of 30 April 2011, and following the Fukushima Daiichi accident, construction was suspended, and plans revised.[213] There is no operational start date for Shimane-3, and barring successful legal

204 - Satoshi Tatara, "I Coop Miyagi", CNIC, 2 August 2018, see http://www.cnic.jp/english/?p=4178, accessed 26 April 2019.

205 - *Kahoku Shimpo*, "<女川再稼働>宮城県議会、住民投票条例案否決 自民など反対多数", 16 March 2019 (in Japanese), see https://www.kahoku.co.jp/tohokunews/201903/20190316_11009.html?fbclid=IwAR2giYZVWqDC-OLCkYdKJHd6c6MW6fYd_b_20erJLPSJm2dJrk1UonqxcV4, accessed 26 April 2019.

206 - *Kahoku Shimpo*, "<女川再稼働>住民投票条例案否決「県民無視」嘆く請求側", 16 March 2019 (in Japanese), see https://www.kahoku.co.jp/tohokunews/201903/20190316_11015.html.

207 - NucNet, "Japan Regulator Says Faults Under Higashi Dori Plant Are Active", 27 December 2012, see https://www.nucnet.org/all-the-news/2012/12/27/japan-regulator-says-faults-under-higashi-dori-plant-are-active/print, accessed 26 April 2019.

208 - *Nikkei*, "Tohoku Electric Power Co., Ltd. Higashidori nuclear power plant released additional investigation site", 22 April 2019 (in Japanese), see https://www.nikkei.com/article/DGXMZO44047130S9A420C1L01000/, accessed 29 April 2019.

209 - Ishibashi Katsuhiko, "Why Worry? Japan's Nuclear Plants at Grave Risk From Quake Damage", *The Asia-Pacific Journal*, Vol.5, Issue 8, 1 August 2007, see https://apjjf.org/-Ishibashi-Gaku/2495/article.pdf, accessed 26 April 2019.

210 - NRA, "Current circumstances regarding examinations for NPP adherence to new regulations", 15 May 2019.

211 - Energia, "Annual Report 2018—Year Ended March 31, 2018", Chugoku Electric, August 2018, see http://www.energia.co.jp/e/ir/report/pdf/ar18/ar18.pdf, accessed 8 July 2019.

212 - Chugoku Electric, "Shimane Nuclear Power Station Unit 3 Reactor Application Change Permit Application for Conformity Assessment to New Regulatory Standard", Press Release, 10 August 2019 (in Japanese), see http://www.energia.co.jp/atom_info/press/2018/11333.html.

213 - JAIF, "Chugoku Electric Applies for Shimane-3 Safety Examination: Second for a Reactor under Construction after Ohma NPP", 16 August 2018, see https://www.jaif.or.jp/en/chugoku-electric-applies-for-shimane-3-safety-examination-second-for-a-reactor-under-construction-after-ohma-npp/, accessed 8 July 2019.

challenges, it can be predicted that it will be several years before operation. It would be the first new reactor to begin operation since 3/11 and the first since Tomari-3 in March 2009.

The Case of TEPCO's Kashiwazaki Kariwa

The status of TEPCO's Advanced Boiling Water Reactor (ABWR) **Kashiwazaki Kariwa-6** and -7 reactors in Niigata Prefecture has not changed significantly in the passt year. When TEPCO submitted its first post-3/11 business plan to the Japanese government in 2012, it predicted that restart of reactors at Kashiwazaki Kariwa would begin in FY2013. This was never credible. On 27 December 2017, Nuclear Regulatory Authority (NRA) approved the initial safety assessment for TEPCO's Kashiwazaki Kariwa Units 6 and 7,[214] the first BWRs to reach this stage of NRA's review process.[215] On 13 December 2018, TEPCO submitted to the NRA a schedule for completion of its engineering work program on Unit 7, by which it aims to complete safety retrofits by December 2020.[216] In its third Special Business Plan in June 2017, it projected income from the reactors with three possible restart dates of 2019, 2020 and 2021.[217] As of July 2019, the earliest the reactors could restart would be 2021, but only if TEPCO were to overcome significant obstacles.

The Kashiwazaki Kariwa site has a history of major seismic activity, with repeated underestimates and non-disclosures of the seismic risks by TEPCO and resultant coverups. At the time of the licensing of the ABWRs Units 6 and 7 in 1991 TEPCO presented evidence to the regulator that the nearby fault lines were not active. This was then proven to be incorrect, with TEPCO's own data showing that they were aware of active faults as early as 1980. None of this was made public though until after the 2007 Niigata Chuetsu-oki quake.[218]

There are multiple seismic fault lines in the area of the Kashiwazaki Kariwa site, including through the site.[219] There are large-scale submarine active faults offshore with four main ones, three of which run along either edge of the Sado Basin, a depression between Sado Island and mainland Kashiwazaki.[220] Seismologists have long warned about the threat from major earthquakes leading to a severe nuclear accident at Kashiwazaki Kariwa.[221] Independent seismologists and citizens' groups continue to oppose restart of the reactors, including

214 - TEPCO, "Receipt of Approval of Revision for Reactor Installation Permit for Kashiwazaki-Kariwa NPS Units 6/7 to comply with the New Regulatory Regulations", Press Release, 27 December 2017, see http://www.tepco.co.jp/en/press/corp-com/release/2017/1470967_10469.html, accessed 26 April 2019.

215 - Justin McCurry, "Fears of another Fukushima as Tepco plans to restart world's biggest nuclear plant", *The Guardian*, 28 December 2017, see https://www.theguardian.com/world/2017/dec/28/fears-of-another-fukushima-as-tepco-plans-to-restart-worlds-biggest-nuclear-plant, accessed 30 April 2018.

216 - *Platts*, "Tepco to finish engineering work program at Kashiwazaki-Kariwa in 2020", *Nuclear News Flashes*, 14 December 2018.

217 - TEPCO, "Outline of the 'Revised Comprehensive Special Business Plan (The Third Plan)", 11 May 2017, see https://www7.tepco.co.jp/wp-content/uploads/hd05-02-03-001-170511_1-e.pdf, accessed 27 April 2019.

218 - Katsuhiko Ishibashi, Mitsuhisa Watanabe, "We demand that the Kashiwazaki-Kariwa Nuclear Power Plant be closed", CNIC, March-April 2008, see http://www.cnic.jp/english/newsletter/pdffiles/nit123.pdf, accessed 27 April 2019.

219 - Kashiwazaki Kariwa Nuclear Power Fault Study Group, "Kashiwazaki Kariwa Nuclear Power Station site and its surroundings—Request for a rigorous scientific review on stratigraphy of Middle and Upper Pleistocene", 22 May 2017 (in Japanese), see http://masatate.blog.fc2.com/blog-entry-55.html, accessed 27 April 2019.

220 - CNIC, "We demand that the Kashiwazaki-Kariwa Nuclear Power Plant be closed", 2008, op. cit.

221 - Ishibashi Katsuhiko, "Why Worry? Japan's Nuclear Plants at Grave Risk From Quake Damage", *The Asia-Pacific Journal*, 1 August 2007, Vol.5, Issue 8, see http://apjjf.org/-Ishibashi-Katsuhiko/2495/article.html, accessed 27 April 2019.

based on evidence that TEPCO has relied on flawed seismic assessments;[222] meanwhile, legal challenges seeking permanent closure are ongoing.

The Niigata governor election of 10 June 2018 led to the appointment of Liberal Democratic Party (LDP)-backed candidate Hideyo Hanazumi.[223] This does not automatically mean any early restart for TEPCOs Kashiwazaki-Kariwa reactors. The newly elected governor, conscious that 65 percent of the Niigata population remain opposed to restart of *any* reactors at the plant, stated, "as long as the people of Niigata remain unconvinced, (the reactors) won't be restarted."[224]

Niigata has a long history of opposition to the nuclear power plant, but this was exacerbated when in September 2002, following disclosures from a General Electric whistleblower, TEPCO was forced to admit that the organization had deliberately falsified data for inclusion in regulatory safety inspection reports of their reactors, a consequence of "systematic and inappropriate management of nuclear power inspections and repair work [over] a long time".[225] As a consequence, at the time, all 17 TEPCO reactors—the 7 at Kashiwazaki-Kariwa and the 10 at Fukushima—were shut down for extended periods, and TEPCO's chairman, president, and executive vice-president all resigned. The major seismic risks at the plant were exposed by the 2007 Niigata Chuetsu-oki earthquake, which once again led to the extended shutdown of all Kashiwazaki Kariwa reactors, while Units 2, 3 and 4 have not operated since then. In February 2019, the NRA announced it was investigating TEPCO for ongoing safety violations, at Kashiwazaki-Kariwa, as well as at Fukushima.[226]

In the aftermath of the 2002 falsification disclosures, the then governor of Niigata established a Technical Committee of 15 experts to review nuclear safety in the prefecture. This committee is currently reviewing the Fukushima Daiichi accidents, including causes as well as ongoing assessments of the safety of the Kashiwazaki Kariwa plant. This includes meetings with NRA, where the regulator has been regularly challenged on its safety approval of the reactors.[227] A second committee, established in August 2017 by then Governor Ryuichi Yoneyama, is reviewing the health impacts of the Fukushima Daiichi accident and a third committee, also established under Yoneyama, is reviewing emergency planning in Niigata in the event of a severe accident at the Kashiwazaki Kariwa plant.[228] The work of the Committees was linked to the then Governor's decision on the restart of Units 6 and 7 and are expected to conclude

222 - Niigata Nippo, "At Kashiwazaki Nuclear Power Station, 'Incomplete fault investigation' residents group proposed to TEPCO", 26 January 2019 (in Japanese), see https://www.niigata-nippo.co.jp/news/national/20190126447009.html, accessed 27 April 2019; and Tateishi Masaaki, "Kashiwazaki-Kariwa nuclear power plant, doubt on TEPCO interpretation of the Terao fault outcrop", 30 January 2019 (in Japanese), see http://masatate.blog.fc2.com/blog-entry-64.html, accessed 27 April 2019.

223 - *Asahi Shimbun*, "LDP-backed candidate wins governor's race in Niigata", 11 June 2019, see http://www.asahi.com/ajw/articles/AJ201806110049.html, accessed 27 April 2019.

224 - Eric Johnston, "If Niigata gubernatorial race was a litmus test, Abe and Nikai passed", *The Japan Times*, 11 June 2018, see https://www.japantimes.co.jp/news/2018/06/11/national/politics-diplomacy/niigata-gubernatorial-race-litmus-test-abe-nikai-passed/#.WzDaTxIzbOQ, accessed 27 April 2019.

225 - TEPCO, "Report on the Investigation into Inspection and Maintenance Problems at TEPCO's Nuclear Power Plants, pointed out by GE", Press Release, 17 September 2002, see http://www.tepco.co.jp/en/press/corp-com/release/02091701-e.html, accessed 27 April 2019.

226 - Yusuke Ogawa, "TEPCO sat by idly on reports of fires, glitches at nuclear plants", *The Asahi Shimbun*, 14 February 2019, see http://www.asahi.com/ajw/articles/AJ201902140054.html, accessed 27 April 2019.

227 - Tadao Yabe, "Preventing the Restart of Kashiwazaki-Kariwa Nuclear Power Station is Possible!", Local Coalition Opposed to the Kashiwazaki-Kariwa Nuclear Power Station, CNIC, 2 August 2018, see http://www.cnic.jp/english/?p=4165, accessed 27 April 2019.

228 - Kentaro Hamada, Osamu Tsukimori, "Niigata governor's plans may upend TEPCO's nuclear restarts, restructuring", *Reuters*, 9 June 2017, see https://www.reuters.com/article/us-japan-nuclear-tepco-idUSKBN1900OR, accessed 27 April 2019.

their investigations in mid-2020. The committees' work is ongoing, and the new Governor has stated since his election that he will await the conclusion of their investigations prior to any decision.[229]

The Case of JAPC's Tokai-2 and the "Ibaraki Method"

On 22 February 2019, Japan Atomic Power Company (JAPC) announced its intention to proceed with the restart of its 1100-MW BWR **Tokai-2** reactor.[230] The target date is January 2023. This followed a 7 November 2018 unanimous decision by Nuclear Regulatory Authority (NRA) commissioners to approve an additional 20 years of operation.[231] On 26 September 2018, the NRA had approved the safety review of the reactor.[232] It was the first BWR to pass all safety stages of the NRA review process and receive a 20-year lifetime extension. The reactor, which was connected to the grid in March 1978, has not operated since 3/11 when it underwent an emergency shutdown resulting from being affected by the magnitude 9.0 earthquake and tsunami. It is located in Ibaraki Prefecture, 70 km from Tokyo and is the closest commercial nuclear reactor to the capital. JAPC was formed in 1957 as the only power company based solely on nuclear reactor operation. The company is jointly owned by Japan's nuclear energy utilities with TEPCO, Kansai Electric, Chubu and Hokuriku being its largest shareholders. The Tokai-2 reactor is the only reactor JAPC is advancing towards restart, given the active fault line at its other site, Tsuruga in Fukui.

There remain major challenges to the eventual restart of Tokai-2. These include the securing of financing for retrofits. JAPC originally estimated costs of ¥174 billion (US$1.54 billion) in retrofits and that the reactor would pass NRA's pre-operational inspections by March 2021.[233] By March 2019, this was revised to ¥300 billion (US$2.73 billion).[234]

Yet the company is in dire financial straits due to loss of revenue from electricity sales following reactor shutdowns, investment in plans for the constructions Tsuruga-3 and -4 (which were abandoned) and decommissioning costs related to Tsuruga-1 and Tokai-1.[235] The NRA in November 2017, in approving the basic safety plan for Tokai-2, requested an "exceptional disclosure", whereby JAPCO had to specify the guarantor of the loan it would be taking out in order to make the necessary safety upgrades. As shareholders of JAPC, TEPCO has agreed in principle to offer ¥190 billion (US$1.75 billion) in up-front bank loans, with Tohoku Electric, Chubu Electric Power Co., Kansai Electric Power Co. and Hokuriku Electric Power Co.

229 - *The Asahi Shimbun*, "LDP-backed candidate wins governor's race in Niigata", 11 June 2018, see http://www.asahi.com/ajw/articles/AJ201806110049.html, accessed 27 April 2019.

230 - JAPC, "Revision of the Tokai Power Station and Tokai No. 2 Power Plant nuclear operator emergency plan", 22 February 2019, see http://www.japc.co.jp/news/press/2018/pdf/310222_1.pdf, accessed 28 April 2019.

231 - JAIF, "NRA Allows Tokai-2 to Be Operated for Sixty Years, a First for a BWR", 16 November 2018, see https://www.jaif.or.jp/en/nra-allows-tokai-2-to-be-operated-for-sixty-years-a-first-for-a-bwr/, accessed 28 April 2019.

232 - *The Asahi Shimbun*, "NRA approves Tokai nuclear plant, but restart hangs in balance", 27 September 2019, see http://www.asahi.com/ajw/articles/AJ201809270039.html, accessed 28 April 2019.

233 - *Platts*, "NRA approves Tokai-2 life extension", 7 November 2018.

234 - *The Asahi Shimbun*, "TEPCO takes risk over soaring costs at Tokai nuclear plant", 15 March 2019, see http://www.asahi.com/ajw/articles/AJ201903150001.html, accessed 28 April 2019.

235 - Mitsunobu Ohishi, "Tokai II Nuclear Power Plant's 20 year extension: A story of economic inefficiency and passing the buck", Co-Representative of the class action lawsuit demanding an injunction on Tokai II, CNIC, 2 February 2018, see http://www.cnic.jp/english/?p=4044, accessed 28 April 2019.

also offering financial support. As of February 2019, the financing agreement had not been implemented and JAPC had insufficient funds to begin engineering retrofits.[236]

Local opposition in Ibaraki Prefecture to operations of Tokai-2 has grown since 3/11. The emergency shutdown due to loss of offsite power during the quake, the loss of all but one emergency generator, and a near miss in terms of tsunami flooding, threatening a meltdown of a reactor with over 960,000 people within a 30 km radius, have all contributed to significant political opposition to any restart proposal. Six municipalities near the Tokai-2 plant have argued that JAPC should gain their consent before restart. On 29 March 2018, after six years of negotiations, a unique safety agreement was reached between JAPC and the six municipalities which lie within 30 km of the plant. According to documents obtained by *The Asahi Shimbun*, the agreement stipulates that "when JAPC seeks to restart the Tokai No. 2 nuclear plant or extend its operation, it will effectively obtain prior approval from Tokai village and five surrounding municipalities."[237]

Despite assurances from JAPC to the municipalities that the company was granting consent rights to them on restart issued prior to NRA approval, once approval was granted in autumn 2018, JAPC started to backtrack. JAPC Vice President Nobutaka Wachi stated: "The word 'veto power' can't be found anywhere in the new agreement."[238] The company's understanding of the agreement, in contrast to what the municipalities believe, is that it "is a plan to effectively obtain prior consent from the six municipalities (by continuing to talk thoroughly with them until they grant their consent)."[239] Relations between JAPC and the municipalities have for obvious reasons deteriorated, and it remains unclear how or whether it will be resolved in the coming few years. A critical issue remains the ability of authorities to establish credible evacuation plans for nearly one million people within 30 km, the highest population density for any nuclear plant in Japan. Reacting to the announcement of JAPC on restart plans, Mayor Takahashi of Mito city (one of the six municipalities) warned that restart is impossible until realistic evacuation plans are made and the citizens' understanding of them is gained.[240] Citizen-led legal challenges to restart are ongoing.

A more immediate effect of the Ibaraki agreement is that the municipalities have signaled they expect JAPC to provide detailed plans for the engineering retrofits prior to the start of any work, with any delay of submission to municipalities likely to delay engineering work, potentially postponing restart, according to an official from Naka city, one of the municipalities within the 30 km area.[241]

The so-called "Ibaraki method", so far unique to Ibaraki, has been exported to other communities around Japan making the case that utilities should have the same conditions in their safety agreement with municipalities. For obvious reasons, power companies are not rushing to adopt the Ibaraki method.

236 - *NW*, "JAPC will need to rebuild trust with local communities, secure cash for Tokai-2 restart", 7 March 2019.

237 - Yosuke Hiruma, "JAPC denies granting local prior consent for reactor restart", *The Asahi Shimbun*, 8 January 2019, see http://www.asahi.com/ajw/articles/AJ201901080045.html, accessed 28 April 2019.

238 - Ibidem.

239 - Ibidem.

240 - *Japan Times*, "Heed opinions of all municipalities near reactors", Editorials, 9 November 2018, see https://www.japantimes.co.jp/opinion/2018/11/09/editorials/heed-opinions-municipalities-near-reactors/#.XOF9JJNKjOQ, accessed 28 April 2019.

241 - *NW*, "Disputes with localities may delay Tokai-2 operation", 7 February 2019.

Other reactors within the NRA review process continue to have multiple challenges. For example, Hokkaido Electric Power Company, the owner of the PWR Tomari nuclear plant, continues to be in dispute with the NRA over the status of a seismic fault line at the site. The utility claims that the fault has not been active for 400,000 years, whereas the NRA takes the position that there is no evidence that the fault was "not active within the past 120,000 years",[242] the latter is the time period which, if confirmed, would preclude restart of the reactor. The utility has committed to submitting more evidence of their case by autumn of 2019. While all three reactors at Tomari have been under NRA review, Unit 3 is the most advanced, but has suffered multiple delays in restart plans.

The risks from major seismic events was demonstrated when on 6 September 2018 a magnitude 6.7 earthquake struck the island of Hokkaido.[243] Thermal power plants shut down across the island, and the Tomari nuclear plant, including spent fuel pools, were reliant upon on-site emergency generators for a period of 10 hours.

Financing Meltdowns

In April 2019, two analysts, Eri Kanamori and Tomas Kåberger, published an assessment of the complex system of financing of the Fukushima Daiichi nuclear disaster related to the prospects for Tokyo Electric Power Company (TEPCO), and wider nuclear utilities in Japan.[244] They explain that immediate payments have been made possible by direct transfers from the Japanese government, and these improvised solutions have for seven years both kept the government's borrowing capacity intact and allowed TEPCO to avoid going bankrupt. But as the analysts explain, these payments "are not acknowledged as government spending. Instead, a complicated system of envisioned re-payments have been created."[245] As with other analysis, they predict that TEPCO's Special Business Plan will be impossible to fulfill, and that further improvised and complicated solutions may follow. Their conclusion is that the system in place in Japan shows a lack of readiness and an absence of any plan on how to manage the economic consequences of an accident of the magnitude of 3/11, and that the repayment schemes in Japan are not compatible with a future efficient and competitive electricity market.

Multiple Reactor Shutdowns from Spring 2020?

As mentioned above, a decision by the NRA over completion of emergency engineering measures at nuclear plants on 24 April 2019 has raised the prospect of multiple reactor shutdowns starting in March 2020.[246] Under post-Fukushima regulatory guidelines, nuclear plant operators are required to have completed work programs that include building a bunkered

242 - *NW*, "NRA's restart review of Onagawa-2 'most progressed' official says", 15 May 2019.

243 - *The Japan Times*, "Powerful M6.7 earthquake rocks Hokkaido, causing massive landslides; nine dead and 31 reported missing", 6 September 2018, see https://www.japantimes.co.jp/news/2018/09/06/national/powerful-m6-7-earthquake-hits-hokkaido-no-tsunami-alert-issued/#.XOGwiZNKjOQ, accessed 29 April 2019.

244 - Eri Kanamori, Tomas Kåberger, "Distributing the Costs of Nuclear Core Melts—Japan's Experience after 7 Years", 27 April 2019, published in Reinhard Haas, Lutz Mez, et al., "The Technological and Economic Future of Nuclear Power", see https://doi.org/10.1007/978-3-658-25987-7_17, accessed 20 July 2019.

245 - Ibidem

246 - *The Mainichi Shimbun*, "Japan to halt nuclear plants if anti-terror steps not taken in time", 24 April 2019, see https://mainichi.jp/english/articles/20190424/p2g/00m/0dm/067000c, accessed 29 April 2019.

second control center comprising an emergency control room, an electricity generator, a water storage tank and multiple pumps to feed cooling water to the containment vessels. These facilities are required to protect against damage in the event of deliberate or accidental aircraft impact, malicious attack, or fire or explosions in the reactor containment. Originally set to be implemented by 2018 (five years after the adoption of the revised Guidelines), in 2015 the NRA extended the compliance period to within five years of approval of reactor Construction Plans. By voting unanimously for maintaining the deadline, and by rejecting the pleading of utilities,[247] the NRA commissioners have apparently set the clock towards multiple reactor shutdowns beginning in spring 2020.

According to Kyushu Electric, Kansai Electric Power and Shikoku Electric Power, ten of their reactors will miss their deadlines. First to close, if the NRA decision remains in place, would be Sendai-1 on 18 March 2020, followed by Sendai-2 on 22 May 2020; Takahama-3 and -4 must meet the deadline of 4 August and 9 October 2020 respectively or shut down. These would be followed by Ikata-3 on 23 March 2021 and Mihama-3 on 26 October 2021; the latter, which remains in Long-Term Outage (LTO), is not scheduled to restart operations until August 2020. Genkai-3 and -4 have until 2022 to complete work; likewise for Takahama-1 and -2, both of which remain in LTO and not due to restart until 2020 and 2021 respectively. Described as a near total shutdown of Japan's reactor fleet, the NRA decision contributed to a 19-percent plunge of the three utilities' share value as of April 2019.[248] All utilities have reported that they are behind schedule in the construction of their "contingency" facilities.[249] It remains to be seen if the NRA commissioners relent under pressure from the utilities.

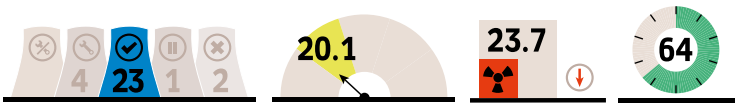
All of these factors contribute to the wholly uncertain prospects for nuclear power in Japan over the next few years.

247 - JAIF, "Electric Power Companies Ask NRA for Understanding on Extending Grace Period for Building Anti-Terrorism Facilities at NPPs", 24 April 2019, see https://www.jaif.or.jp/en/electric-utilities-ask-nra-for-understanding-on-extending-grace-period-for-building-anti-terrorism-facilities-at-npps/, accessed 29 April 2019.

248 - Robin Harding, "Japan's nuclear reactors face new near-total shutdown", *Financial Times*, 25 April 2019, see https://www.ft.com/content/1b2c395e-6724-11e9-9adc-98bf1d35a056, accessed 29 April 2019.

249 - Yomiuri Shimbun, "NRA, power utilities should promote in-depth dialogue for nuclear safety", *The Japan News, The Yomiuri Shimbun*, 8 May 2019, see http://the-japan-news.com/news/article/0005725420.

SOUTH KOREA FOCUS



On the Korean Peninsula, South Korea (Republic of Korea) operates 23 reactors, with one new reactor startup and one permanent closure decision over the past year, and one reactor entering Long-Term Outage or LTO status. Shin-Kori-4 was connected to the grid on 22 April 2019, five years later than planned. In June 2018, the commercial operation of Wolsong-1 was "terminated", long before a 2022 deadline.[250] As the reactor had not generated power since May 2017, WNISR considers it closed as of that date.

South Korea's nuclear fleet, owned by Korea Hydro & Nuclear Power Company (KHNP), is located at the Hanbit, Hanul, Kori and Wolsong sites. Nuclear power provided 127 TWh in 2018, a drop of 10 percent compared to 2017, and 19 percent below the maximum production in 2015. Nuclear power supplied 23.7 percent of the nation's electricity in 2018, less than half of the maximum of 53.3 percent in 1987. The capacity factor for KHNP reactors was 63.8 percent; the decline in nuclear generation was mainly due to reduced availability as a result of extended reactor outages.

In April 2018, 11 reactors in Korea were shut down for maintenance and inspection;[251] and on 1 July 2018, eight reactors remained shut down,[252] while six remained offline on 18 December 2018.[253] Hanbit-4 has been shut down in May 2017, and as it had not restarted by mid-2019, it meets the LTO criteria. One of the issues that has led to delays in restarts of reactors has been the discovery of reactor Containment Liner Plate (CLP) corrosion (see **hereunder**).[254] As a consequence, KHNP reactor maintenance outages increased 75 percent, from 1,373 days in 2016 to 2,397 days in 2017.[255]

In December 2017, the government approved the 8th Basic Plan for long-term Electricity supply and demand (BPE), which marks a major shift in overall energy policy, while confirming the gradual nuclear phase-out road map announced in October 2017.[256] In the period to 2030, four new reactors will begin operation, while ten reactors would be taken offline as eight reach their 40-year lifetime and two their 30-year limit (different reactor technologies). Nuclear power capacity would peak in 2022, before declining towards phase-out. Thus, under current policy,

250 - KHNP, "Nuclear Power Operation - Plant Status", 31 December 2018, see http://cms.khnp.co.kr/eng/content/529/main.do?mnCd=EN03020101, accessed 27 March 2019.

251 - Operating reactors as of 11 June 2018: Kori-2, Hanbit-3 & -4, Wolsong-1, Shin Wolsong-1, Hanul-4, Hanul-6, Shin-Kori-3. Joori Roh, Sunil Nair, "Status of South Korea's nuclear reactors", *Reuters*, 17 April 2018, see https://af.reuters.com/article/commoditiesNews/idAFL3N1RU20O, accessed 7 June 2019.

252 - KHNP, "Real Time Operating Status", 1 July 2018 (in Korean), see http://www.khnp.co.kr/main.do, accessed 11 July 2018.

253 - Jane Chun, "S.Korea's 2018 LNG imports to hit record high over 42 mln T", *Reuters*, 19 December 2018, see https://www.reuters.com/article/southkorea-lng/s-koreas-2018-lng-imports-to-hit-record-high-over-42-mln-t-idUSL3N1YN31D, accessed 5 June 2019.

254 - The Nuclear Safety and Security Commission (NSSC) required inspection of corrosion at 19 nuclear units with containment liner plate (CLP), after the corrosion of CLP of Hanbit unit #2 was found in June 2016. As of February 2018, 17 out of 19 units had completed inspection, with 9 reactors found with corrosion. four reactors have completed repair and five units are under maintenance. Inspection of the remaining two reactors was scheduled to be completed by April 2018. See NSSC multiple reports on inspections, the most recent being Hanul-5 in May 2018, see NSSC, "Approval of re-operation after preventive maintenance", 16 May 2018 (in Korean), see http://www.nssc.go.kr/nssc/notice/report.jsp?mode=view&article_no=44264&pager.offset=0&board_no=2, accessed 7 June 2019.

255 - Market Screener, "Korea Electric Power : KEPCO recorded 5 trillion won of operating profit", 4-Traders, 26 February 2018, see https://www.marketscreener.com/KOREA-ELECTRIC-POWER-CORP-6494969/news/Korea-Electric-Power-KEPCO- recorded-5-trillion-won-of-operating-profit--26055391/, accessed 7 June 2019.

256 - Se Young Jang, "South Korea's Nuclear Energy Debate", Carnegie Endowment for International Peace, 26 October 2017, see http://carnegieendowment.org/2017/10/26/south-korea-s-nuclear-energy-debate-pub-73561, accessed 7 June 2019.

nuclear power will remain a significant source of electricity generation in South Korea well into mid-century.

The new BPE stipulates close to 12 percent nuclear in the power generating capacity as of 2030, then producing almost 24 percent of the country's electricity. The new BPE projects an increase of installed renewables capacity (excluding large hydro and mainly solar photovoltaics and wind) from 11.3 GW in 2017 to 58.5 GW in 2030, leading to a 20 percent market share of national generation capacity—a major policy shift. Over more than three decades the energy policy of successive South Korean governments had been premised on the continued expansion of nuclear power, including for example a target of 41 percent by 2030 (2008 first National Energy Basic Plan for 2008–2030) and Korea Electric Power Corporation's (KEPCO) 2011 proposed 43 GW of nuclear capacity for 2035.

Table 6 | Scheduled Closure Dates for Nuclear Power Reactors in Korea 2023–2029

Reactor	Type	MW	Grid connection	Expected Closure
Kori-2	PWR	640	1983	2023
Kori-3	PWR	1 011	1985	2024
Hanbit-1	PWR	995	1986	2025
Kori-4	PWR	1 012	1985	2025
Hanbit-2	PWR	988	1986	2026
Wolsong-2	PHWR	611	1997	2026
Hanul-1	PWR	966	1988	2027
Wolsong-3	PHWR	641	1998	2027
Hanul-2	PWR	967	1989	2028
Wolsong-4	PHWR	622	1999	2029
Hanbit-3	PWR	986	1994	
Hanbit-5	PWR	992	2001	
Hanbit-6	PWR	993	2002	
Hanul-3	PWR	997	1998	
Hanul-4	PWR	999	1998	
Hanul-5	PWR	998	2003	
Hanul-6	PWR	997	2005	
Shin-Kori-1	PWR	996	2010	
Shin-Kori-2	PWR	996	2012	
Shin-Kori-3	PWR	1 416	2016	
Shin-Kori-4	PWR	1 340	2019	
Shin-Wolsong-1	PWR	997	2012	
Shin-Wolsong-2	PWR	993	2015	

Sources: MOTIE, 2017

Following the closure of Wolsong-1, the seven reactors that are now planned to be closed just prior to reaching their 40-year operating lifetime total 6.6 GW of capacity and are Kori-2 in 2023, Kori-3 in 2024, Kori-4 and Hanbit-1 in 2025, and Hanbit-2 in 2026, Hanul-1 in 2027 and

Hanul-2 in 2028. Three reactors are scheduled to be closed as they reach their 30-year lifetime: Wolsong-2 in 2026, Wolsong-3 in 2027 and Wolsong-4 in 2029 (see **Table 6**).[257]

The government had indicated that it would compensate KHNP for the closure of Wolsong-1, citing the company's own data for a total of 244.1 billion won (US$230 million), whereas opposition lawmakers had cited figures as high as 995 billion won (US$920 million). However, KHNP's own figures show that compensation may not be justified given the reactor's poor performance. When announcing its closure in June 2018, KHNP stated that its decision was based on the "uncertain economic viability" of its continued operation and recent low operating performance. The reactor's generating unit costs stood at 120 won (US$0.109) per kWh as of late 2017 or double the current market price of 60 won (US$0.054) per kWh. President Chung Jae-Hoon of KHNP reported that "After the 2016 earthquakes in Gyeongju, Wolsong 1's operation rate dropped below 50 percent, and it remains suspended now [because of maintenance].(...) Wolsong 1 is already running in the red."[258]

The troubled Wolsong-1 was already shut down in 2012 as its operating license expired. In 2015, the Nuclear Safety and Security Commission (NSSC), against strong local opposition, approved a ten-year extension allowing it to restart and operate until 2022.[259] It generated power for only half of the granted lifetime extension before it was taken off the grid in 2017 and has remained closed ever since.

Reactor Startup

Shin-Kori-4, located at Gori in the southeast of the Republic of Korea, was connected to the grid on 22 April 2019.[260] The KHNP-owned reactor is the second APR-1400 (Advanced Pressurized Reactor) to begin operation and the nation's 26th commercial nuclear reactor. As noted, startup occurred five years later than the initial startup planned for 2014. The Nuclear Safety and Security Commission (NSSC) had granted an operational permit on 1 February 2019.[261] Factors that contributed to the delays included the 5.8 magnitude Gyeongju earthquake in September 2016[262]—the most powerful quake to have hit the Korean peninsula since recording began in 1978— and the 5.4 magnitude Pohang quake in November 2017[263], both of which occurred in the southeast of the peninsula, where the majority of the nation's reactors are located, including the Shin-Kori site. Other causes for delay included a far-reaching scandal over falsifications of quality certificates for reactor components, as reported in WNISR2017,

257 - Ministry of Trade, Industry and Energy, "The 8th Basic Plan for Long-term Electricity Supply and Demand (2017-2031)", 2017, see https://www.kpx.or.kr/www/downloadBbsFile.do?atchmnflNo=30051, accessed 31 July 2019.

258 - Choi Ha-yan, "Wolsong 1 reactor to be undergo early closure", *Hankyoreh*, 17 June 2018, see http://english.hani.co.kr/arti/english_edition/e_national/849404.html, accessed 7 June 2019.

259 - NSSC, "The Commissioners Decided to Approve Continued Operation of Wolsong Unit 1 in the 35th Meeting", Press Release, 27 February 2015, see http://www.nssc.go.kr/nssc/english/release/list.jsp?mode=view&article_no=17977&pager.offset=10&board_no=501, accessed 7 June 2019.

260 - KHNP, "Commemorative ceremony for the first system connection of Shin-Kori No. 4", 25 April 2019 (in Korean), see http://www.khnp.co.kr/board/BRD_000187/boardView.do?pageIndex=1&boardSeq=70129&mnCd=FN070107, accessed 7 June 2019.

261 - NSSC, "The NSSC Decided to Issue Operation Permit of Shinkori Unit 4", Press Release, 1 February 2019, see http://www.nssc.go.kr/nssc/english/release/list.jsp?mode=view&article_no=45147&pager.offset=30&board_no=501, accessed 5 June 2019.

262 - Jane Chung, "South Korea's biggest earthquake triggers nuclear safety concerns", *Reuters*, 13 September 2016, see https://www.reuters.com/article/us-southkorea-nuclear-quake-idUSKCN11J0R2, accessed 7 June 2019.

263 - *Hankyoreh*, "Latest earthquake shows importance of phasing out nuclear power on Korean Peninsula", 16 November 2017, see http://english.hani.co.kr/arti/english_edition/e_editorial/819393.html, accessed 7 June 2019.

details of which continued to emerge in 2019;[264] and policy changes after the election of President Moon Jae-In in 2017.[265]

In May 2015, the NSSC confirmed that there had been quality-control falsification issues within the Korean nuclear industry that lasted for a decade. Shin-Kori-3 as well as Unit 4 were found to have had falsified quality-control documents requiring the replacement of plant cabling (see WNISR17 and WNISR18). The operational license for Shin-Kori-3 was only granted by the NSSC on 29 October 2015 and the reactor was connected to the grid on 15 January 2016.[266]

Corruption and safety violations in the Korean nuclear program have continued to emerge in recent years, with one nuclear industry whistleblower in April 2019 stating that, "On principle, I don't trust anything that KHNP built."[267]

The NSSC in April 2019 passed a bill that ordered the KHNP to construct on-site emergency response facilities for all nuclear reactors.[268] The NSSC decision was part of the post-3/11 measures to be applied in Korea. The additional base is to be secured inside the nuclear power plant site, other than the existing emergency response facility, which is currently off site, so that emergency personnel perform accident response and post-accident management. It is unknown at this stage whether or not this measure will have the same implications as the recent decision by Japan's Nuclear Regulatory Authority (NRA) that set a five-year timeframe for completion of such facilities. Utilities in Japan are set to miss the deadline and on current trajectory will be forced to close reactors starting in March 2020.

New Reactor Construction

Four additional APR-1400 reactors remain under construction. At Shin-Kori work resumed on Unit 5 in October 2017 and construction officially started on 6 September 2018 on Unit 6 with startup scheduled for June 2024. As this would be the last nuclear plant to start up with a nominal operational lifetime of 60 years, nuclear power capacity would peak in 2022, before declining towards an "organic" phase-out expected to occur in the middle of 2080s. Construction of twin APR-1400 units, Shin-Hanul-1 and Shin-Hanul-2, continues, after starting in July 2012 and June 2013, while missing their original completion dates of 2017 and 2018.[269] The latest dates provided by KHNP are November 2019 and September 2020 for commercial operation; but according to those estimates, fuel loading for Shin-Hanul-1 should have taken place in June 2019, which it did not.[270]

264 - Max S. Kim, "How greed and corruption blew up South Korea's nuclear industry", *MIT Technology Review*, 22 April 2019, see https://www.technologyreview.com/s/613325/how-greed-and-corruption-blew-up-south-koreas-nuclear-industry, accessed 7 June 2019.

265 - KHNP, "Commemorative ceremony for the first system connection of Shin-Kori No. 4", 25 April 2019 (in Korean), see http://www.khnp.co.kr/board/BRD_000187/boardView.do?pageIndex=1&boardSeq=70129&mnCd=FN070107, accessed 2 June 2019.

266 - WNISR, "Shin Kori-3 Connected to the South Korean Grid", 20 January 2016, see https://www.worldnuclearreport.org/Shin-Kori-3-Connected-to-the-South-Korean-Grid.html, accessed 7 June 2019.

267 - Max S. Kim, "How greed and corruption blew up South Korea's nuclear industry", *MIT Technology Review*, 22 April 2019, op. cit.

268 - NSSC, "The 100th Meeting of the Commission Was Held", Press Release, 12 April 2019, see http://www.nssc.go.kr/nssc/english/release/list.jsp?mode=view&article_no=45343&pager.offset=10&board_no=501, accessed 5 June 2019.

269 - WNISR, "New Reactor Under Construction in South Korea", 1 July 2013, see https://www.worldnuclearreport.org/New-Reactor-Under-Construction-in.html, accessed 7 June 2019.

270 - KHNP, "Nuclear Power Construction - Shin-Hanul #1,2", 31 January 2019, see http://cms.khnp.co.kr/eng/content/547/main.do?mnCd=EN03020303, accessed 17 June 2019.

The government 2017 Basic Plan for long-term Electricity supply and demand (BPE) energy plan confirmed cancellation of six new reactor projects (all APR-1400 design): Shin-Hanul-3 and -4, Cheonji-1 and -2 (in Yeongdeok) and either Cheonji-3 and -4 or Daejin-1 and -2 (in Samcheok). The cancellation of these projects comes after successive governments had failed to secure new sites for plants, due to local opposition, including at Samcheok and Yeongdeok.[271]

Energy Policy Under Attack

The past year has seen an escalation of the campaign against President Moon's energy policy by the nuclear industry and its supporters in the former government Liberty Korea Party (LKP) as well as the largely conservative print media.[272] As a consequence, President Moon's energy policy has become more contested. One reason for this is the relentless media coverage that has falsely conflated in the public's mind Moon's energy policy as being responsible for the severe air pollution experienced in Seoul during the past year. In March 2019 the National Assembly passed a bill on the designation of fine dust as a social disaster as Seoul and other parts of Korea face serious particle pollution.[273] The reason for air pollution levels reaching such proportions is due in large part to micro-dust and yellow dust blown in from China.[274] The contribution from Korea's coal-fired plants is also a major factor. However, it was the previous conservative government that expanded coal plant use by 50 percent in the ten years prior to 2017.[275]

In January 2019, the LKP and the nuclear industry collected more than 300,000 signatures to oppose the long-term nuclear phase-out policies, calling for a restart of construction of the two Shin-Hanul nuclear power plants in Uljin County, North Gyeongsang Province.[276] The LKP and Bareun Party aim to ultimately stop the long-term nuclear phase-out. However, the Ministry of Trade, Industry and Energy restated in February 2019 that "There is no change in the government policy to reduce the country's heavy reliance on nuclear in power generation... The 2017 state [organized citizens'] panel recommended to scale back nuclear power generation, so the government will not revive Shin Hanul-3 and -4."[277]

Despite the push back from industry and media, the government restated its commitment to its energy transition in April and June 2019. Expansion of its renewable energy target to 30–35 percent by 2040 was confirmed by the government on 19 April 2019.[278] Confirming its energy transition, including electricity demand reduction by 18 percent by 2040, Joo Young-joon,

271 - *NW*, "South Korea government unveils roadmap for reducing nuclear power role", 21 December 2017.

272 - *The Dong-A Ilbo*, "Govt. should establish reasonable energy policy", 5 June 2019, see http://www.donga.com/en/article/all/20190605/1751460/1/Govt-should-establish-reasonable-energy-policy, accessed 7 June 2019.

273 - *Yonhap*, "Parliament passes bill on designating fine dust as social disaster", 19 March 2019, see https://en.yna.co.kr/view/AEN20190312010651315, accessed 7 June 2019.

274 - Wooyoung Lee, "South Korea smothered in Chinese air pollution", *UPI*, 27 November 2018, see https://www.upi.com/Top_News/World-News/2018/11/27/South-Korea-smothered-in-Chinese-air-pollution/3891543308613/, accessed 7 June 2019.

275 - Darrell Proctor, «Coal Generation Reaches New High in South Korea", *PowerMag*, 4 January 2018, see https://www.powermag.com/coal-generation-reaches-new-high-in-south-korea, accessed 7 June 2019.

276 - *Korea Herald*, "[Going Renewable (1)] Korea steps in right direction for renewable energy, but challenges await", 7 February 2019, see http://www.koreaherald.com/view.php?ud=20190207000497, accessed 7 June 2019.

277 - *NW*, "South Korean government faces calls for easing of nuclear phase-out plan", 28 February 2019.

278 - Institute for Energy Economics and Financial Analysis, "Revised South Korea energy plan boosts renewables, cuts coal", *Reuters*, 19 April 2019, see http://ieefa.org/revised-south-korea-energy-plan-boosts-renewables-cuts-coal, accessed 7 June 2019.

Deputy Minister for Energy and Resources stated that, "South Korea will build a highly efficient and clean, but stable energy structure. [...] The transition itself will create new opportunities, ranging from nuclear decommissioning to hydrogen fuel cells. The change will eventually provide the country with sustainable growth."[279]

Containment Liner Plate Corrosion

As noted above, the past few years have witnessed extended outages of South Korea's nuclear reactors. The principle reason for this has been that out of the 24 reactors South Korea operated (prior to startup of Shin-Kori-4 in 2019) 20 were found to have corrosion in the Containment Liner Plates (CLP) and/or voids in the concrete structure.[280] A total of 13 units have been found to have both CLP corrosion and voids in their concrete, while seven have only void issues.

Nuclear reactor containment-buildings in Korea are insulated with a CLP of six millimeters in diameter, and then concrete 1.2 meters in diameter thick. As the U.S. Nuclear Regulatory Commission noted in 1997, "Any corrosion (metal thinning) of the liner plate could change the failure threshold of the liner plate under a challenging environmental or accident condition. Thinning changes the geometry of the liner plate, creating different transitions and strain concentration conditions. This may reduce the design margin of safety against postulated accident and environmental loads."[281]

Under nuclear regulation evidence of structural deterioration that could affect the structural integrity or leak-tightness of metal and concrete containments must be corrected before the containment can be returned to service. Corrosion of a liner plate can occur at a number of places where the metal is exposed to moisture, or where moisture can condense (behind insulation) or accumulate. Corrosion damage of CLPs historically has primarily been either the result of embedded foreign material (e.g. wood) in contact with the liner resulting in corrosion or inside initiated corrosion resulting from coating failures or moisture barrier degradation. The corrosion repair has consisted of removal of the damaged liner section and embedded foreign material, grouting the resulting void, and replacing the liner plate section.[282]

In June of 2016, the corrosion on the liner plate of Hanbit-2 was discovered during in-service inspection. The Nuclear Safety and Safety Commission (NSSC) ordered the licensee to perform the extensive examination for liner plates of all operating Pressurized Water Reactors (PWRs). The Korea Institute of Nuclear Safety (KINS) reported that the discovery of the liner plate

279 - Kang Yoon-seung, "S. Korea increasingly 'going clean' in energy policy", *Yonhap*, 7 June 2019, see https://en.yna.co.kr/view/AEN20190607001051320, accessed 7 June 2019; and Sung Yoon-mo, "The blueprint of energy policy in 2040 / Sung Yun-mo", Minister of Commerce, Industry and Energy, *Hankyoreh*, 6 June 2019 (in Korean), see http://www.hani.co.kr/arti/opinion/column/896925.html, accessed 7 June 2019.

280 - Jeong Jong-Yeong, head of the nuclear industry division of the Ministry of Trade, Industry and Energy, as reported in *Nucleonics Week*, "South Korea completing safety checks on all reactor containment structures", 9 May 2019.

281 - Office Of Nuclear Reactor Regulation, "Information Notice No. 97-10: Liner Plate Corrosion in Concrete Containments", U.S.NRC, 13 March 1997, see https://www.nrc.gov/reading-rm/doc-collections/gen-comm/info-notices/1997/in97010.html, accessed 7 June 2019.

282 - Jason P. Petti, Dan Naus, et al., "Nuclear Containment Steel Liner Corrosion Workshop: Final Summary and Recommendation Report", Report SAND2010-8718, Sandia National Laboratories, Operated for the U.S. Department of Energy, July 2011, see https://www.nrc.gov/docs/ML1121/ML112150012.pdf, accessed 7 June 2019.

corrosion was confirmation of the limitations of in-service inspection.[283] One example reported by the NSSC in the past year was Hanbit-1, where thickness of the CLP was found to be thinner than the standard.[284]

Root cause analysis of the causes of CLP corrosion reported by Korea Institute of Nuclear Safety were predominately due to exposure to moisture (environment), as well as the presence of foreign debris.[285] It is unclear when the recommendations of lessons learned from the CLP issue, including and specifically, over-reliance on visual inspection rather than more extensive limited ultrasonic testing, will be applied by the NSSC. The NSSC confirmed repairs where required at Hanbit-1 and approved re-criticality of the reactor on 9 May 2019.

On 7 July 2019, Korean broadcaster *MBC* reported that KHNP had confirmed that 94 holes had been found between the steel plate and concrete inside the reactor building of Hanbit-3 and 96 holes in Hanbit-4. KHNP, according to *MBC*, explained that the holes found are up to 90 cm in size, but there would be "no problem with the structural stability of the containment." Hanbit-3 and -4 remain shut down.[286] As of 19 July 2019, the NSSC had yet to confirm these reports.

As reported, the extended shutdown of multiple reactors in Korea over the past few years has been used by those opposed to President Moon's energy policy to criticize the NSSC for prolonging inspections. In 2018, the availability factor for reactors in Korea declined further to an average of 65.9 percent in 2018, compared with 71.2 percent in 2017, 79.7 percent in 2016 and 85 percent in 2015.[287] In 2018, the NSSC responded robustly to criticism of delayed regulatory approval, noting: "When an urgent regulatory issue is found, such as the recent case of corrosion in the Containment Liner Plate, the NSSC inspects all reactor units to find out the cause of the same case and to ensure safety."[288] In May 2018, NSSC stated that in terms of reduced nuclear output over the past year, "the operation rate fell to 71% last year and 58% last January because KHNP's facility maintenance has been prolonged due to the problems caused by their poor safety management practice [that] have been simultaneously found at all nuclear power plants."[289]

Hanbit Power Surges

Safety concerns with KHNP nuclear operations were triggered after it was disclosed on 10 May 2019 that Hanbit-1 had been manually shut down following an instantaneous increase

283 - Yonglak Paek, Sangyun Kim, et. al., "Introduction of Containment Liner Plate (CLP) Corrosion", KINS, Transactions of the Korean Nuclear Society Spring Meeting, 17–18 May 2018, see https://www.kns.org/files/pre_paper/39/18S-189%EB%B0%B1%EC%9A%A9%EB%9D%BD.pdf, accessed 7 June 2019.; and NSSC, "NSSC Reveals the Inspection Results of the Backside Corrosion of the CLPs in the Containment Buildings and Future Plans", 27 July 2017.

284 - NSSC, "The NSSC Approved Criticality After Planned Overhaul", 9 May 2019.

285 - Ibidem.

286 - *MBC News*, "190 hatch holes in the containment building of Hanvit 3. 4", 7 July 2019, see https://n.news.naver.com/article/214/0000961974, accessed 19 July 2019.

287 - *NW*, "South Korea completing safety checks on all reactor containment structures", 9 May 2019, op. cit.

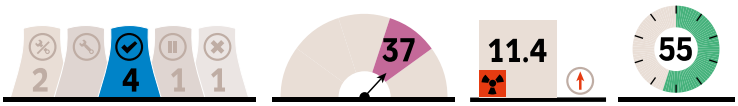
288 - NSSC, "The NSSC Approves Resumption of NPPs Only When Safety Is Guaranteed", Press Release, 1 February 2018, see http://www.nssc.go.kr/nssc/english/release/list.jsp?mode=view&article_no=44078&pager.offset=50&board_no=501, accessed 7 June 2019.

289 - NSSC, "Regarding the Chosul Ilbo op-ed titled "KEPCO in the red again, the nuclear phase-out policy is a nonsense that badly affects only citizens", 16 May 2018.

in thermal power.[290] The reactor had been in maintenance outage since 2018 but authorized to return to service. The NSSC reported thermal power had exceeded the 5 percent limit set in the reactor license Technical Specifications, reaching 18 percent.[291] This caused the temperature of the reactor coolant to rise rapidly, along with the steam generator level. The rising level of the steam generator tripped the main feed water pump, activating the auxiliary water pump. The NSSC reported that KHNP did not immediately shut down the reactor even though the thermal output of the reactor exceeded the limit during a test. In addition, the control rods were operated by a person who does not hold a Reactor Operator's license (RO). The reactor was eventually shut down 12 hours after the initial event.[292]

The NSSC, in announcing expansion of their investigation on 20 May 2019, reported that negligence on the part of the Senior Reactor Operator (SRO) in supervising and directing the operation is suspected, and therefore there is a possibility of violation of the Nuclear Safety Act.[293] Under the Act, KHNP is required to immediately shut down the reactor when thermal power exceeds the limit. For the first time, the NSSC ordered special judiciary police to investigate KHNP's actions. The regulator ordered the suspension of operation of Hanbit-1 at least until 20 July 2019, with the NSSC stating that "Since the thermal output rose so suddenly, we'll also have to check the integrity of the nuclear fuel. After thoroughly ensuring that the nuclear rods and nuclear fuel are both safe, we'll take action related to nuclear power legislation."[294] On 24 June 2019, the NSSC released its interim report finding that: the dynamic control rod reactivity measurement (DCRM), which has been used for 14 years, failed, and was replaced with other test methods; that excessive withdrawal of control rods had occurred; that control rods that became stuck was a result of latch jam (malfunctioning latch), accumulation of crud, influx of foreign materials, misalignment caused by aging and other causes; and that the operator had miscalculated reactivity and therefore the reactor went from sub-critical to super-critical. The NSSC reported that the specific reactor operator responsible for calculating reactivity did not have experience related to reactor startup operations.[295]

TAIWAN FOCUS



Taiwan has four operating reactor units at Kuosheng (Guosheng) and Maanshan, all owned by Taipower, the state-owned utility monopoly.[296] Since WNISR2018, the two reactors at Chinshan (also spelled Jinshan) were announced for closure. In December 2018, it was made

290 - NSSC, "The NSSC to Start Inspection of Hanbit Unit 1 After Manual Shutdown", 10 May 2019, see http://www.nssc.go.kr/nssc/english/release/list.jsp?mode=view&article_no=45422&pager.offset=0&board_no=501, accessed 20 July 2019.

291 - NSSC, "The NSSC to Expand the Special Inspection on Manual Shutdown of Hanbit Unit 1", 20 May 2019, see http://www.nssc.go.kr/nssc/english/release/list.jsp?mode=view&article_no=45431&pager.offset=10&board_no=501, accessed 20 July 2019.

292 - *Hankyoreh*, "Nuclear reactor kept running for 12 hours after it should have been shut down", 21 May 2019, see http://english.hani.co.kr/arti/english_edition/e_business/894763.html, accessed 20 July 2019.

293 - Ibidem.

294 - *NEI*, "Serious nuclear safety violation under investigation in South Korea", 24 May 2019, see https://www.neimagazine.com/news/newsserious-nuclear-safety-violation-under-investigation-in-south-korea-7224435, accessed 20 July 2019.

295 - NSSC, **"The NSSC Announced Interim Results of Special Investigation on Hanbit Unit 1", 24 June 2019, see** http://www.nssc.go.kr/nssc/english/release/list.jsp?mode=view&article_no=45519&pager.offset=0&board_no=501**, accessed 20 July 2019.**

296 - Atomic Energy Council, "NPP Real-time Operating Status", 9 June 2019, see https://www.aec.gov.tw/english/nuclear/index11.php, accessed 9 June 2019.

official that Chinshan-1 would not restart. WNISR considers it closed as of December 2014, when it was shut down for refueling and never put back on-line.

At the same time nuclear generation increased in 2018 with the restart of two reactors after long outages. In 2018, there was 26.6 TWh of nuclear generation, compared with 21.6 TWh in 2017, but still less than 30.5 TWh in 2016. Nuclear generation provided 11.4 percent of the country's electricity in 2018, compared with 9.3 percent in 2017 and its maximum share of 41 percent in 1988.

The government of President Tsai Ing-wen of the Democratic Progressive Party (DPP), which was elected in May 2016, remains committed to a nuclear phase-out by 2025, while transitioning the energy economy to renewables.[297] Historical public opposition to nuclear power in Taiwan dramatically escalated during and in the months following the start of the Fukushima Daiichi accident and has been a principal driver of the nation's ambitious plans for a renewable energy transition. The "New Energy Policy Vision", announced by the administration of President Tsai in summer 2016, aims at establishing "a lowcarbon, sustainable, stable, high-quality and economically efficient energy system" through an energy transition and energy industry reform.[298] On 12 January 2017, the Electricity Act Amendment completed and passed its third reading in the legislature, setting in place the mechanisms for Taiwan's energy transition, including nuclear phase-out.[299] The law also gives priority to distributed renewable energy generation, by which its generators will be given preferential rates, and small generators will be exempt from having to prepare operating reserves. The monopoly of the state-run Taipower will also be terminated.[300]

The plans for ending nuclear power progressed significantly during the past year with the approval of Taipower's decommissioning plan for the two units at Chinshan and preparations for submission of the decommissioning plan for the two units at Kuosheng, which are due to close in December 2021 and December 2023 respectively.

To reach its renewable energy goals of 20 percent of the nation's generation by 2025, approximately 27 GW of new offshore wind and solar capacity will be required.[301] In the past year, the Ministry of Economic Affairs (MOEA) awarded grid capacity to nine developers for 14 offshore wind projects, with 738 MW operating capacity by 2020 and 4,762 MW between 2021 and 2025.[302] The attractive feed-in tariffs offered for offshore have attracted overseas

297 - MOEA, "Taiwan's New Energy Policy", 6 April 2017, Ministry of Economic Affairs, see https://www.moea.gov.tw/Mns/ ietc_e/content/Content. aspx?menu_id=21511, accessed 9 June 2019.

298 - Ibidem.

299 - Bureau of Energy, "The Three-Stage Reading Process for Electricity Act Amendment Completed Moving Towards the 2025 Target of Nuclear-Free Homeland", Ministry of Economic Affairs, 1 March 2017, see https://eng.wra.gov.tw/7618/7662/7717/30138/, accessed 9 June 2019.

300 - *The China Post*, "Lawmakers OK wide-ranging amendments to Electricity Act", 12 January 2017, see https://chinapost.nownews.com/20170112-14213, accessed 9 June 2019.

301 - Miaojung Lin, Lianting Tu, "Taiwan Lays Plans for $59 Billion in Renewable-Energy Finance", *Bloomberg*, 18 June 2017, see https://www.bloomberg.com/news/articles/2017-06-18/taiwan-lays-plans-for-59-billion-in-renewable-energy-finance, accessed 9 July 2019.

302 - Bureau of Energy, "Offshore wind auction winners announced! 2 winners with 4 projects will provide 1,664 MW by 2025", Ministry of Enconomic Affairs, Press Release, 26 July 2018, see https://www.moeaboe.gov.tw/ECW/english/news/News.aspx?kind=6&menu_id=958&news_id=16111.

companies,[303] with Mitsubishi Heavy Industries Ltd. (MHI)-Vesta signing contracts for localized production of wind turbine towers and blades with the objective of supplying both Taiwan and the wider Asia region.[304] In the case of solar PV, the target is for 20 GW by 2025, and with 2.24 GW installed as of September 2018,[305] there will need to be a rapid scaling up if Taiwan is to meet its target.

Reactor Closures

On 5 December 2018, Taipower announced the closure of Chinshan-1, four years after being taken off-line.[306] It had not operated since 10 December 2014. The Atomic Energy Council (AEC) had approved the reactor for restart, but lawmakers required the issue to be addressed by the national parliament prior to restart.[307] Both reactors at Chinshan are Mark 1 BWRs, which began operation in 1977 and 1978 respectively. In May 2016, environmental groups launched a court case against the restart of Chinshan-1 calling it the "most dangerous reactor in the world".[308] Taipower's decommissioning plan for both units at Chinshan had been approved by the AEC in June 2017.[309]

Chinshan-1 is the first commercial reactor in Taiwan to be closed for decommissioning. Chinshan-2 has remained shut down since June 2017—thus considered in Long-Term Outage (LTO) as of 1 July 2019—was officially closed on 15 July 2019, when its 40-year operating license expired. On 16 July 2019, the AEC issued the Decommissioning Permit for the Chinshan nuclear plant in accordance with the "Nuclear Reactor Facilities Regulation Act".[310] (See **Table 7** for details).

Referendum

An effort by pro-nuclear activists to overturn the government's nuclear phase-out plans through a referendum has failed to change the reality that Taiwan is exiting nuclear energy. The referendum was held in November 2018, sponsored by those closely tied to the opposition Chinese Nationalist Party (Kuomintang or KMT). So-called "Referendum No. 16", asked: "Do you agree that subparagraph 1, Article 95 of the Electricity Act, which reads: 'Nuclear-energy-

303 - Heidi Vella, "Taiwan: pursuing a new green energy revolution in the East", *Power Technology*, 5 November 2018, see https://www.power-technology.com/features/taiwan-pursuing-new-green-energy-revolution-east/, accessed 9 July 2019.

304 - MHI Vestas, "MHI Vestas Signs Tower Contract, Firms Up Localisation Plans in Taiwan", Press Release, 30 October 2018, see http://www.mhivestasoffshore.com/tower-contract-tw/, accessed 9 July 2019.

305 - Rhea Tsao, "Will Taiwan meet its 20 GW solar goal by 2025?", *PV Magazine*, 7 September 2018, see https://www.pv-magazine.com/2018/09/07/will-taiwan-meet-its-20-gw-solar-goal-by-2025/, accessed 9 July 2019.

306 - Taipower, "Nuclear No. 1 machine No. 1 machine license expired according to law, pending decommissioning, officially started decommissioning", Press Release, 5 December 2018 (in Chinese), see https://www.taipower.com.tw/tc/news_info.aspx?id=2732&chk=0f0e1a36-c68b-43c1-81d9-0144b5df4475&mid=17&param=pn%3d4%26mid%3d17%26key%3d, accessed 8 June 2019.

307 - *NW*, "Chinshan-1 might not restart until after September: lawmakers", 2 July 2015.

308 - Chen Wei-han, "Activists file suit over Jinshan reactor", *Taipei Times*, 31 May 2016, see http://www.taipeitimes.com/News/taiwan/archives/2016/05/31/2003647555, accessed 8 June 2019.

309 - Ibidem.

310 - AEC, "The Atomic Energy Council Issued the Decommissioning Permit for Chinshan Nuclear Power Plant on July 12, 2019", Press Release, 12 July 2019, see https://www.aec.gov.tw/, accessed 26 July 2019.

based power-generating facilities shall wholly stop running by 2025,' should be abolished?" The referendum passed with 5.89 million "yes" votes and 4.01 million "no" votes.

However, according to Atomic Energy Council regulations, a proposal to update a nuclear power generator's operating permit must be filed five to 15 years before the permit expires, according to AEC Deputy Minister Chiou Syh-tsong.[311] The deadlines for extending operations at the Chinshan and Kuosheng nuclear power plants had already passed by the time of the referendum. The licenses for Guosheng's two reactors expire on 27 December 2021, and 14 March 2023. Operations at the Jinshan plant's two reactors have been suspended and, while decommissioning plans are going through an environmental impact assessment, they would remain suspended until they can be officially decommissioned, according to the AEC.[312] The only licenses that could in theory be extended are for the two reactors at Maanshan as they expire on 26 July 2024 and 17 May 2025. There is no indication, though, that a license extension is to be applied for Maanshan-1, which would be due no later than 26 July 2019.

At a Chernobyl commemorative rally in Taipei in April 2019, President Tsai Ing-wen said that as long as she and her administration remain in power, she will stick to her goal of a "nuclear-free homeland."[313] Taiwan is at no risk of an electricity shortage, so its fourth nuclear power plant will not be put into operation, she said, referring to the Lungmen plant that had been under construction for 15 years (see **No Future for Lungmen?** for details). Critical to the orientation of energy policy in Taiwan will be whether or not Tsai Ing-wen secures re-election as President on 11 January 2020.

On 7 May 2019, as formally required following the referendum, but with no impact on plans for Taiwan's nuclear phase-out, the Legislative Yuan abolished a provision in Article 95 of the Electricity Act stipulating that all nuclear energy generation facilities must stop operations before 2025.[314]

No Future for Lungmen?

On 1 February 2019, Taipower, the operator of the nation's nuclear plants, effectively ruled out any prospects for the operation of the two Lungmen reactors, but without making a formal decision to do so.[315] The two General Electric (GE) 1300 MW Advanced Boiling Water Reactors (ABWR) had been listed as "under construction" at Lungmen, near Taipei, since 1998 and 1999 respectively. According to the AEC, as of the end of March 2014, Lungmen1 was 97.7 percent complete,[316] while Unit 2 was 91 percent complete. The plant was, as of

311 - Sean Lin, "Provision on halting nuclear power plants removed", *Taipei Times*, 8 May 2019, see http://www.taipeitimes.com/News/taiwan/archives/2019/05/08/2003714760, accessed 9 June 2019.

312 - Lin Chia-han, "Cabinet to examine options for nuclear power: William Lai", *Taipei Times*, 27 November 2018, see http://www.taipeitimes.com/News/taiwan/archives/2018/11/27/2003705010, accessed 9 June 2019.

313 - Wen Kuei-hsiang et al., "Thousands join anti-nuclear rallies in Taipei, Kaohsiung", *Focus Taiwan News Channel*, 27 April 2019, see http://focustaiwan.tw/search/201904270012.aspx?q=lungmen, accessed 8 June 2019.

314 - Sean Lin, "Provision on halting nuclear power plants removed", *Taipei Times*, 8 May 2019, see http://www.taipeitimes.com/News/taiwan/archives/2019/05/08/2003714760, accessed 9 June 2019.

315 - Taipower, "Nuclear four restarts difficult 3 years to complete", Press Release, 1 February 2019 (in Chinese), see https://www.taipower.com.tw/tc/news_info.aspx?id=2790&chk=a33e9884-eff5-468e-b549-7a31775486398mid=17&param=pn%3d3%26mid%3d17%26key%3d, accessed 9 July 2019.

316 - Planning Department, "Status and Challenges of Nuclear Power in Taiwan", AEC, April 2014, see http://www.aec.gov.tw/english/whatsnew/files/20140506-5.pdf, accessed 9 June 2019.

2014, estimated to have cost US$9–9.9 billion so far.[317] After multiple delays, rising costs, and large-scale public and political opposition, including through local referendums, on 28 April 2014, the then Premier Jiang Yi-huah announced that Lungmen-1 will be mothballed after the completion of safety checks, while work on Unit 2 at the site was to stop. The Democratic Progressive Party (DPP) government was elected with a pledge to halt construction of the Lungmen reactors, and with a nuclear phase-out planned for 2025, there is little prospect that they will ever operate. A formal decision on terminating the project would potentially force Taipower to file for bankruptcy as the listing of Lungmen as an investment asset would put the company in the red.[318] Taipower's February 2019 announcement of the time period required to complete Lungmen is not a formal decision to abandon Lungmen. With the official freeze of construction, WNISR took the units off the listing in 2014, where they remain as of 1 July 2019. The International Atomic Energy Agency (IAEA) continues to list the reactors as under construction.[319]

Any resumption of Lungmen construction would require Taiwan's legislature and AEC approval, which, given the current government, is not going to happen. Taipower explained in February 2019 that it would not be able to replace major components installed nearly 20 years ago, including instrumentation and control as well as renegotiation with the main supplier General Electric (GE).[320] Taipower stated that it could take 6–7 years to complete construction if all of these obstacles were overcome.

The announcement from Taipower was made one day after the Ministry of Economic Affairs published its revised national energy policy, according to which the Chinshan nuclear plant would be decommissioned as planned, there would be no extension for the Kuosheng and Maanshan reactors and the Lungmen plant would not be operated.[321]

Table 7 | Scheduled Closure Dates for Nuclear Reactors in Taiwan 2018–2025

Reactor	Type	Capacity MW	Grid Connection (dd/mm/yyyy)	Date of Cessation of Operation (dd/mm/yyyy)
Chinshan-1	BWR	604	16/11/1977	05/12/ 2018[a]
Chinshan-2	BWR	604	19/12/1978	15/07/2019
Kuosheng-1	BWR	951	21/05/1981	27/12/ 2021
Kuosheng-2	BWR	951	29/06/1982	14/03/ 2023
Maanshan-1	PWR	890	09/05/1984	26/07/ 2024
Maanshan-2	PWR	890	25/02/1985	17/05/ 2025

Sources: Taipower, 2017, WNISR, 2019

Note
a – Official closure date for Chinshan-1

317 - *WNN*, "Political discord places Lungmen on hold", 28 April 2014, see http://www.world-nuclear-news.org/NN-Political-discord-places-Lungmen-on-hold-2804144.html, accessed 9 June 2019.

318 - Lee I-chia, "Nuclear Power Debate: Scrapping plant would ruin Taipower: Duh", *Taipei Times*, 29 April 2014, see http://www.taipeitimes.com/News/taiwan/archives/2014/04/29/2003589160, accessed 9 June 2019.

319 - IAEA-PRIS, "Taiwan, China", as of 10 June 2019, see https://pris.iaea.org/PRIS/CountryStatistics/CountryDetails.aspx?current=TW, accessed 11 June 2019.

320 - *NEI*, "Taipower rules out operation of Lungmen", 6 February 2019, see https://www.neimagazine.com/news/newstaipower-rules-out-operation-of-lungmen-6970272, accessed 9 July 2019.

321 - Liao Yu-yang, Ko Lin, "Taiwan will not face electricity shortages: economics minister", *Focus Taiwan*, 11 February 2019, see http://focustaiwan.tw/search/201902110024.aspx?q=nuclear%20energy, accessed 9 July 2019.

On 30 May 2019, Taipower announced that it had agreed to settle a dispute out of court with GE over payment for components for the Lungmen project.[322] Taipower agreed to pay GE, which designed the plant's reactors, US$22.50 million as part of the out-of-court settlement. GE had filed two arbitration cases against the company at the International Chamber of Commerce (ICC) in September 2015. In January 2019, the ICC ruled that Taipower should pay GE NT$4.88 billion (US$158 million) under the terms of the contract.[323] In the second case, yet to be ruled on, GE was seeking more than NT$2 billion (US$66 million) from the state utility firm for equipment already installed at the plant.

The only, and currently remote, prospects for Lungmen being completed and operated would be an election victory for the KMT party in the 2020 presidential elections.

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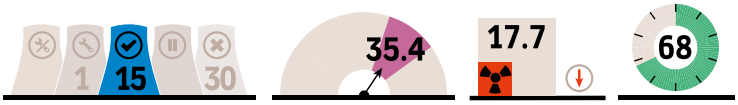


In 2018, the United Kingdom operated 15 reactors, which provided 59.1 TWh (a 7.5 percent fall from 63.9 TWh in 2017, due to extended outages) or 17.7 percent of the country's electricity, down from a maximum of 26.9 percent in 1997. The U.K.'s reactor fleet achieved an average load factor of 68.4 percent in 2018, a significant drop of 6.3 percentage points over 2017, but still better than the lifetime average of 63.2 percent. The average age of the U.K. fleet stands at 35.4 years (see **Figure 31**).

2018 was a remarkable year for the nuclear industry in the U.K., and historically it may well be seen as a pivotal year in the decline of the sector. Some of the key developments were: the extent of the age related cracking of the two Advanced Gas-cooled Reactors (AGR) at Hunterston, leading to their extended closure and potentially their retirement; the abandonment of both the Horizon and the NuGen new build programs; and the start of the closure of the Thermal Oxide Reprocessing Plant (THORP) at Sellafield.

A total of 30 power reactors have been permanently closed, all 26 Magnox reactors, both fast reactors, a prototype Advanced Gas-cooled Reactor (AGR) at Windscale and a prototype Steam Generating Heavy Water Reactor (SGHWR) at Winfrith. The U.K.'s seven second-generation nuclear stations, each with two AGRs, are all operating past the end of their original 25 year design lives. However, their owner EDF Energy, is planning to further extend the lifetimes of the two oldest AGR stations until 2023 (Hinkley Point B, Hunterson B). The other five stations (Dungeness B, Hartlepool, Heysham-1, Heysham-2 and Torness) are all due to complete their mandatory 10-year Periodic Safety Reviews in 2019 or 2020 and it will then become clearer how long EDF will be able to operate these plants. The country's only Pressurized Water Reactor (PWR), at Sizewell B, is expected to operate until at least 2035.[324]

322 - Tsai Peng-min, Ko Lin, "Taipower, GE reach out-of-court settlement", *Focus Taiwan*, 30 May 2019, see http://focustaiwan.tw/news/aeco/201905300026.aspx, accessed 8 June 2019.

323 - King & Spalding, "GE Hitachi Nuclear Energy Wins a US$158 Million Award in ICC Arbitration Against Taiwan", 21 February 2019, see https://www.kslaw.com/news-and-insights/ge-hitachi-nuclear-energy-wins-a-us158-million-award-in-icc-arbitration-against-taiwan, accessed 8 June 2019.

324 - EDF, "Nuclear Lifetime Management", Undated, see https://www.edfenergy.com/energy/lifetime-management, accessed 7 May 2018.

EDF Energy is owned largely by EDF, although Centrica has a minority share (20 percent) in EDF Energy's U.K. nuclear subsidiary, Lake Acquisitions. However, Centrica has been trying to sell its stake since 2013 and is increasingly vocal in its desire to leave the nuclear business. In February 2018, CEO Iain Conn said that "we would hope to divest of our shareholding in U.K. nuclear power by the end of 2020".[325] In its 2018 annual report, Centrica stated that it would give an update of the "prospects for a trade sale of our Nuclear investment" in the Interim Results, to be published in July 2019.[326] It has been reported that the Chinese firm CGN is interested in the deal. Uncertainty over the operational life of the AGR fleet is likely to impact on the timing, attractiveness and price of the proposed sale. EDF has also been trying to reduce its stake in Lake Acquisitions to 51 percent since 2015 but, like Centrica, with no success.

Managing reactors as they age is a constant problem for any technology design, and the AGRs are no exception. In recent years problems with the core's graphite moderator bricks have raised concerns. In particular, keyway root cracks, exceeding the number the U.K. regulator, the Office for Nuclear Regulation (ONR) previously deemed permissible, have been found at one of the Hunterston B reactors. This is of concern as it can lead to the degradation of the keying system, a vital component as it forms the channels within the reactor, which house the fuel, the control rods and the coolant (CO_2). Such cracking or distortion could affect the insertion of the control rods or the flow of the coolant. There are also issues of erosion of the graphite and a number of the AGRs are close to the erosion limit set by the ONR. With age, the graphite bricks also distort and may eventually compromise the operation of the safety control rods. These issues are likely to be the life-limiting factor for the AGRs, as it is not possible to replace the graphite bricks.

In March 2018, during a scheduled outage, EDF discovered a higher number of keyway root cracks in the older of the two reactors than was predicted by its computer models in 2016. Then in May that year, EDF announced that Hunterston B-1's present shutdown would be extended for further investigation and revised modelling, with the intention of restarting the reactor before the end of 2018. In late December 2018, EDF stated that it had "observed around 100 keyway root cracks in Reactor 3. This is from the inspection of just over a quarter of the reactor. Using modelling to project the number of cracks across the whole reactor our best estimate of the current number of cracks is around 370. This takes the core over the operational limit of 350 contained in the existing safety case for that period of operation."[327]

In December 2018, EDF estimated that reactors would be restarted in March 2019 (B-1) and April 2019 (B-2), but this deadline passed and, as of June 2019, restarts were scheduled for later in July 2019 (B-2) and October 2019 (B-1).[328] Age-related problems have also been found at similar-age reactors at Dungeness B, with Unit 2 closed for what was supposed to be a 12-week outage in August 2018 and then Unit 1 for "common statutory outage work", with both expected to restart in April 2019. However, the outage has been extended, with current

325 - *NIW*, "Weekly Roundup", 23 March 2018.

326 - Centrica, "Annual Report and Accounts 2018", 2019, see https://annual-report.centrica.com/assets/pdf/2018%20Annual%20Report.pdf, accessed 22 April 2019.

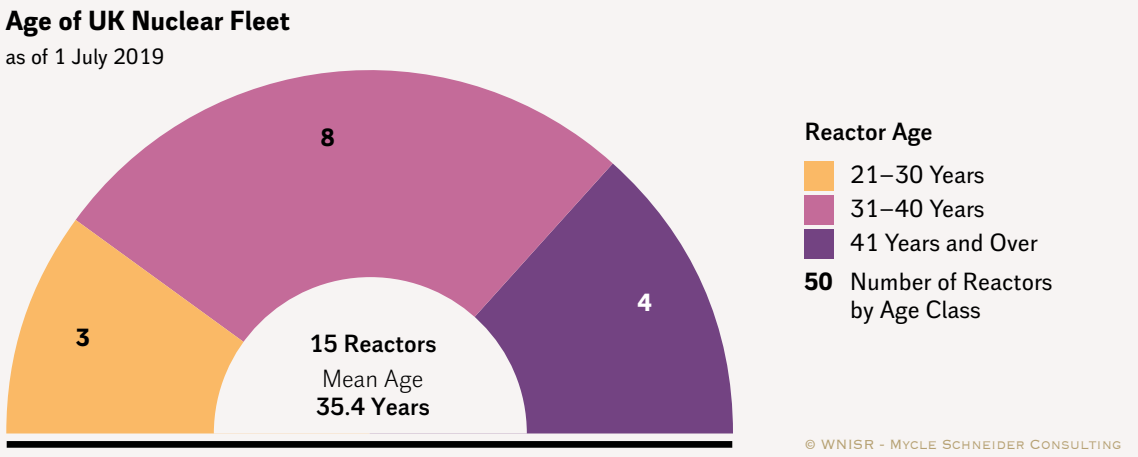
327 - EDF Energy, "Hunterston Graphite Inspections—December 2018", December 2018, see https://www.edfenergy.com/sites/default/files/hunterston_december_update_final.pdf, accessed 22 April 2019.

328 - EDF Energy, "Community Update— Hunterston B", 20 June 2019, see https://www.edfenergy.com/media-centre/news-releases/community-update-8, accessed 20 June 2019. In August 209, EDF obtained permission to restart B-2 for a 4-month period with an uncertain follow-up.

restart dates for the units being September and October 2019. In June 2019, in the Office for Nuclear Regulation's Annual report, it was stated that Dungeness B and Hunterston B were in an "enhanced level of regulatory attention", rather than routine. This was because assessment of the cracks was "intensive" and required "substantial additional effort."[329]

The impact of the cracking on the lifetime of the AGR fleet is yet to be determined. The two reactors at Hinkley Point B, the sister station to Hunterston, are also due for statutory outages with unit 1 starting in March 2019 and then returning to service in June 2019, and unit 2 expected in April 2021.

Figure 31 | Age Distribution of U.K. Nuclear Fleet



Sources: WNISR, with IAEA-PRIS, 2019

The development of new nuclear reactors in the U.K. has been slow and will be significantly less successful than envisaged. The current development cycle was "officially launched" in 2006, when then Prime Minister Tony Blair stated that nuclear issues were "back on the agenda with a vengeance".[330] In July 2011, the Government released the National Policy Statement (NPS) for Nuclear Power Generation.[331] The eight "potentially suitable" sites considered in the document for deployment "before the end of 2025" are exclusively current or past nuclear power plant sites in England or Wales, except for one new site, Moorside, adjacent to the fuel-chain facilities at Sellafield. Northern Ireland and Scotland are not included. The Scottish government is opposed to new-build and said it would not allow replacement of Scotland's Torness and Hunterston plants once they are shut down.[332]

329 - Office for Nuclear Regulation, "Annual Report and Accounts 2018/19", HC2271, June 2019, see http://www.onr.org.uk/documents/2019/onr-annual-report-and-accounts-2018-19.pdf, accessed 11 July 2019.

330 - *BBC*, "Blair backs nuclear power plans", 16 May 2006, see http://news.bbc.co.uk/1/hi/uk_politics/4987196.stm, accessed 7 May 2018.

331 - DECC, "National Policy Statement for Nuclear Power Generation", U.K. Government, July 2011.

332 - Scottish Government, "Energy: Frequently Asked Questions", 25 June 2009, see http://www.gov.scot/Topics/Business-Industry/Energy/Facts/faqs, accessed 7 May 2018.

Hinkley Point C Construction Start – Not That Concrete?

EDF Energy was given planning permission to build two reactors at Hinkley Point in April 2013. In October 2015, EDF and the U.K. Government[333] announced updates to the October 2013 provisional agreement of commercial terms of the deal for the £16 billion (US$20 billion) overnight cost of construction of Hinkley Point C (HPC).[334] The estimated price of construction has since risen and as of 2017 stood at £$_{2015}$19.6 billion (US$$_{2015}$25.3 billion), up from the £$_{2015}$18bn (US$$_{2015}$23.2 billion) quoted in 2016; no official update has been given since. EDF says the £1.5bn (US$1.9 billion) increase announced in 2017 results mainly "from a better understanding of the design adapted to the requirements of the British regulators, the volume and sequencing of work on site and the gradual implementation of supplier contracts"[335].

EDF maintains the official construction-start target date as "mid-2019" and the "initial delivery objective for Unit 1 at the end of 2025".[336] However, EDF have acknowledged that pouring the first safety-related concrete for Hinkley Point C-1 in mid-2019 can only happen if "the final design, which is on a tight schedule, is completed by the end of 2018."[337]

The International Atomic Energy Agency (IAEA) dates formal start of construction for a nuclear power plant as the pouring of first structural concrete and this occurred for the first reactor at HPC on 11 December 2018. WNISR is thus considering Hinkley Point C under construction as of that date.[338] However, an EDF Energy spokesperson told WNISR in June 2018 that "the recognised 'construction start' has not yet been reached. In the HPC project, this date is termed 'J0' and is scheduled to be reached in June 2019" and "It was ***not*** the base slab of the reactor building. As I say, this is due to happen in June 2019." [Emphasis by EDF Energy].[339] This is despite, the "site construction director" stating in spring 2018 that "activity is ramping up with over 3,000 people now on-site (...) and over 100,000 tonnes of concrete has already been poured".[340] On 28 June 2019, EDF Energy announced that "Hinkley Point C has hit its biggest milestone yet on schedule. The completion of the base for the first reactor, known as 'J-zero', means that the construction of the nuclear buildings above ground can now begin in earnest".[341]

By completing a large amount of the work before formally declaring construction began, EDF is able to claim a shortened construction timetable and be more likely to meet the construction deadline. Given the construction delays in China, Finland and France, this could be of primary importance for EDF.

333 - DECC, "Hinkley Point C to power six million UK homes", Press Release, U.K. Government, 21 October 2015, see https://www.gov.uk/government/news/hinkley-point-c-to-power-six-million-uk-homes, accessed 7 May 2018.

334 - The 2013 and 2015 figures are all in 2012 money unless otherwise specified.

335 - EDF, "Clarifications on Hinkley Point C project", Press Release, 3 July 2017, see https://www.edf.fr/en/the-edf-group/dedicated-sections/journalists/all-press-releases/clarifications-on-hinkley-point-c-project, accessed 6 August 2019.

336 - Ibidem.

337 - Ibidem.

338 - For details, see WNISR, "The Oddly Discreet Construction Start of Hinkley Point C", 29 December 2018, see https://www.worldnuclearreport.org/The-Oddly-Discreet-Construction-Start-of-Hinkley-Point-C.html, accessed 6 August 2019.

339 - Gordon Bell, EDF Energy, spokesperson for Hinkley Point C, personal communication, email to Mycle Schneider, 8 June 2018.

340 - EDF Energy, "Reactor one takes shape—Achievements at Hinkley Point C", *Plugged in to Hinkley Point C*, Spring 2018, p.4, see https://www.edfenergy.com/sites/default/files/edf_4731_plugged_in_spring_1.18_14_web_dps.pdf, accessed 10 June 2019.

341 - EDF Energy, "Hinkley Point C hits its biggest milestone yet", 28 June 2019, see https://www.edfenergy.com/energy/nuclear-new-build-projects/hinkley-point-c/news-views/hinkley-point-c-hits-biggest-milestone-yet, accessed 10 July 2019.

The key points of the Hinkley deal were a Contract for Difference (CfD), effectively a guaranteed real electricity price for 35 years, which, depending on the number of units ultimately built, would be £89.5–92.5/MWh, in 2012 values (US$115–120/MWh), with annual increases linked to the retail price index. The cost of this support scheme has skyrocketed, with the U.K. National Audit Office (NAO) suggesting that the additional 'top-up' payments—the difference between the wholesale price (as of early 2018 at about £50/MWh) and the agreed fixed price (or Strike Price), required through the CfD—have increased from £6.1 billion (US_{2013}9.9 billion) in October 2013 to £29.7 billion (US_{2016}41.2 billion) in March 2016, due to falling wholesale electricity prices. This is the discounted estimate; the undiscounted estimate would be closer to £50 billion. The NAO also stated that "the [Government] Department's deal for HPC has locked consumers into a risky and expensive project with uncertain strategic and economic benefits."[342]

There was an expectation that HPC's construction would be primarily funded by debt (borrowing) backed by U.K. sovereign loan guarantees, expected to be about £17 billion (US$26.9 billion). EDF announced in November 2015 its intention to sell non-core assets worth up to €10 billion (US$11.4 billion), including a stake in Lake Acquisitions, to help finance Hinkley and other capital-intensive projects.[343] This includes the partial sale of the French high voltage network (RTE) to the state bank Caisse des Dépôts in March 2017, which raised €4 billion (US_{2018}4.6 billion),[344] and in November 2017 the sale of EDF Polska assets, including electricity and combined heat and power plants to Polska Grupa Energetyczna (PGE) for about €1.4 billion (US_{2018}1.6 billion).[345]

The May administration finally approved the HPC project in September 2016, with the government retaining a "special share", that would give it a veto right over future ownership if national security concerns arose.[346] The expected composition of the consortium owning the plant had changed from October 2013 to October 2015. The effective bankruptcy and dismantling of AREVA made their planned contribution impossible, the Chinese stake had fallen to 33.5 percent and the other investors had not materialized, leaving EDF with 66.5 percent. In May 2016, the China National Nuclear Corporation (CNNC) indicated it didn't rule out participation in the 33.5 percent Chinese stake.[347] However, no changes were reported as of mid-2019.

342 - Sir Amyas Morse KCB, "Hinkley Point C", Comptroller and Auditor General, Department for Business, Energy & Industrial Strategy, U.K. National Audit Office, 23 June 2017, see https://www.nao.org.uk/wp-content/uploads/2017/06/Hinkley-Point-C.pdf, accessed 7 May 2018.

343 - Michael Stothard, "EDF looks to sell €10bn of assets to boost balance sheet", *Financial Times*, 18 October 2015, see https://www.ft.com/content/fcd6a462-7578-11e5-a95a-27d368e1ddf7, accessed 7 May 2018.

344 - EDF, "EDF finalised the indirect sale of 49.9% of RTE assets to Caisse des Dépôts and CNP Assurances", Press Release, 31 March 2017, see https://www.edf.fr/en/the-edf-group/dedicated-sections/journalists/all-press-releases/edf-finalised-the-indirect-sale-of-49-9-of-rte-assets-to-caisse-des-depots-and-cnp-assurances, accessed 4 July 2018.

345 - EDF, "EDF finalizes the disposal of EDF Polska's assets to PGE", 14 November 2017, Press Release, see https://www.edf.fr/en/the-edf-group/dedicated-sections/journalists/all-press-releases/edf-finalizes-the-disposal-of-edf-polska-s-assets-to-pge, accessed 4 July 2018.

346 - Rowena Mason, Simon Goodley, "Hinkley Point C nuclear power station gets government green light", *The Guardian*, 15 September 2016, see http://www.theguardian.com/uk-news/2016/sep/15/hinkley-point-c-nuclear-power-station-gets-go-ahead, accessed 7 May 2018.

347 - *The Times*, "Chinese give Hinkley Point nuclear project a boost", 9 May 2016.

Other U.K. New-Build Projects

Chinese stakes in the mooted follow-on Sizewell C project would be limited to 20 percent, leaving EDF with 80 percent. Given the problems EDF is having financing Hinkley, this makes the Sizewell project appear implausible. However, EDF is allowing CGN to use the Bradwell site it had bought as back-up, if either the Hinkley or Sizewell sites proved not to be viable. CGN plans to build its own technology, the Hualong One (or HPR-1000) at this site, with EDF taking a 33.5 percent stake.[348] In January 2017, the U.K. Government requested that the regulator begin the Generic Design Assessment (GDA) of the HPR-1000 reactor,[349] and by November 2018 the Office for Nuclear Regulation (ONR) and Environment Agency had completed an initial high-level scrutiny of the design.[350] Work is expected to be complete in 2021.

Of potential importance to the Bradwell project was that in March 2019, Rolls-Royce confirmed that it was reviewing its options for its civil nuclear industry. This could include selling its civilian nuclear arm, which manufactures controls and systems technologies including its supply deal with CGN for reactors in the U.K.[351]

Foreign ownership of critical infrastructure hasn't had the same degree of concern as in other countries. Even for nuclear power, CGN's proposal to build, operate and own a reactor designed in China has not been vetoed, despite growing action in the United States to stop the export of nuclear technology to China for "national security" concerns.[352] However, aware of the sensitivities, CGN has indicated that it might be willing to hand over ownership of Bradwell to another operator if that might reduce concerns.[353]

At the beginning of 2018, there were two other consortia planning to build new nuclear power in the U.K., but these projects were both shelved over the year.

Moorside

In June 2014, NuGen finalized a new ownership structure with Toshiba-Westinghouse (60 percent) and Engie (40 percent), as Iberdrola sold its shares to Toshiba-Westinghouse. The group planned to build three Toshiba-Westinghouse-designed AP-1000 reactors at the Moorside site, with units proposed to begin operating in 2024.[354] However, Westinghouse, after its financial collapse, filed for Chapter 11 bankruptcy protection in the U.S. in March 2017. This had a disastrous impact on the parent company Toshiba, when the extent of Westinghouse's

348 - EDF Energy, "Agreements in place for construction of Hinkley Point C nuclear power station", Press Release, 21 October 2015, see https://uk.ambafrance.org/IMG/pdf/edf_press_release_hpc.pdf?6641/5060ea5271274dd6fc8234726c5962c9813fc14e, accessed 7 May 2018.

349 - ONR, "Assessing new nuclear reactor designs—Generic Design Assessment Periodic Report: November 2016 – January 2017", March 2017, see http://www.onr.org.uk/new-reactors/reports/gda-quarterly-report-nov16-jan17.pdf, accessed 7 May 2018.

350 - ONR, "UK HPR1000 completes GDA Step 2", 15 November 2018, see http://news.onr.org.uk/2018/11/uk-hpr1000-completes-gda-step-2/, accessed 27 May 2019.

351 - *NIW*, "Weekly Roundup - Rolls-Royce Mulls selling nuclear business", 8 March 2019.

352 - Jessica Resnick-Ault, "U.S. tightens controls on China imports of nuclear components", *Reuters*, 11 October 2018, see https://uk.reuters.com/article/us-china-usa-nuclear/u-s-tightens-controls-on-china-imports-of-nuclear-components-idUKKCN1ML2V9, accessed 22 April 2019.

353 - Sylvia Pfeifer, Myles McCormick, "Chinese willing to hand over control of UK nuclear plant", *Financial Times*, 18 September 2018, see https://www.ft.com/content/1a44e152-b762-11e8-b3ef-799c8613f4a1, accessed 22 April 2019.

354 - *NucNet*, "Toshiba Finalises Controlling Stake In UK Nuclear Company NuGen", 30 June 2014, see https://www.nucnet.org/all-the-news/2014/06/30/toshiba-finalises-controlling-stake-in-uk-nuclear-company-nugen, accessed 7 May 2018.

problems came to light.[355] The perilous state of the project also led to Engie selling its remaining 40 percent for US$138 million to Toshiba-Westinghouse, which was contractually obliged to buy them at the pre-determined price.[356] In late April 2017, the national press reported that Toshiba was preparing to mothball the project, warning suppliers of spending cuts and ordering seconded staff to return to their employers.[357] Amid this economic chaos, the U.K. Office of Nuclear Regulation had approved the AP-1000 reactor design on 30 March 2017.[358]

Toshiba was initially in talks with both Korea's KEPCO (Korea Electric Power Corporation), a nationally owned utility and reactor vendor, and CGN of China as potential buyers of NuGen. In October 2017, the CEO of NuGen said he expected to find a buyer by early 2018,[359] but KEPCO put off a decision until the autumn of 2018 and said they would only proceed if "a preliminary analysis concludes the project serves the national interests."[360] However, in November 2018 Toshiba announced that it was winding down NuGen, without finding a buyer. This might open up the opportunities for others to buy the Moorside site and build their own reactors—although this has not yet occurred. In the meantime, the Moorside site has reverted to the U.K.'s Nuclear Decommissioning Authority (NDA).

Wylfa and Oldbury

The other company that was involved in proposed nuclear new-build is Horizon Nuclear, which was bought by the Japanese company Hitachi-GE from German utilities E.ON and Rheinisch-Westfälisches Elektrizitätswerk (RWE) for an estimated price of £700 million (US$1.2 billion) in 2012. The company submitted its Advanced Boiling Water Reactor (ABWR) design for technical review, whilst at the time making it clear that its continuation in the project would depend on the outcome of the negotiations with the Government.[361] The ABWR, two of which were planned for both the Wylfa and Oldbury sites, passed the justification procedure in January 2015, and the Generic Design Assessment (GDA) was completed in December 2017.[362] In April 2017, Horizon Nuclear applied for a site license at the Wylfa location. If everything had gone according to plan, the reactor would have started up in 2025.[363]

Hitachi was looking for partners in their project, hoping to reduce its stake to 50 percent and, if no other investors could be found, the company would have to withdraw. This is because

355 - Kana Inagaki, "Westinghouse files for Chapter 11 bankruptcy protection", *Financial Times*, 29 March 2017, see https://www.ft.com/content/ba9d8e42-de63-320e-b29c-70dcf19e1f28, accessed 7 May 2018.

356 - Marcus Leroux, "French investor deals new blow to nuclear project", *The Times*, 5 April 2017.

357 - John Collingridge, "Toshiba mothballs Cumbrian nuclear power project", *Sunday Times*, 30 April 2017.

358 - ONR, "Design acceptance for the AP1000 reactor", 30 March 2017, see http://news.onr.org.uk/2017/03/design-acceptance-for-the-ap1000-reactor/, accessed 7 May 2018.

359 - *NIW*, "United Kingdom", 6 October 2017.

360 - Phil Chaffee, "With Eyes on Saudi Arabia, Kepco Treads Water in the UK", *NIW*, 4 May 2018.

361 - Ambrose Evans-Pritchard, "Hitachi reluctant about UK nuclear reactor plan", *The Telegraph*, 14 April 2013, see https://www.telegraph.co.uk/finance/newsbysector/energy/9993564/Hitachi-reluctant-about-UK-nuclear-reactor-plan.html, accessed 7 May 2018.

362 - ONR, "Assessement of reactors—UK-ABWR—Design acceptance", December 2017, see http://www.onr.org.uk/new-reactors/uk-abwr/design-acceptance.htm, accessed 7 May 2018.

363 - *WNN*, "Horizon clears justification hurdle", 28 January 2015, see http://www.world-nuclear-news.org/NN-Horizon-clears-justification-hurdle-2801151.html, accessed 7 May 2018.

an internal review by the company had found that the cost of construction was likely to be US$27.5 billion, considered too big a risk for the company on its own.[364]

In order to attract a partner, Hitachi sought clarification on the financial support that the U.K. Government was willing to facilitate or the extent to which the Government would invest. One option being considered was a trilateral partnership between Hitachi and the U.K. and Japanese Governments. It was reported that the U.K. Government was prepared to make available £13.3billion (US$17.5 billion) in financial support for Hitachi.[365]

In June 2018, the Government formally announced that it was considering taking an equity stake in the Wylfa project, with a suggestion that the Government share could be up to one-third of the project costs and would provide all the loans needed for the project. The other two-thirds were to be taken up by Hitachi and by Japanese investors identified by the Japanese government. This highlighted the extent to which the Government, despite previous statements to the contrary, recognized that, as *The Times* puts it, "nuclear power in reality seems to be untenable without it [state support]."[366] The Government seemed to hope that by directly investing into the project, it would drive the strike price down to £70–78/MWh (US$92–103 MWh).[367] Subsequently Energy Minister Greg Clark said a strike price above £75/MWh (US$96.5/MWh) could not be justified for new nuclear.[368]

In January 2019, Hitachi announced that it was suspending the project and that this decision was taken "from the standpoint of economic rationality"; in doing so the company accepted a ¥300 billion (US$2.75 billion) impairment. Hitachi pointed to "significant changes in the power market environment," including the competitiveness of renewable energies.[369]

The partners and potential partners for the NuGen and Horizon projects will face an uphill battle to get a level of CfD similar to that was awarded to EDF for Hinkley Point C. Criticism of the high support cost for Hinkley and other nuclear projects has intensified with the awarding of tenders for offshore wind, with 2017 support prices of £57.50–74.75 in 2012 money (US$80–101/MWh) in 2017.[370] The next round of CfD announcements for offshore wind is expected in late 2019.

A New Funding Model for Nuclear?

In July 2019, the Government announced a consultation for the introduction of a new funding model to facilitate the construction of new nuclear via a Regulated Asset Base (RAB), which "in the case of a nuclear RAB, suppliers would be charged as users of the electricity system and

364 - Chartered Institute of Building, "Hitachi gets cold feet over UK's $27bn nuclear scheme", *Global Construction Review*, 30 April 2018, see http://www.globalconstructionreview.com/news/hitachi-gets-cold-feet-over-uks-27bn-nuclear-schem/, accessed 8 May 2018.

365 - Sarah Dickins, "UK 'set to finance' Wylfa nuclear plant", *BBC News*, 17 May 2018, see http://www.bbc.co.uk/news/uk-wales-44161097, accessed 18 May 2018.

366 - Robin Pagnamenta, "Pumping more money into nuclear power leaves nation at a loss", 7 June 2018, see https://www.thetimes.co.uk/article/pumping-more-money-into-nuclear-power-leaves-nation-at-a-loss-v2lr5ppw5, accessed 6 August 2019.

367 - Phil Chaffee, "UK Launches Formal Talks for Wylfa Equity Stake", *NIW*, 8 June 2018.

368 - Greg Clark, "Statement at the House of Commons—Nuclear Update", Secretary of State for Business, Energy and Industrial Strategy, *Hansard*, 17 January 2019, see https://hansard.parliament.uk/Commons/2019-01-17/debates/9C841326-B63A-4790-867F-905DEDDDD8AC/NuclearUpdate, accessed 10 June 2019.

369 - Dennis Engbarth, "Hitachi Cites 'Economic Rationality' for Wylfa Decision", *NIW*, 1 January 2019.

370 - *NIW*, "Briefs—UK", 15 September 2017.

would be able to pass these costs onto their consumers who also use the electricity system".[371] If approved by the Government, the project developer could charge consumers upfront for the construction, which would be broken down into different phases during the build process. EDF have indicated that all households would have to pay £6 (US$7.5) per year additionally for them to build the proposed reactors at Sizewell C.[372]

Charging upfront reduces the construction costs as it avoids the need to include interest during the construction phase, thus cutting the amount of compounded debt to be serviced and paid off during the life of the asset, which could be key for nuclear projects as financing represent a significant share of the overall construction costs. Furthermore, by breaking the construction into different phases, it is expected that this would increase certainty and therefore reduce the cost of finance. It is argued by EDF that the aim would be to reduce the weighted [annual] average cost of capital (WACC) from the 9.2 percent on Hinkley to close to 5.5–6 percent.[373]

For nuclear, the segmented RAB might include "initial costs of preparing to get started; the costs of laying the foundations; the installation of the reactor; and commissioning—and at each stage, with the costs agreed in advance, there would be scrutiny by the regulator and then, subject to this efficiency test, these costs would then go into the RAB and be recovered from the use of systems charges".[374]

A key advantage selling point for the government is that it means that funding does not have to come from the treasury—and therefore off the Government's balance sheet—and that it removes the need for or at least reduces the level of the Contract for Difference, which highlights the high cost of nuclear compared to all other generating sources.

However, this model is seen as transferring the financing risks to the customer, as the *Financial Times* reported:

> What RAB financing does is transfer project risks to customers, who are least well placed to bear them," said [the late] Martin Blaiklock, an infrastructure expert who likened the technique to "being forced to pay for a meal at a restaurant before the restaurant has even been built, let alone served any food.[375]

The U.K. Government has asked for comments on the proposal until October 2019 and it will then decide whether to approve this approach to project financing.

Renewables Kicking In

The constant decline in energy *and* electricity consumption in the U.K. does not favor the economic case for nuclear new-build. Meanwhile, renewables' share of electricity generation

371 - Electricity and RAB Strategy Team, "Consultation on a Regulated Asset Base (RAB) Model for Nuclear", Department for Business, Energy & Industrial Strategy, Open Consultation, 22 July 2019, see https://www.gov.uk/government/consultations/regulated-asset-base-rab-model-for-nuclear, accessed 23 July 2019.

372 - Department for Business, Energy & Industrial Strategy and UK Government, "Regulated Asset Base (RAB) model for nuclear", 22 July 2019, see https://www.gov.uk/government/consultations/regulated-asset-base-rab-model-for-nuclear, accessed 23 July 2019.

373 - Jonathan Ford, "EDF seeks to charge customers upfront for UK nuclear plants", *Financial Times*, 22 November 2018, see https://www.ft.com/content/f9a96304-e980-11e8-885c-e64da4c0f981, accessed 23 July 2019.

374 - Dieter Helm, "The Nuclear RAB Model", 12 June 2018, see http://www.dieterhelm.co.uk/energy/energy/the-nuclear-rab-model/, accessed 23 July 2019.

375 - Jonathan Ford, "EDF seeks to charge customers upfront for UK nuclear plants", *Financial Times*, 22 November 2018.

reached 33 percent in 2018, largely outpacing nuclear power's contribution of 17.7 percent. The rise in renewables is increasingly impacting the other generators. In April 2019, National Grid published a documentation on "Zero carbon operation 2025", which makes no reference to nuclear power and states "Our ambition is that, by 2025, we will have transformed the operation of the electricity system such that we can operate it safely and securely at zero carbon whenever there is sufficient renewable generation on-line and available to meet the total national load".[376]

Over the past decade the extraordinary cost of the U.K.'s proposed nuclear power program has become apparent to a wider academic community and public bodies. Even when the Government was willing to invest directly into the project, nuclear costs were prohibitive. This is perhaps most clearly demonstrated by the change in the views of the Committee on Climate Change (CCC), an independent body established to advise the Government on meeting its climate-change objectives. In 2011, it stated that "nuclear power currently appears to be the most cost-effective of the low-carbon technologies".[377] Yet in its June 2018 report, the CCC says that "if new nuclear projects were not to come forward, it is likely that renewables would be able to be deployed on shorter timescales and at lower cost".[378] Then in May 2019, in its report on "Net Zero", the CCC states that "cost reductions in low-carbon technologies is not a universal story. Several technologies which have not been deployed at scale—such as nuclear power, carbon capture and storage (CCS) and heat pumps—have failed to come down in cost". The Committee estimates that the cost of power in 2025 from solar PV could be £47/MWh (US$58/MWh), for wind £69/MWh (US$48/MWh) and nuclear £98/MWh (US$123/MWh).[379]

Plutonium – From Long-Term Resource Dream to Endless Liability

The reprocessing of spent fuel, the use of plutonium and the re-use of reprocessed uranium were at the heart of the U.K.'s nuclear industry from inception. Initially this was for military reasons, as the plutonium was for weapons, but then came the development of fast reactors, to enable a "closed fuel cycle". However, the failure of the global deployment of nuclear power, the rising costs and technical challenges of fast breeders and the availability of uranium have undermined the justification of reprocessing. As of the start of 2017, the U.K. owned over 110 tons of unirradiated separated plutonium, looking for a use.[380] Consequently, the start of the cessation of reprocessing at the Thermal Oxide Reprocessing Plant (THORP) in November 2018, with the last fuel put into the plant,[381] was an important development for the nuclear industry, although it received surprising little press or political interest. While this

376 - Julian Leslie, "Zero Carbon Operation 2025—Executive summary", National Grid, April 2019, see https://www.nationalgrideso.com/document/141031/download, accessed 27 April 2019.

377 - CCC, "The Renewable Energy Review", May 2011, see https://www.theccc.org.uk/wp-content/uploads/2011/05/The-renewable-energy-review_Printout.pdf, accessed 4 July 2018.

378 - CCC, "Reducing UK emissions—2018 Progress Report to Parliament", June 2018, see https://www.theccc.org.uk/wp-content/uploads/2018/06/CCC-2018-Progress-Report-to-Parliament.pdf, accessed 4 July 2018.

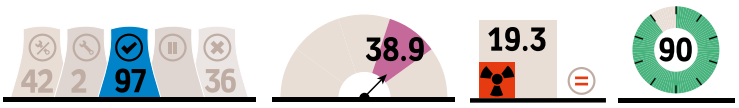
379 - CCC, "Net Zero—The UK's contribution to stopping global warming", 2 May 2019, see https://www.theccc.org.uk/publication/net-zero-the-uks-contribution-to-stopping-global-warming/, accessed 11 July 2019.

380 - ONR, "Annual figures for holdings of civil unirradiated plutonium as at 31 December 2016", 10 July 2017, see http://www.onr.org.uk/safeguards/civilplut16.htm, accessed 22 April 2019.

381 - Nuclear Decommissioning Authority and Sellafield Ltd, "End of reprocessing at Thorp signals new era for Sellafield", 16 November 2018, see https://www.gov.uk/government/news/end-of-reprocessing-at-thorp-signals-new-era-for-sellafield, accessed 27 April 2019.

marks the end of an era for the industry, it is not the end of activities at the Sellafield plant, which will be decommissioning the facility for decades to come and managing the plutonium for at least centuries.

UNITED STATES FOCUS



With 97 commercial reactors operating as of 1 July 2019, the U.S. possesses the largest nuclear fleet in the world. Construction has continued on the one new nuclear plant in the U.S., the twin AP-1000 at Plant Vogtle-3 and -4, following a vote of the owners in September 2018 to continue the project.[382] Further cost increases have been reported but with reportedly an improved work schedule.

Two reactors, both General Electric BWR MK 1 designs, were permanently closed in the year to 1 July 2019. The Oyster Creek-1 reactor in New Jersey generated its last kilowatthour on 17 September 2018.[383] Connected to the grid in September 1969, it was the oldest operating commercial reactor in the U.S., and was required to be closed no later than December 2018 under an agreement with the state.[384] On 31 May 2019, Entergy permanently shut down its Pilgrim reactor in Massachusetts, which was connected to the grid on 19 July 1972.

The fallout from the decision in July 2017[385] to terminate construction of the twin V.C. Summer AP-1000 reactors continued through the past year. This included legal action over the recovery of billions of dollars of ratepayers' money lost to the abandoned project,[386] ongoing disclosures of the failure of the project and culpability of utility executives,[387] including criminal investigations, and the takeover of the V.C. Summer owner, South Carolina Electric & Gas (SCG&E) and its parent SCANA, by Dominion.[388]

During the past year, utilities have both succeeded and failed in their ongoing efforts to secure state financial support for operating nuclear plants, with the balance being in the industry's favor. As of 2019, subsidies will be provided to eight nuclear plants in the U.S., in the form of

382 - U.S. Securities And Exchange Commission, "Form 8-K—Current Report—Pursuant to Section 13 or 15(d) of the Securities Exchange Act of 1934", Commission File Numbers 1-3526 and 1-6468, 26 September 2018, see https://d18rn0p25nwr6d.cloudfront.net/CIK-0000092122/4fc0aa9c-c108-4fe6-ad75-2057ebd606c1.pdf, accessed 2 May 2019.

383 - Exelon, "Oyster Creek Generating Station Retires from Service", 17 September 2018, see https://www.exeloncorp.com/newsroom/oyster-creek-retires, accessed 10 May 2019.

384 - Wayne Parry, "Long held as oldest in US, New Jersey nuclear plant closes", *Associated Press*, 17 September 2018, see https://www.apnews.com/916bbe07dab744edac460a50d5cad7f8, accessed 10 May 2019.

385 - SCANA, "South Carolina Electric & Gas Company To Cease Construction And Will File Plan Of Abandonment Of The New Nuclear Project", *CISION PR Newswire*, 31 July 2017, see https://www.prnewswire.com/news-releases/south-carolina-electric--gas-company-to-cease-construction-and-will-file-plan-of-abandonment-of-the-new-nuclear-project-300496644.html, accessed 10 May 2019.

386 - Andrew Brown, Thad Moore, "Q&A: What does SCE&G decision mean for ratepayers, investors and Dominion?", *The Post And Courier*, 14 December 2018, see https://www.postandcourier.com/business/q-a-what-does-sce-g-decision-mean-for-ratepayers/article_5c483dc2-fe40-11e8-9495-a33c4842df79.html, accessed 10 May 2019.

387 - *AP*, "More former top SCE&G officials say bosses knew VC Summer would fail and lied to cover it up", *ABC Columbia*, 20 November 2018, see https://www.abccolumbia.com/2018/11/20/more-former-top-sceg-officials-say-bosses-knew-vc-summer-would-fail-and-lied-to-cover-it-up/, accessed 10 May 2019.

388 - Thad Moore, John McDermott, "Dominion officially owns SCANA, SCE&G, a year after offering to resolve SC nuclear fiasco", *Post and Courier*, 2 January 2019, see https://www.postandcourier.com/business/dominion-officially-owns-scana-sce-g-a-year-after-offering/article_6e6ce794-0e96-11e9-a427-f39103ba4115.html, accessed 10 May 2019.

Zero Emission Credits (ZEC): Nine Mile Point, FitzPatrick and Ginna in New York; Clinton and Quad Cities in Illinois; Salem and Hope Creek in New Jersey; and Palisades in Michigan.[389] Legal challenges against ZEC nuclear legislation from consumers, NGOs and energy companies are ongoing in all of these states.

The Nuclear Energy Institute (NEI), the advocacy organization for the U.S. nuclear industry, has continued to lobby for financial support for nuclear plants,[390] while the Department of Energy (DOE) provided a further loan guarantee of US$3.7 billion to Plant Vogtle construction, the first and only loan guarantee issued under the Trump administration so far.[391] This brings the total loan guarantees provided by the DOE for nuclear new-build projects to US$12.03 billion.[392]

In a further measure to reduce costs for reactor operators, the Nuclear Regulatory Commission's (NRC) commissioners on 24 January 2019 voted by majority to remove safety requirements proposed in a draft rule making issued in 2016, that, if applied, would have forced utilities to take measures to upgrade their plants to protect against such hazards as flooding and major seismic events.[393] The draft NRC rulemaking had already rejected stricter measures proposed by the "Near Term Taskforce Review of Insights from the Fukushima Daiichi Accident" in 2011.[394]

While it is inevitable that the size of the U.S. nuclear fleet will continue to decline for the foreseeable future, the decline is likely to be slowed by directly subsidizing economically threatened operating plants.

The U.S. reactor fleet provided 808.03 TWh in 2018—a new historic maximum—compared with 805 TWh in 2017. Consequently, the load factor remained stable at a high level (89.8 percent), significantly above the modest lifetime load factor of 75.9 percent. Nuclear plants provided 19.3 percent of U.S. electricity in 2018, compared with 20.1 percent of U.S. electricity in 2017, and about 3 percentage points below the highest nuclear share of 22.5 percent, reached in 1995.

With only one new reactor started up in 20 years, the U.S. reactor fleet continues to age, with a mid-2019 average of 38.9 years, amongst the oldest in the world: 46 units have operated for 41 years or more (see **Figure 32**).

389 - Geoffrey Haratyk, "Early Nuclear Retirements in Deregulated U.S. Markets: Causes, Implications and Policy Options", *Working Paper Series*, Center for Energy and Environmental Policy Research, Massachusetts Institute of Technology, March 2017, see https://assets.documentcloud.org/documents/3723775/MIT-Early-Nuclear-Retirement-3-2017.pdf, accessed 10 May 2019.

390 - NEI, "Maria Korsnick Testifies on the Value of Nuclear in Pennsylvania", NEI Testimony before the Pennsylvania House of Representatives", 15 April 2019, see https://www.nei.org/resources/testimony/korsnick-testifies-pennsylvania-nuclear, accessed 10 May 2019; and Maria Korsnick, "Testimony for the Record", President and Chief Executive Officer, Nuclear Energy Institute, Testimony to the Appropriations Subcommittee on Energy and Water Development, U.S. House of Representatives, 12 April 2019, see https://www.nei.org/CorporateSite/media/filefolder/resources/testimony/testimony-nei-korsnick-house-energy-water-appropriations-20190412.pdf, accessed 10 May 2019.

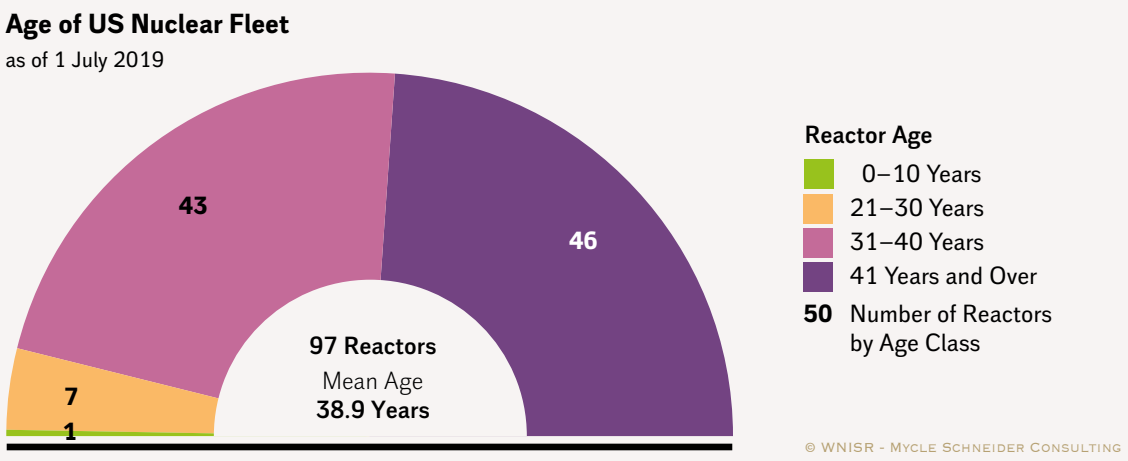
391 - Jacqueline Toth, "DOE Program's $3.7 Billion Loan Highlights Lack of Action on Other $40 Billion It Holds", *Morning Consult*, 8 April 2019, see https://morningconsult.com/2019/04/08/doe-programs-3-7-billion-loan-highlights-lack-of-action-on-other-40-billion-it-holds/, accessed 10 May 2019.

392 - Taxpayers for Common Sense, "DOE Loan Guarantee Program: Vogtle Reactors 3 & 4", 21 March 2019, see https://www.taxpayer.net/wp-content/uploads/2019/03/3-21-19-ENR-Vogtle-Fact-Sheet_MARCH-2019_-v.4.pdf, accessed 10 May 2019.

393 - Dave Flessner, "NRC backs away from strictest flood, seismic rules adopted after Fukushima", *Times Free Press*, 25 January 2019, see https://www.timesfreepress.com/news/business/aroundregion/story/2019/jan/25/nrc-backs-away-strictest-flood-seismic-rules/487429/, accessed 10 May 2019.

394 - Union of Concerned Scientists, "Preventing an American Fukushima—Limited Progress Five Years after Japan's Nuclear Power Plant Disaster", March 2016, see https://www.ucsusa.org/sites/default/files/attach/2016/03/Preventing-American-Fukushima-full-report.pdf, accessed 10 May 2019.

Figure 32 | Age Distribution of U.S. Nuclear Fleet



Sources: WNISR, with IAEA-PRIS, 2019

In the year to 1 July 2019, NRC issued 20-year license renewals for four nuclear plants (five reactors): Indian Point-2 and -3[395], River Bend-1[396], Waterford-3[397], and Seabrook-1[398]. Utility owners of two nuclear plants submitted applications for subsequent license renewal, which, if granted, could see the reactors operate for an additional 20 years beyond their current sixty-year license. Exelon Generation Company, LLC (Exelon), applied to the NRC on 10 July 2018 for subsequent license renewal for Peach Bottom-2 and -3.[399] These reactors, both connected to the grid in 1974, are General Electric MK1 BWRs.

The subsequent license request for Peach Bottom -2 and -3 is being contested by the organization Beyond Nuclear.[400] In evidence seeking a review by the Atomic Safety Licensing Board (ASLB), expert witness Dave Lochbaum contends that Exelon in its application to the NRC had failed to address how operating experience will be applied during the 60–80-year period of operation of

395 - NRC, "Indian Point Nuclear Generating Unit Nos. 2 and 3 - License Renewal Application", 17 September 2018, see https://www.nrc.gov/reactors/operating/licensing/renewal/applications/indian-point.html#application, accessed 10 May 2019.

396 - NRC, "River Bend Nuclear Generating Station, Unit 1 – License Renewal Application", 20 December 2018, see https://www.nrc.gov/reactors/operating/licensing/renewal/applications/river-bend.html, accessed 10 May 2019.

397 - NRC, "Waterford Steam Electric Station, Unit 3 – License Renewal Application", 27 December 2018, see https://www.nrc.gov/reactors/operating/licensing/renewal/applications/waterford.html, accessed 10 May 2019.

398 - NRC, "Seabrook Station, Unit 1 – License Renewal Application", 12 March 2019, see https://www.nrc.gov/reactors/operating/licensing/renewal/applications/seabrook.html, accessed 10 May 2019.

399 - NRC, "Subsequent License Renewal Application: Peach Bottom Atomic Power Station Units 2 and 3— The Second License Renewal Application", Facility Operating License Nos. DPR-44 and DPR-56, 10 July 2018, see https://www.nrc.gov/docs/ML1819/ML18193A773.pdf, accessed 10 May 2019.

400 - NRC, "U.S.NRC Before The Atomic Safety And Licensing Board—In the Matter of Exelon Generation Company, LLC Peach Bottom Atomic Power Station, Units 2 & 3—Beyond Nuclear, Inc.'s Amended Hearing Request And Petition To Intervene", Docket Nos. 50-277/278 SLR, 1 May 2019, see https://www.nrc.gov/docs/ML1912/ML19121A453.pdf; and Lindsay C. VanAsdalan, "Activists challenge license extension for Peach Bottom nuclear plant", *York Dispatch*, 6 March 2019, see https://eu.yorkdispatch.com/story/news/2019/03/05/activists-challenge-license-extension-peach-bottom-nuclear-plant/3060252002/, both accessed 12 July 2019.

Peach Bottom-2 and -3. This is despite the fact that "[a]bundant evidence also speaks to gaps, deficiencies, and uncertainties in present understanding of aging degradation mechanisms." [401]

In October 2018, Dominion Energy Virginia submitted its Subsequent License Renewal application for the Surry Power Station 1 and 2, which were connected to the grid in March 1972 and March 1973 respectively.[402] The NRC is now reviewing six reactors for 60–80-year operation, following the application for the Turkey Point-3 and -4 reactors in May 2018.[403] The NRC is planning to issue a final decision on the Turkey Point reactors in October 2019.[404] In July 2017, the NRC published a final document describing "aging management programs" that might allow the NRC to grant nuclear power plants operating licenses for "up to 80 years".[405]

As of 1 July 2019, 89 of the 97 operating U.S. units had received a license extension.[406] However, experience shows that many reactors are closing long before their license expires.

Reactor Closures

On 17 September 2018, the oldest reactor in the U.S. fleet, the 650 MW **Oyster Creek** reactor in New Jersey, entered permanent closure. Exelon, the owner of the 49-year-old BWR GE MK1 connected to the grid on 23 September 1969, had confirmed its intention for closure in February 2018.[407] The safety of the reactor had long been under contention from a coalition of NGOs, including evidence of severe corrosion of the reactor containment system that was effectively ignored by the NRC during the reactor's relicensing process in the mid-2000s.[408] The NRC issued 20-year life extension approval for Oyster Creek in August 2009, granting the reactor operation until 2029.

In August 2015, Exelon had announced that Oyster Creek (together with Quad Cities and Three Mile Island) had not cleared the Pennsylvania New Jersey Maryland Interconnection LLC (PJM) capacity auction for the 2018–19 planning year.[409] Exelon announced on 31 July 2018 that Holtec

401 - David A. Lochbaum, "Proposed Subsequent License Renewal of Peach Bottom Units 2 and 3: Exelon's Aging Management Programs Fail to Provide Adequate Measures for Consideration of Operating Experience Throughout the Period of Extended Operation", Report prepared for Beyond Nuclear, 16 November 2018; attached to "Declaration of David A. Lochbaum—In the Matter of Exelon Generation Co., L.L.C., Peach Bottom Atomic Power Station, Units 2 & 3", Docket Nos. 50-277/278 SLR, U.S.NRC before the Secretary, 16 November 2018, see http://static1.1.sqspcdn.com/static/f/356082/28029077/1542673242727/PB-SLR_11192018_Attachments+to+Hearing+Request.pdf?token=6dfkmNSlZgmM33rZ%2Fx%2FV4Bp3%2FWk%3D, 12 July 2019.

402 - NRC, "Surry Power Station Units 1 and 2 Application for Subsequent License Renewal", 15 October 2018, see https://www.nrc.gov/docs/ML1829/ML18291A828.pdf, accessed 10 May 2019.

403 - NRC, "South Texas Project, Units 1 and 2 – License Renewal Application", Updated 28 September 2017, see https://www.nrc.gov/reactors/operating/licensing/renewal/applications/south-texas-project.html, accessed 10 May 2019.

404 - NRC, "Turkey Point Nuclear Plant, Units 3 & 4 – Subsequent License Renewal Application", see https://www.nrc.gov/reactors/operating/licensing/renewal/applications/turkey-point-subsequent.html, accessed 11 May 2019.

405 - Office of Nuclear Reactor Regulation, "Generic Aging Lessons Learned for Subsequent License Renewal (GALL-SLR) Report", U.S.NRC, Final Report, NUREG-2191, Vol. 2, July 2017, see https://www.nrc.gov/docs/ML1718/ML17187A204.pdf, accessed 10 May 2019.

406 - NRC, "Status of Initial License Renewal Applications and Industry Initiatives", Updated 13 March 2019, see https://www.nrc.gov/reactors/operating/licensing/renewal/applications.html, accessed 12 May 2019.

407 - Exelon Corporation, "Oyster Creek Generating Station Retires from Service", 17 September 2018, see https://www.exeloncorp.com/newsroom/oyster-creek-retires, accessed 12 May 2019.

408 - Richard Webster, "Urgent - concern regarding current safety at Oyster Creek Nuclear Power", Rutgers Environmental Law Clinic, School of Law (Newark), Letter to the U.S.NRC on behalf of the citizen coalition Stop the Relicensing of Oyster Creek (STROC), 7 November 2006, Docket No. 50-219-LR, see https://www.nrc.gov/docs/ML0631/ML063120572.pdf, accessed 12 May 2019.

409 - Exelon Corporation, "Exelon Announces Outcome of 2018-19 PJM Capacity Auction", *Business Wire*, 24 August 2015, see http://www.businesswire.com/news/home/20150824005330/en/Exelon-Announces-Outcome-2018-19-PJM-Capacity-Auction, accessed 12 May 2019.

International was interested in the purchase of the Oyster Creek reactor.[410] The NRC approved the sale to Holtec on 20 June 2019.[411] As WNISR 2018 reported, this model of transferring ownership was already adopted by the utility Entergy for its Zion plant in Illinois (with ownership transferred to EnergySolutions). These developments are problematic as limited-liability companies are only financially liable—in the case of an accident or other legal dispute—up to the value of their assets. Therefore, if the decommissioning funds are exhausted, such a third-party company could declare bankruptcy, leaving the bill for the taxpayer.[412]

On 31 May 2019, Entergy permanently closed its 47-year old GE MK1 **Pilgrim** reactor. The 668 MW unit was connected to the grid on 19 July 1972.[413] Senator Ed Markey described the plant as having "one of the worst safety records of any nuclear facility in the country".[414] The reactor remained embroiled in safety concerns, not least after four emergency shutdowns (SCRAMs) between 2013–15.[415] Long-standing opponents of the plant had challenged Entergy's application for a 20-year license extension, which was granted by the NRC in 2012, though opposed by then NRC Chair Gregory Jazcko, and which permitted the reactor to operate until 2032.[416] Only three years after being granted lifetime extension, Entergy was facing mounting costs, including for safety retrofits, which the utility was reluctant to invest in. These difficulties, combined with loss of competitiveness in the electricity market, led Entergy in 2015 to announce that Pilgrim was "simply no longer financially viable" and would be closed on 31 May 2019.[417]

In November 2018, Entergy filed notice with the NRC for the sale of the Pilgrim reactor to Holtec International. Holtec would take ownership after closure, justified by the utility on the grounds that Holtec would "complete decommissioning and site restoration decades sooner than if Entergy completed decommissioning".[418]

410 - Exelon, "Holtec International to Purchase Oyster Creek Generating Station, Decommission Nuclear Plant within Eight Years", Press Release, 31 July 2018, see https://www.exeloncorp.com/newsroom/Documents/Press-Release-Holtec%20International%20to%20Purchase%20Oyster%20Creek%20Generating%20Station,%20Decommission%20Nuclear%20Plant%20within%20_3846.pdf#search=holtec, accessed 12 May 2019.

411 - Holtec International, "NRC Approves Oyster Creek License Transfer to Holtec for Decommissioning", 20 June 2019, see https://holtecinternational.com/2019/06/20/nrc-approves-oyster-creek-license-transfer-to-holtec-for-decommissioning/, accessed 12 July 2019.

412 - D. Schlissel, et. al., "Financial Insecurity: The Increasing Use of Limited Liability Companies and Multi-Tiered Holding Companies to Own Nuclear Power Plants", STAR Foundation Riverkeeper, 2002.

413 - Entergy, "Pilgrim Nuclear Power Station Shut Down Permanently", 31 May 2019, see https://www.entergynewsroom.com/news/pilgrim-nuclear-power-station-shut-down-permanently/, accessed 1 June 2019.

414 - Kathryn Miles, "Pilgrim nuclear plant due to close in two years, but safety concerns linger", *Boston Globe*, 25 August 2017, see https://www.bostonglobe.com/magazine/2017/08/22/pilgrim-nuclear-plant-due-close-two-years-but-safety-concerns-linger/JB5u9wtKekShHNgHKQouxO/story.html, accessed 12 May 2019.

415 - Ibidem.

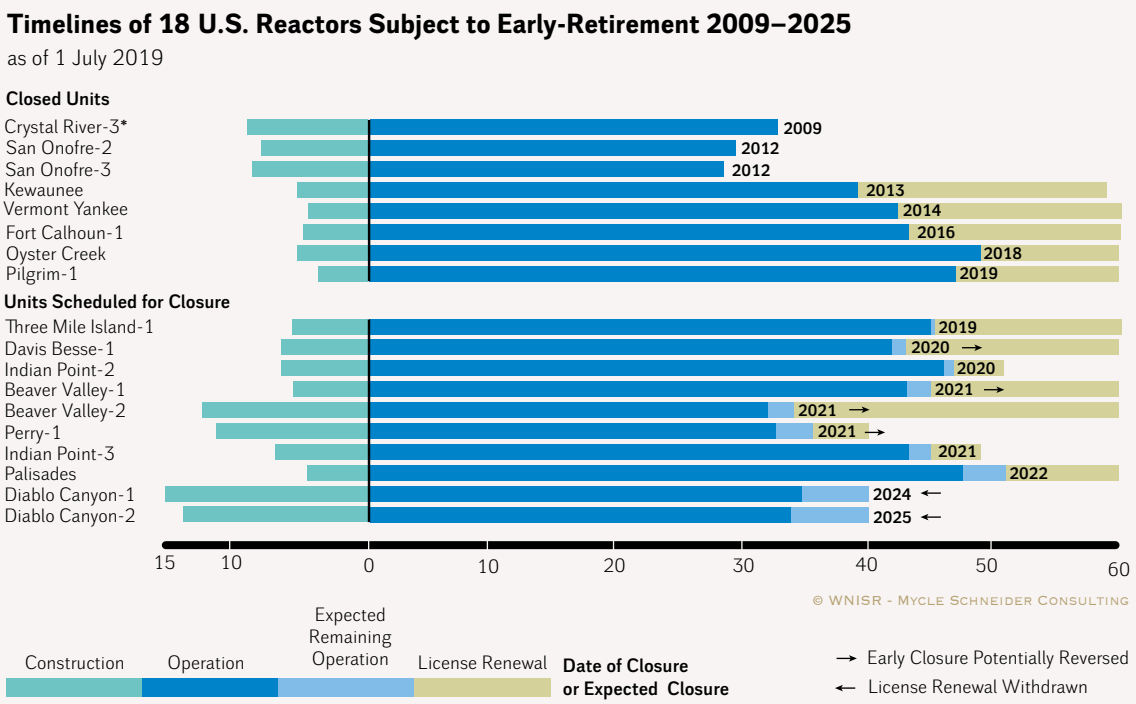
416 - Entergy, "Entergy's Pilgrim Nuclear Power Station Gets New 20-Year License NRC Finds Plant Safe; Renewal Preserves 650 Jobs, $135 million in Economic Impact", 25 May 2012, see http://www.pilgrimpower.com/newsroom/press-releases/Entergy-s-Pilgrim-Nuclear-Power-Station-Gets-New-20-Year-License.html, accessed 12 May 2019.

417 - Jim Ostroff, William Freebairn, "Entergy to shut Pilgrim nuclear power plant as early as 2017", *S&P Global, Platts*, 13 October 2015, see https://www.platts.ru/latest-news/electric-power/washington/entergy-to-shut-pilgrim-nuclear-power-plant-as-21284265, accessed 12 May 2019. For comprehensive history of the Pilgrim reactor, safety issues and citizens interventions over the decades see Mary Lampert, "Pilgrim Nuclear Power Station Plymouth, Massachusetts—Citizen Handbook", Director, Pilgrim Watch, see http://pilgrimwatch.org/wp-content/uploads/PilgrimHandbook20181106.pdf, accessed 12 May 2019.

418 - Entergy, "Holtec Files Request to Acquire Pilgrim Nuclear Power Station by End of 2019, Complete Decommissioning Decades Sooner than Entergy", 16 November 2018, see http://www.pilgrimpower.com/holtec-files-request-to-acquire-pilgrim-nuclear-power-station-by-end-of-2019-complete-decommissioning-decades-sooner-than-entergy/, accessed 12 May 2019.

Exelon Generation announced on 8 May 2019 that **Three Mile Island-1** (TMI) will permanently close by 30 September 2019.[419] The 45year old reactor was connected to the grid on 19 June 1974. In 2009, the NRC granted a 20-year license extension to operate until 2034. In August 2015, TMI did not clear the PJM capacity auction for the 2018–19 planning year,[420] and Exelon warned in 2017 that failure to approve subsidies by the Pennsylvania legislature before 1 June 2019 would lead to the reactor's closure.[421] As of 1 July 2019, no such legislation had been passed (see section on Zero Emission Credits (ZECs) hereunder). The decision to finally close nuclear operations at the power plant site came 40 years after TMI-2 suffered a partial core fuel meltdown on 28 March 1979. (See **Table 8** and **Figure 33**).

Figure 33 | Timelines of Early Retirement in the United States



Sources: Various, compiled by WNISR, 2019

419 - Exelon Generation, "Three Mile Island Unit 1 To Shut Down By September 30, 2019", Press Release, 8 May 2019, see https://www.exeloncorp.com/newsroom/Pages/Three-Mile-Island-Unit-1-To-Shut-Down-By-September-30,-2019.aspx, accessed 13 May 2019.

420 - Sonal Patel, "Two Exelon Nuclear Plants Fail to Clear PJM Auction", *POWER*, 25 May 2016, see http://www.powermag.com/two-exelon-nuclear-plants-fail-to-clear-pjm-auction/, accessed 23 May 2017.

421 - Michael Brooks, "Exelon to Close Three Mile Island", *RTO Insider*, 10 May 2019, see https://rtoinsider.com/exelon-to-close-three-mile-island-115980/; and Jacey Fortin, "Three Mile Island Nuclear Power Plant Is Shutting Down", *New York Times*, 8 May 2019, see https://www.nytimes.com/2019/05/08/us/three-mile-island-shut-down.html, both accessed 28 May 2019.

Table 8 | Early-Retirements for U.S. Reactors 2009-2025

Reactor	Owner	Decision Date	Closure/Expected Closure Date (last electricity generation)	Age at Closure (in years)	NRC 60-Year License Approval
Oyster Creek	Exelon	8 December 2010	December 2019 brought forward to 17 September 2018	49	Yes
Crystal River-3	Duke Energy	5 February 2013	26 September 2009	32	Application withdrawn
San Onofre-2 & -3	SCE/SDG&E	7 June 2013	January 2012	29 / 28	No application
Kewaunee	Dominion Energy	22 October 2012	7 May 2013	39	Yes
Vermont Yankee	Entergy	28 August 2013	29 December 2014	42	Yes
Pilgrim	Entergy	13 October 2015	31 May 2019	47	Yes
Diablo Canyon -1 & -2	PG&E	21 June 2016	November 2024 & August 2025	40	Suspended
Fort Calhoun	OPPD	26 August 2016	24 October 2016	43	Yes
Palisades	Entergy	8 December 2016/ 28 September 2017	2022	51	Yes
Indian Point-2 & -3	Entergy	9 January 2017	No later than 30 April 2020 / 30 April 2021	47 / 44	Yes
Three Mile Island-1	Exelon	30 May 2017	September 2019	45	Yes
Beaver Valley-1 & -2	First Energy	March 2018	2021[a]	45/34	Yes
Davis Besse-1	First Energy	March 2018	2020[a]	43	Yes
Perry	First Energy	March 2018	2021[a]	35.5	Cancelled[b]

Sources: Various, compiled by WNISR, 2019

Notes

a - Early closure potentially reversed – see Table 9.

b – According to the NRC, FENOC indicated that with the planned closure of Perry they no longer plan to submit a license renewal application[422].

SCE: Southern California Edison; **SDG&E**: San Diego Gas & Electric; **PG&E**: Pacific Gas & Electric Company; **OPPD**: Omaha Public Power District

422 - NRC, "Status of Initial License Renewal Applications and Industry Initiatives", Updated 13 March 2019, see https://www.nrc.gov/reactors/operating/licensing/renewal/applications.html, accessed 27 August 2019.

New Reactor Construction

"If we were deciding today, I don't think we would decide to build these units (at Plant Vogtle) because natural gas and solar are so cheap today."

Tim Echols
Georgia Public Service Commission (PSC)
who voted for completing the Vogtle project in May 2019.[423]

The cancellation of the V.C. Summer reactors means that the only new nuclear plant construction in the United States is Plant Vogtle in Georgia. Construction of Vogtle-3 officially began in March 2013, with Unit 4 following in November 2013.[424] The original project cost approved by the Georgia Public Service Commission (PSC) was US$6.1 billion in 2009, which corresponds to a cost of US$2,350/kW, whereas the 2017 cost estimates of US$23 billion translates to a cost of US$10,000/kW. The revised 2018 estimates in the range of US$28 billion have increased costs to US$11,000/kW.[425] These costs compare with the Massachusetts Institute of Technology (MIT) 2009 assessment of the prospects for new nuclear power based on overnight costs of US$$_{2007}$4,000/kW[426] (US$$_{2018}$4,800). During the past year, further cost increases have been reported. There are differing opinions on completion schedules with the utility expressing confidence that it can meet target dates of November 2021 and November 2022 for Units 3 and 4 respectively. Critics of the Vogtle project had long predicted over the past decade that costs would be much higher, as now confirmed.[427]

As WNISR2018 reported, on 31 August 2017 Southern Company (parent company of majority Vogtle plant owner, Georgia Power) filed its recommendation with the Georgia PSC to continue construction of Vogtle—supported by its other owners Oglethorpe Power Corporation (OPC), Municipal Electric Authority of Georgia (MEAG) and Dalton Utilities.[428] In addition to continuation of the project, Georgia Power reported that it had also reviewed the options of cancellation of Unit 4, as well as cancellation of both units. The recommendation was based on the results of a comprehensive schedule, cost-to-complete and cancellation assessment, according to Southern Company. The President of Georgia Power stated that "Completing the

423 - Dave Fessler, "Solar power gets cheaper, more popular in Georgia", *Times Free Press*, 21 May 2019, see https://www.timesfreepress.com/news/breakingnews/story/2019/may/21/solar-power-gets-cheaper-more-popular-georgia/495053/, accessed 28 May 2019.

424 - WNISR, "Construction Start on US Vogtle Unit 4", 25 November 2013, see https://www.worldnuclearreport.org/Construction-Start-on-US-Vogtle.html, accessed 28 May 2019.

425 - Liam Denning, "Nuclear Power's Big Problem Isn't That It's Nuclear", *Bloomberg*, 27 September 2018, see https://www.bloomberg.com/opinion/articles/2018-09-27/nuclear-power-s-big-problem-isn-t-that-it-s-nuclear, accessed 28 May 2019.

426 - John M. Deutch, Charles W. Forsberg, et al., "Update of the MIT 2003 Future of Nuclear Power", MIT Energy Initiative, Interdisciplinary Study, Massachusetts Institute of Technology, 2009, see http://web.mit.edu/nuclearpower/pdf/nuclearpower-update2009.pdf, accessed 5 August 2019.

427 - For example, see Michael Marriotte,"MIT Nuke Study Uses Unsupportable Reactor Cost Estimates", Nuclear Information and Resource Service, 16 September 2010, see https://www.commondreams.org/newswire/2010/09/16/mit-nuke-study-uses-unsupportable-reactor-cost-estimates, accessed 23 May 2018; and Travis Madsen et al., "The High Cost of Nuclear Power—Why America Should Choose a Clean Energy Future Over New Nuclear Reactors", Maryland PIRG Foundation, March 2009, see https://www.nirs.org/wp-content/uploads/nukerelapse/calvert/highcostnpower_mdpirg.pdf, accessed 28 May 2019.

428 - Southern Company, "Southern Company subsidiary Georgia Power files recommendation to complete construction of Vogtle nuclear expansion", Press Release, 31 August 2017, see https://www.southerncompany.com/newsroom/2017/aug-2017/georgia-power-vogtle-recommendation.html, accessed 28 May 2019.

Vogtle-3 & 4 expansion will enable us to continue delivering clean, safe, affordable and reliable energy to millions of Georgians, both today and in the future".[429]

As WNISR2018 also reported, in December 2017 the Georgia PSC, following the recommendation from Southern Company, decided to continue to support the project. The Georgia PSC has backed the Plant Vogtle project from the start, including awarding the generous Construction Work In Progress (CWIP), where all construction costs incurred by Georgia Power are passed directly on to the customer. The Georgia Nuclear Energy Financing Act, signed into law in 2009, allows regulated utilities to recover from their customers the financing costs associated with the construction of nuclear generation projects—years before those projects are scheduled to begin producing benefits for ratepayers. As a result of the CWIP legislation, out of Georgia Power's original estimated US$6.1 billion Vogtle costs, US$1.7 billion is financing costs recoverable from the ratepayer. The utility began recovering these financing costs from its customers starting in 2011. For that first year, the rule translates to Georgia Power electric bills' rising by an average of US$3.73 per month. Georgia Power estimated that this monthly charge would escalate so that by 2018, a Georgia Power residential customer using 1,000 kWh per month would have seen his/her bill go up by US$10 per month due to Vogtle-3 and -4. As a result of increased costs of the project and approval by the PSC, ratepayers had already paid US$2 billion to Georgia Power as of November 2017.[430] But given the long timescale of the project, including planned operational life, the actual costs to ratepayers will be much higher. In December 2017, under cross-examination from Georgia Watch, a public interest group, Georgia PSC staff had confirmed that "the nominal life cycle capital cost revenue requirement collected from ratepayers would increase from US$23 billion to US$37 billion..." Georgia Watch's Liz Coyle concluded that "if the Commission adopts the Company's recommendations as filed, the Company profits will increase by 5.2 billion dollars and ratepayers will pay an additional 14 billion dollars."[431]

In early August 2018, Southern Company reported that it had revised its own expenditure for the project from US$7.3 billion to US$8.4 billion, stating that the increase would be absorbed by the company (i.e. its shareholders), not by customers.[432]

As to the construction schedule, in 2017, officially Southern Company gave fuel-loading times as November 2021 for Unit 3 and November 2022 for Unit 4, which compares with an original planned startup date of 2016. However, the operational dates from Southern are at variance with the assessment made by the Georgia PSC in its December 2016 quarterly progress report, which indicated a credible completion date of 2023. Obtained by *E&E News*[433]—one public version, the other classified as "Highly Confidential Trade Secret EPC Information"—the

429 - Ibidem.

430 - Southern Environmental Law Center, "Groups Intervene in Vogtle Cost Proceedings—Georgians Should Not Bear Financial Burden of Georgia Power's Project Mismanagement", Press Release, 6 November 2017, see https://www.southernenvironment.org/news-and-press/press-releases/groups-intervene-in-vogtle-cost-proceedings-georgians-should-not-bear-finan, accessed 28 May 2019.

431 - Gloria Tatum, "Ratepayers, Experts Urge PSC to Cancel Vogtle Nuclear Reactors 3 and 4 (Update 1)", *Atlanta Progressive News*, as published online by Georgia Watch, 19 December 2017, see http://www.georgiawatch.org/ratepayers-experts-urge-psc-to-cancel-vogtle-nuclear-reactors-3-and-4-update-1/, accessed 28 May 2019.

432 - Anastaciah Ondieki, "Vogtle costs to go up by $1.1 billion, Georgia Power says", *The Atlanta Journal-Constitution*, 8 August 2018, see https://www.ajc.com/business/economy/vogtle-costs-billion-georgia-power-says/UABAtyEgToN58ObAgdro8K/, accessed 28 May 2019.

433 - Kristi E. Schwartz, "Evidence mounts that Vogtle project won't start up in 2020", *E&E News*, 8 February 2017, see https://www.eenews.net/energywire/2017/02/08/stories/1060049693, accessed 28 May 2019.

report cast major doubts on the company's estimated completion dates of the Vogtle reactors, with future long-term activities identified by "staff as high risk for delay." Although both versions of the report were heavily redacted, it confirmed that "there have been continued delays" and "that all of the paths to Unit 3 completion are under schedule stress and will likely incur additional delays."[434] The 2023 date itself was highly speculative, and was on the basis of maintaining the 2016 nine-percent annual construction completion-rate, with no further delays, which given the track record of the project must be in serious doubt.

During the past year, Southern Company reported that the completion schedule was on track. On 20 February 2019, Southern Company's CEO Tom Fanning said that "a lot of work ahead of us to sustain this performance, but we are pleased with our progress and are confident that we can meet the schedule approved by regulators."[435] The optimism of the utility contrasts with continuing warnings from Georgia PSC staff. In their November 2018 report to the Georgia PSC, which was an analysis of the "Nineteenth Semi-Annual Vogtle Construction Monitoring Report", they questioned both the credibility of the construction schedule and the risk of further cost increases, noting that "the +21-month schedule is highly unlikely to be achieved" and even the "+29-month schedule is also stressed."[436] In terms of costs, the Georgia PSC staff noted that at "the monthly spending rate, currently $200 million per month (100 %) on the Project, the cost consequences of Project delay could be severe depending on the duration of the delay." Staff concluded that "at this time the status of the Project is uncertain,"[437] with major uncertainties whether the target date of Hot Functional Tests scheduled for Unit 3 on 31 March 2020 can be achieved. Fuel loading is scheduled for 14 October 2020.

According to a media write-up,[438] during December 2018 hearings on the latest assessment from Southern, expert testimony warned that the cost to ratepayers will be nearly "US$4 billion in financing costs and income tax expenses upon completion. That figure is likely to increase and affect ratepayers who have financed the project since construction began in 2011"; with experts warning that "a delay of more than eight months may deem the project, now about 71 percent complete, 'uneconomic to continue.'"[439]

At the February 2019 session of the Georgia PSC, regulators approved a further US$526.4 million in costs for the Vogtle plant to be paid for by Georgia ratepayers.[440]

As reported in WNISR2018, on 13 February 2018 a coalition of groups filed in Fulton County Superior Court a complaint challenging the Georgia PSC decision, declaring that it was

434 - Georgia PSC, "Vogtle 3 and 4 Nuclear Project Monthly Report—Public Disclosure", December 2016, see https://www.eenews.net/assets/2017/02/08/document_ew_02.pdf, accessed 28 May 2019.

435 - *NW*, "Vogtle expansion project productivity increases, executives say", 28 February 2019.

436 - Georgia PSC, "Public Disclosure—Direct Testimony And Exhibits Of Steven D. Roetger and William R. Jacobs, Jr., PhD.—On Behalf Of The Georgia Public Service Commission Public Interest Advocacy Staff—In The Matter Of Georgia Power Company's Nineteenth Semi-Annual Vogtle Construction Monitoring Report", Testimony Before The Georgia Public Service Commission, Docket No. 29849, 30 November 2018, see https://coschedule.s3.amazonaws.com/88545/0065fd85-52df-4714-916c-88da7d3bcfca/29849%2019VCM%20Roetger-Jacobs-PD.PDF, accessed 28 May 2019.

437 - Ibidem.

438 - Anastaciah Ondieki, "PSC staff concerned more project delays ahead for Vogtle nuclear plant", *The Atlanta Journal-Constitution*, 23 December 2018, see https://www.ajc.com/business/economy/psc-staff-concerned-more-project-delays-ahead-for-vogtle-nuclear-plant/jrKjH9KmdOseU1zEqaKrmI/, accessed 28 May 2019.

439 - Ibidem.

440 - Darrell Proctor, "Georgia PSC Backs Additional Costs for Vogtle Nuclear Project", *POWER*, 19 February 2019, see https://www.powermag.com/georgia-psc-backs-additional-costs-for-vogtle-nuclear-project/, accessed 12 July 2019.

unlawful, violating the PSC's own guidelines and Georgia state law.[441] The coalition contended that new investments in solar power and energy efficiency would be less risky, more affordable, and more than up to the job of powering Georgia's economy. On 21 December 2018, the court found that dissatisfied customers cannot raise concerns about the unfairness of Goergia PSC process "until 2022 or later, after the project is complete."[442] "The court dismissed the appeal on technical grounds without addressing its substance," attorney Kurt Ebersbach of Southern Environmental Law Center (SELC) stated.[443] "The people of Georgia have been pre-paying for this mismanaged project since 2011, while the price tag has ballooned and the project timeline has slipped again and again," Liz Coyle, executive director of Georgia Watch, said. "Unless the court reverses the commission's decision, Georgia Power customers remain exposed to significant financial risk with seemingly no end in sight."[444] The groups are planning to challenge the court decision.

Under the financing terms agreed with the Georgia PSC, the longer the Vogtle plant takes to construct, the higher its costs, which have invariably been passed on to Georgia ratepayers, resulting in higher income streams for Georgia Power and therefore Southern. In reporting 2018 Southern earnings, CEO Thomas A. Fanning stated that, "2018 was a banner year for Southern Company (...) All of our state-regulated electric and gas companies delivered strong performance." Full-year 2018 earnings were US$2.23 billion, compared with earnings of US$842 million in 2017.[445]

The Vogtle plant construction has faced ongoing legal challenges since approval for construction in 2009. On 19 February 2019, the Fulton County Superior Court in Georgia granted class-action status to a lawsuit challenging charges Georgia Power Co. collects from customers each month related to Vogtle construction. The lawsuit, originally filed in 2011,[446] charges Georgia Power with artificially raising municipal franchisee fees. "This is a good day for electric power customers in Georgia. For the first time in over seven years, a court has authorized plaintiffs to move forward as a group representing all two million-plus ratepayers", said the plaintiffs' lawyer and former speaker of the state House of Representatives, Glenn Richardson.[447]

In a separate lawsuit, on 18 June 2019, the Georgia Court of Appeals heard arguments about whether the 2017 Georgia PSC decision to continue the construction of Vogtle broke regulatory

441 - Dave Williams, "Plant Vogtle opponents appeal vote to complete nuclear project", *Atlanta Business Chronicle*, 12 February 2018, see https://www.bizjournals.com/atlanta/news/2018/02/12/plant-vogtle-opponents-appeal-vote-to-complete.html, accessed 28 May 2019.

442 - *Albany Herald*, "Groups Challenge Court Decision Regarding Plant Vogtle Over Cost Concerns", as published by Georgia Watch, 10 January 2019, see https://www.georgiawatch.org/groups-challenge-court-decision-regarding-plant-vogtle-over-cost-concerns/, accessed 28 May 2019.

443 - Ibidem. The coalition consists of Partnership for Southern Equity, Georgia Interfaith Power and Light, and Georgia Watch.

444 - Ibidem.

445 - Southern Company, "Southern Company reports fourth-quarter and full-year 2018 earnings", *PR Newswire*, 20 February 2019, see https://www.prnewswire.com/news-releases/southern-company-reports-fourth-quarter-and-full-year-2018-earnings-300798574.html, accessed 28 May 2019.

446 - Kristi E. Swartz, "Lawsuit challenging sales tax on Georgia Power's nuclear fee to move forward", *The Atlanta Journal-Constitution*, 29 March 2012, see https://www.ajc.com/business/lawsuit-challenging-sales-tax-georgia-power-nuclear-fee-move-foward/ehbVuRgOy7SJgYM5uWnsIO/, accessed 12 July 2019.

447 - Dave Williams, "Lawsuit aimed at Plant Vogtle charges gains class-action status", *Atlanta Business Chronicle*, 19 February 2019, see https://www.bizjournals.com/atlanta/news/2019/02/19/lawsuit-aimed-at-plant-vogtle-gains-class-action.html, accessed 12 July 2019.

rules.[448] The coalition of citizens' organizations challenging the Georgia PSC, including Georgia Watch and Georgia Interfaith Power and Light, filed the appeal after their case was dismissed on technical grounds in December 2018.[449] They contend that the 2017 decision approving the completion of the Vogtle reactors should have been subject to judicial review.[450] Under Georgia PSC guidelines, commissioners are not required to judge whether costs are prudent until after the plant is complete, when retroactive prudency hearings are held. Only then advocates are allowed to challenge expenses. As the lawyer representing the plaintiffs states, "And that's their [Georgia Power's] argument: 'Wait until we build it.' But if you wait 'til you build it, you can't go back and say, was it right to continue? It's moot at that point. They're taking away one of the powerful arguments to hold the company accountable, which is whether or not the additional expenses are reasonable. And that matters. Because it shifts the burden of proof."[451] Georgia Power's attorney stated that "It's not a question of whether they can seek judicial review. It's a question of when."[452] A decision by the court is expected by the end of 2019.

Vogtle Federal Loan Guarantees

Under the terms of the Department of Energy (DOE) Loan Guarantee Program, owners of nuclear projects are able to borrow at below-market Federal Financing Bank rates with the repayment assurance of the U.S. Government. DOE loan guarantees permitted Vogtle's owners to finance a substantial portion of their construction costs at interest rates well below market rates, and to increase their debt fraction, which significantly reduced overall financing costs. In justification for the loan guarantee to Vogtle, the Obama administration stated in 2010 that

> the Vogtle project represents an important advance in nuclear technology, other innovative nuclear projects may be unable to obtain full commercial financing due to the perceived risks associated with technology that has never been deployed at commercial scale in the U.S. The loan guarantees from this draft solicitation would support advanced nuclear energy technologies that will catalyze the deployment of future projects that replicate or extend a technological innovation.[453]

The loan guarantee program has therefore played a critical role in permitting the Vogtle project to proceed but has failed to catalyze a nuclear revival, with no prospects of further new nuclear plants being built in the U.S. in the coming decades. Oglethorpe Power Corporation (OPC), which has a 30 percent stake in Vogtle, confirmed in August 2017 that it had submitted a request to DOE for up to US$1.6 billion in additional loan guarantees. The company already had a US$3 billion loan guarantee from DOE. The other owners, Georgia Power and Municipal

448 - Emma Hurt, "Appeals Court Hears Argument On Nuclear Plant Decision", *WABE*, 18 June 2019, see https://www.wabe.org/appeals-court-hears-argument-on-nuclear-plant-decision/, accessed 12 July 2019.

449 - Fulton County Superior Court, "Georgia Interfaith Power & Light et al v. Georgia Public Service Commission, et al.—Civil Action File No. 2018CV301128", and "Georgia Watch v. Georgia Public Service Commission, et al.—Civil Action File No. 2018CV302152", 9 January 2019, see https://www.georgiawatch.org/wp-content/uploads/2019/01/Notice-of-Appeal-Fulton-Co-Sup-Ct-1.pdf, accessed 12 July 2019.

450 - Mycle Schneider, Antony Froggatt, et al., "WNISR2018", 4 September 2018.

451 - Emma Hurt, "Appeals Court Hears Argument On Nuclear Plant Decision", *WABE*, 18 June 2019.

452 - Ibidem.

453 - Peter W. Davidson, "Fostering the Next Generation of Nuclear Energy Technology—Investing in American Energy", Loan Programs Office, U.S.DOE, 29 September 2014, see https://energy.gov/lpo/articles/fostering-next-generation-nuclear-energy-technology, accessed 28 May 2019.

Electric Authority of Georgia (MEAG), have secured US$8.3 billion in separate loan guarantees from DOE since 2010, when they were approved by the Obama administration. Both of these companies confirmed in August 2017 that they were seeking additional loan guarantee funding.

On 29 September 2017, DOE Secretary Perry announced approval of additional US$3.7 billion loan guarantees for the Vogtle owners, with US$1.67 billion to Georgia Power, US$1.6 billion to OPC, and US$415 million to MEAG.[454] A decision on terminating the Vogtle project would raise the prospect of repayment of the previous US$8.3 billion loan to Southern.[455]

In April 2019, the DOE provided a further loan guarantee of US$3.7 billion to Plant Vogtle construction, only the second loan guarantee issued under the Trump administration and the second to Plant Vogtle.[456] This brings the total loan guarantees provided for the Vogtle project by the DOE to US$12.03 billion.[457]

Ongoing Fallout from Termination of V.C. Summer Project

As in WNISR2018, the decision on 31 July 2017 by Santee Cooper and SCANA Corporation (the parent company of South Carolina Electric & Gas or SCG&E) to terminate construction of the V. C. Summer project during the past year has seen ongoing financial and legal fallout for the companies and ratepayers of South Carolina.

On 24 November 2018, SCANA and SCG&E agreed to a US$2 billion settlement to resolve a ratepayer lawsuit over cost recovery for the abandoned V.C. Summer nuclear expansion project.[458] Under the controversial Base Load Review Act (where ratepayers pay during the construction period) there had been nine rate increases that to date have cost ratepayers US$2 billion. Under the agreement, approved by the Georgia PSC on 14 December 2018, while there was to be a reduction of 15 percent in electricity prices, South Carolina's citizens will continue to pay towards the abandoned project for an additional US$2.26 billion over the next 20 years.[459] The decision of Georgia PSC was part of an overall settlement whereby SCANA would be taken over by Dominion Energy; the utility had threatened to walk away from its SCANA takeover if the Georgia PSC were to approve higher rate cuts.[460] Critics of the agreement estimated that total costs to ratepayers will amount to US$5 billion.[461] When

454 - U.S.DOE, "Secretary Perry Announces Conditional Commitment to Support Continued Construction of Vogtle Advanced Nuclear Energy Project", 29 September 2017, see https://www.energy.gov/articles/secretary-perry-announces-conditional-commitment-support-continued-construction-vogtle, accessed 28 May 2019.

455 - Peter Maloney, "Westinghouse bankruptcy puts $8.3B in federal loan guarantees for Vogtle plant at risk", *Utility Dive*, 3 April 2017, see http://www.utilitydive.com/news/westinghouse-bankruptcy-puts-83b-in-federal-loan-guarantees-for-vogtle-pl/439508/, accessed 28 May 2019.

456 - Jacqueline Toth, "DOE Program's $3.7 Billion Loan Highlights Lack of Action on Other $40 Billion It Holds", *Morning Consult*, 8 April 2019, see https://morningconsult.com/2019/04/08/doe-programs-3-7-billion-loan-highlights-lack-of-action-on-other-40-billion-it-holds/, accessed 10 May 2019.

457 - Taxpayers for Common Sense, "DOE Loan Guarantee Program: Vogtle Reactors 3 & 4", 21 March 2019, see https://www.taxpayer.net/wp-content/uploads/2019/03/3-21-19-ENR-Vogtle-Fact-Sheet_MARCH-2019_-v.4.pdf, accessed 10 May 2019.

458 - *NW*, "SCANA, SCE&G reach settlement on Summer project", 29 November 2018.

459 - Tom Barton, "Dominion-SCANA merger mixed bag for ratepayers. What it means for SC power bills", *The State*, 14 December 2018, see https://www.thestate.com/news/politics-government/article223058755.html, accessed 26 May 2019.

460 - Ibidem.

461 - Gwendolyn Glenn, "Consumer Advocate Calls SCANA Deal A 'Bad Deal For Consumers'", *WFAE*, 20 December 2018, see https://www.wfae.org/post/consumer-advocate-calls-scana-deal-bad-deal-consumers#stream/0, accessed 26 May 2019.

V.C. Summer was cancelled in 2017 total costs for completion of the two AP-1000 reactors was projected to exceed US$25 billion—a 75 percent increase over initial estimates.[462]

Meanwhile, legal action against SCANA continues in 2019, including a civil fraud lawsuit that will proceed to jury trial,[463] with a ratepayers' lawyer telling the federal court judge: "The bottom line is they (SCANA executives) lied to everyone, and they did it intentionally."[464] It is known that since 2017 the Federal Bureau of Investigations (FBI) and the U.S. Attorney's office of South Carolina have been conducting an investigation into alleged criminal fraud by former SCANA top officials.[465]

The cancellation of the V.C. Summer project adds to the history of 40 other stranded nuclear reactor projects in the United States whose construction started in the 1970s and which were abandoned between 1977 and 1989, as can be seen from the WNISR's Global Nuclear Power Database.[466]

Securing Subsidies to Prevent Closures

"This is the only industry known where when you're not doing well you don't go to shareholders and have them pay and suffer the losses, you go to the ratepayers and make them pay. This is a bailout for aging and obsolete technology."

Ohio State Senator Sean O'Brien
May 2019 [467]

Utilities have been actively lobbying for state legislation and contracts that would provide significant financial support for their reactor operations (for details see WNISR2018—Annex 4). In addition to legislation that has been enacted in New York and Illinois, new policies have been implemented in Connecticut and New Jersey, while efforts are ongoing to secure funding mechanisms continue in Pennsylvania and Ohio. Central to the future of nuclear power in the Pennsylvania-New Jersey-Maryland Interconnection LLC (PJM) wholesale electricity market are the rules expected to be proposed by the Federal Energy Regulatory Commission (FERC).[468] PJM is a Regional Transmission Organization (RTO) that coordinates the wholesale electricity market in all or parts of Delaware, Illinois, Indiana, Kentucky, Maryland, Michigan, New Jersey,

462 - Robert Walton, "SCANA agrees to settle $2B class action suit over nuclear costs", *Utility Dive*, 26 November 2018, see https://www.utilitydive.com/news/scana-agrees-to-settle-2b-class-action-suit-over-nuclear-costs/542911/, accessed 26 May 2019.

463 - John Monk, "Former SCANA executives must face civil fraud charges in federal court, judge rules", *The Charlotte Observer*, 1 April 2019, see https://www.charlotteobserver.com/news/state/south-carolina/article228693009.html, accessed 27 May 2019.

464 - John Monk, "Lawyer: Ex-SCANA officials 'whitewashed,' lied about defects at failed nuclear plant", *The* State, 4 March 2019, see https://www.thestate.com/news/local/crime/article227087214.html, accessed 27 May 2019.

465 - Russell Grantham, "Feds investigating Plant Vogtle nuke project's twin in South Carolina", *The Atlanta Journal-Constitution*, 21 September 2017, see https://www.ajc.com/business/feds-investigating-plant-vogtle-nuke-project-twin-south-carolina/a7k2OsiAOiTeGrAqMCKAaN/, accessed 12 July 2019.

466 - WNISR/Visionscarto/*Bulletin of the Atomic Scientists*, "Global Nuclear Power Database", 2017, see http://thebulletin.org/global-nuclear-power-database, accessed 27 May 2019.

467 - *21 WFMJ*, "House Bill 6 - clean air or multi-million dollar bailout paid by energy customers?", 21 May 2019, see http://www.wfmj.com/story/40506111/house-bill-6-clean-air-or-multi-million-dollar-bailout-paid-by-energy-customers, accessed 28 May 2019.

468 - The Federal Energy Regulatory Commission, or FERC, is an independent agency that regulates the interstate transmission of natural gas, oil, and electricity. FERC also regulates natural gas and hydropower projects.

North Carolina, Ohio, Pennsylvania, Tennessee, Virginia, West Virginia and the District of Columbia. In June 2018, FERC invalidated the PJM market rules.[469] The FERC order relates to how the PJM sets the price of capacity it procures through its capacity market, known as the Reliability Pricing Model (RPM). As state subsidies, including Zero Emission Credits or ZECs, have evolved from small-scale renewables to thousands of megawatts from larger nuclear units, FERC noted: "With each such subsidy, the market becomes less grounded in fundamental principles of supply and demand."[470] The next PJM capacity market auction will take place in August 2019.[471] As of 1 July 2019 the rule changes from FERC have not been issued. They will affect how state subsidies, including ZECs, will be considered in the wholesale market. At issue is whether the subsidies being received by utilities for their nuclear plants will be factored into the capacity auction pricing. The PJM stated that pending new rules from FERC it will hold the August auction under current rules.[472]

As a result of securing financial support for reactors, it is likely that "early closures" of several additional reactors will be cancelled (see **Table 9**).

In December 2018, Dominion secured approval to gain subsidies for its two reactors at Millstone in **Connecticut**. Existing generating capacity in the state, such as the Millstone plant, cannot be credited for its zero-carbon and other environmental attributes unless it is designated by state regulators as being at risk of early closure. Dominion applied for that status for Millstone and received it in early December 2018. Prior to this approval, under the Low and Zero Emissions Renewable Energy Credit Program only renewable energy was eligible. Dominion threatened to close Millstone early unless recognized as a renewable source. In December 2018, Dominion got state approval to purchase just over 50 percent of the Millstone output over a period of ten years but without setting a contract price. The state had passed in November 2017 legislation that secured just under 50 percent of Millstone's output over a ten-year period.

Dominion in early 2019 continued to lobby over pricing[473] and on 15 March 2019, Dominion announced that it had reached agreement with state utilities and therefore would not be closing the Millstone reactors.[474]

469 - Sonal Patel, "FERC Nixes PJM's Fixes for Capacity Market Besieged by Subsidized Resources", *POWER*, 5 July 2018, see https://www.powermag.com/ferc-nixes-pjms-fixes-for-capacity-market-besieged-by-subsidized-resources/?printmode=1, accessed 30 May 2019.

470 - FERC, "Order Rejecting Proposed Tariff Revisions, Granting In Part And Denying In Part Complaint, And Instituting Proceeding Under Section 206 Of The Federal Power Act", Docket Nos. EL16-49-000, issued 29 June 2018, see https://www.ferc.gov/CalendarFiles/20180629212349-EL16-49-000.pdf, accessed 30 May 2019.

471 - Gavin Bade, "PJM won't delay capacity market order despite FERC impasse over rule changes", *Utility Dive*, 11 April 2019, see https://www.utilitydive.com/news/pjm-wont-delay-capacity-market-order-despite-ferc-impasse-over-rule-change/552530/, accessed 30 May 2019.

472 - Sonal Patel, "PJM Will Hold Capacity Auction Under Current Rules in August", *POWER*, 10 April 2019, see https://www.powermag.com/pjm-will-hold-capacity-auction-under-current-rules-in-august/, accessed 30 May 2019.

473 - Darren Sweeney, "Dominion Energy says current contract for Millstone nuke not acceptable", *S&P*, 1 February 2019, see https://www.spglobal.com/marketintelligence/en/news-insights/trending/-UEreLMB5A4Eb-60gtr2Ig2, accessed 29 May 2019.

474 - Darrel Proctor, "Dominion Reaches Deal to Keep Millstone Nuclear Plant Open", *POWER*, 17 March 2019, see https://www.powermag.com/dominion-reaches-deal-to-keep-millstone-nuclear-plant-open/, accessed 29 May 2019.

Table 9 | U.S. State Emission Credits for Uneconomic Nuclear Reactors 2016–2019 (as of 1 July 2019)

State	Utility	Reactors	Planned Permanent Closure Date	Status of Permanent Closure Planning	Status of Emissions Credit Legislation	Value	Legal Status
Illinois	Exelon	Clinton-1	June 2017	Cancelled	Illinois Future Energy Jobs Act passed by legislature – June 2016	US$16.50/MWh (US$200 million a year)	ZEC Upheld in Court[a]
		Quad Cities-1 &- 2	June 2018	Cancelled			
Pennsylvania	Exelon	TMI	September 2019	Planned	Legislation not passed as of 1 July 2019	N/A	N/A
	FirstEnergy	Beaver Valley-1 & -2	2021	Uncertain			
New Jersey	PSEG/Exelon	Salem-1 & -2	Threatened by 2019	Likely to be cancelled	Legislature passed – April 2018 (reactors with operating license through 2030 only)	US$300 million a year[b]	Legal challenge filed[c]
	PSEG	Hope Creek	Threatened by 2019	Likely to be cancelled	Eligible		
Connecticut	Dominion	Millstone-2 & -3	Threatened – no date	Cancelled	Senate Zero Carbon Procurement Act approved by Governor November 2017[d]	US$330 million a year	N/A
New York	Exelon	Fitzpatrick	Threatened	Likely to be cancelled	NYPSC Clean Energy Standard ZEC passed in 2016	US$482 million 2018–2019; US$8 billion 2017–2029	N/A
	Entergy	Ginna	Threatened	Likely to be cancelled			
		Nine Mile Point-1	Threatened	Likely to be cancelled			
Ohio	FirstEnergy	Davis Besse	May 2020	To be cancelled[e]	Legislation passed as of 27 July 2019	US$150 million per year	N/A
		Perry	May 2021				

Sources: Various, compiled by WNISR, 2019

Notes

a - See Pamela King, "SUPREME COURT—The fight's not over yet on state nuclear credits", *E&ENews*, 16 April 2019, see https://www.eenews.net/stories/1060166933, accessed 12 July 2019.

b - *RTO Insiders*, "NJ Approves $300M ZECs for Salem, Hope Creek Nukes", 19 April 2019, see https://rtoinsider.com/nj-approves-zecs-nukes-114741/, accessed 15 July 2019.

c - *ProPublica*, "New Jersey's $300 Million Nuclear Power Bailout Is Facing a Court Challenge. Does It Have a Chance?", 16 May 2019, see https://www.propublica.org/article/new-jerseys-300-million-nuclear-power-bailout-is-facing-a-court-challenge-does-it-have-a-chance, accessed 13 July 2019.

d - Robert Walton, "Dominion threatens Millstone closure if plant shut out of support program", *Utility Dive*, 10 July 2018, see https://www.utilitydive.com/news/dominion-threatens-millstone-closure-if-plant-shut-out-of-support-program/527364/, accessed 12 July 2018.

e - FirstEnergy has announced that it will begin the process to rescind the deactivation orders for its Perry and Davis Besse reactors. See FirstEnergy Solutions, "FirstEnergy Solutions Applauds Enactment of HB6 Legislation", 24 July 2019, op. cit.

The Millstone nuclear plant was listed in 2017 as the most profitable in the U.S. through 2019, at US$14/MWh.[475] Yet Dominion used the threat of closure of Millstone as leverage to secure state support. In a 2017 study commissioned by the Stop the Millstone Payout coalition, a group composed of competitive energy companies—NRG, Calpine and Dynegy and the Electric Power Supply Association (EPSA)—challenged Dominion's claims. The study showed that state support for Millstone would cost ratepayers US$330 million per year, translating to a 15–20 percent increase in supply costs.[476]

475 - Geoffrey Haratyk, "Early Nuclear Retirements in Deregulated U.S. Markets: Causes, Implications and Policy Options", Center for Energy and Environmental Policy Research, MIT, March 2017, see https://assets.documentcloud.org/documents/3723775/MIT-Early-Nuclear-Retirement-3-2017.pdf, accessed 29 May 2019.

476 - Stop The Millstone Payout, "Amid New Data, Dominion's Closure Threats Face The $1 Billion Question Administrator", 11 October 2017.

Exelon Generation communicated in February 2019, that its three nuclear plants in **Illinois**, Braidwood, Byron and Dresden were

> ...showing increased signs of economic distress, which could lead to an early retirement, in a market that does not currently compensate them for their unique contribution to grid resiliency and their ability to produce large amounts of energy without carbon and air pollution. The May 2018 PJM capacity auction for the 2021-2022 planning year resulted in the largest volume of nuclear capacity ever not selected in the auction, including all of Dresden, and portions of Byron and Braidwood. Exelon continues to work with stakeholders on state policy solutions, while also advocating for broader market reforms at the regional and federal level.[477]

As noted by *Nucleonics Week* (*NW*), "The company had not previously said publicly that those plants were at risk of early closure."[478]

In January 2018, Exelon had already secured Zero Emissions Credits for its Quad Cities and Clinton reactors, which equates to a cumulative value over the expected life of the ZEC contracts, without any adjustments, of US$3.5 billion.[479] Currently, its Dresden, Byron and Braidwood reactors with an installed capacity of 6.9 GW, are not eligible for ZECs, as the existing support for Quad Cities and Clinton "fill[s] up the scope of the existing ZEC program under Illinois law".[480]

Legal efforts to overturn ZEC contracts in Illinois (and New York) were rejected by the Supreme Court on 14 April 2019.[481] As WNISR2018 reported, the Electric Power Supply Association (EPSA) had filed a complaint in the U.S. District Court of the Northern District of Illinois opposing the proposed ZECs for Exelon, stating that "bailing out uneconomic power plants is a bad deal for Illinois ratepayers, who will see their electric bills go up across the state".[482]

The Supreme Court ruling follows federal appeals court rulings in New York[483] and Illinois[484] during September 2018, which endorsed the constitutional rights of states to establish financing for generators and to regulate electricity prices. By doing so the courts have rejected contentions that support for nuclear power by state legislation (such as ZECs) influences

477 - United States Securities And Exchange Commission, "Annual Report Pursuant To Section 13 Or 15(d) Of The Securities Exchange Act Of 1934 For The Fiscal Year Ended December 31, 2018", Form 10-K, 8 February 2019, see https://otp.investis.com/clients/us/exelon1/SEC/sec-show.aspx?FilingId=13204272&Cik=0001109357&Type=PDF&hasPdf=1, accessed 29 May 2019.

478 - *NW*, "Changes needed to help Illinois plants: Exelon", 28 February 2019.

479 - Illinois Commerce Commission, "Public Notice of Successful Bidders and Average Prices —Illinois Power Agency January 2018 Procurement of Zero Emission Credits from Facilities Fueled by Nuclear Power", 25 January 2018, see https://www.ipa-energyrfp.com/?wpfb_dl=1450, accessed 29 May 2019.

480 - Ibidem.

481 - Barbara Grzincic, "Supreme Court lets New York, Illinois nuclear power subsidies stand", *Reuters*, 14 April 2019, see https://www.reuters.com/article/nuclear-subsidies-lawsuit/supreme-court-lets-new-york-illinois-nuclear-power-subsidies-stand-idUSL1N21X1N8, accessed 30 May 2019.

482 - Keith Goldberg, "Nuke Plant Subsidies Flout FERC, Power Cos. Say", *Law360*, 15 February 2017, see https://www.law360.com/articles/892374/ill-nuke-plant-subsidies-flout-ferc-power-cos-say, accessed 15 May 2017.

483 - U.S. Court of Appeals for the Second Circuit, "Coalition for Competitive Electricity, et al. v. Zibelman, et al.", Case 17-2654, Document 224-1, Decided 27 September 2018, see https://statepowerproject.files.wordpress.com/2018/09/second-circuit-zec-decision.pdf, accessed 30 May 2019.

484 - U.S. Court of Appeals For the Seventh Circuit, "Electric Power Supply Association, et al., Plaintiffs Appellants, v. Anthony M. Star, Director of the Illinois Power Agency, et al., Defendants Appellees", Appeals from the U.S. District Court for the Northern District of Illinois, Eastern Division, Case 17-2433 and 17-2445, Document 151, Argued 3 January 2018, Filed 13 September 2018, see https://statepowerproject.files.wordpress.com/2018/09/7th-circuit-zec-decision.pdf, accessed 30 May 2019.

the prices that result from the wholesale auction system established by the Federal Energy Regulatory Commission (FERC) and therefore distorts the market mechanism for determining which energy generators should close.[485] Lawyers observed that the rulings do not resolve the underlying tensions between state subsidies and wholesale electricity markets.[486]

On 18 April 2019, the **New Jersey** Board of Public Utilities (NJBPU) awarded Zero Emission Certificates (ZECs)[487] to Salem-1 and -2 and Hope Creek reactors.[488] The State Legislature passed the Zero Emissions Certificate Law in May 2018[489], noting the "moral imperative for the State to invest in energy infrastructure that does not produce greenhouse gases."[490] Welcoming the decision, Public Service Enterprise Group (PSEG) stated that, "We are pleased with the decision to award ZECs to PSEG to help support New Jersey's primary supply of zero-carbon electricity. The BPU just saved the people of the State hundreds of millions of dollars in what would have been higher energy costs, thousands of jobs lost and tons of environmentally damaging air emissions."[491] Opposition to the ZEC legislation, including from New Jersey's Ratepayer Advocate and a generators' group in the Pennsylvania-New Jersey-Maryland Interconnection LLC (PJM) market, said there is no evidence three nuclear units in New Jersey need ratepayer subsidies to survive.[492] In testimony to the Board, from State Rate Counsel President Stephanie Brand it was stated that modeling used by the utilities in the subsidy application did not account for the addition of renewable energy resources over the long term or increased energy efficiency requirements: "In short, they skewed the analysis of future revenues in order to deflate those revenues and support their claim 3 of financial distress."[493]

> The data suggests that the ZEC Act would require New Jersey electric distribution companies ("EDC") to collect approximately [US]$300 million per year from New Jersey retail distribution customers based on annual data. This amount would be incremental to charges collected from distribution customers and transmission for other programs. For the three nuclear units, the ZEC Act would result in a [US]$10/MWh revenue adder for each unit's

485 - U.S. Court of Appeals For the Seventh Circuit, Appeals from the U.S. District Court for the Northern District of Illinois, Case 17-2433 and 17-2445, Document 151, Filed 13 September 2018, op. cit.

486 - *NW*, "US Supreme Court declines ZEC ruling review, boosting nuclear subsidies", 18 April 2019.

487 - In other states, ZEC also stands for Zero Emission Credits.

488 - Division of State Energy Services, "In The Matter Of The Implementation Of L. 2018, c. 16 Regarding The Establishment Of A Zero Emission Certificate Program For Eligible Nuclear Power Plants", Before the NJBPU, Application for Zero Emission Certificates of Salem 1, Salem 2 and Hope Creek Nuclear Power Plants, Docket No. EO18080899, and Dockets Nos EO18121337–EO18121339, 18 April 2019, see https://www.bpu.state.nj.us/bpu/pdf/boardorders/2019/20190418/4-18-19-9A.pdf, accessed 29 May 2019.

489 - Peter Key, "NJ Lawmakers Pass Nuke Subsidies, Boosted RPS", *RTO Insider*, 12 April 2018, see https://www.rtoinsider.com/nuclear-subsidies-new-jersey-zec-rps-90356/, accessed 29 May 2019.

490 - -NJBPU, "Citing Urgency of Climate Change, New Jersey Board of Public Utilities Awards ZECs to Preserve Salem One and Two and Hope Creek", Press Release, 18 April 2019, see https://www.nj.gov/bpu/newsroom/2019/approved/20190418.html, accessed 29 May 2019.

491 - PSEG, "PSEG Responds to BPU Decision to Award Zero Emission Certificates (ZECs) to its Nuclear Plants", Press Release, 18 April 2019, see https://nj.pseg.com/newsroom/newsrelease72, accessed 12 July 2019.

492 - NW, "No case for new Jersey nuclear subsidies, state ratepayer advocate says", 7 February 2019.

493 - Anjalee Khemlani, "Rate Counsel president tells BPU: PSEG should not qualify for subsidies", *ROI-NJ*, 4 February 2019, see https://www.roi-nj.com/2019/02/04/uncategorized/rate-counsel-president-tells-bpu-pseg-should-not-qualify-for-subsidies/, accessed 29 May 2019.

> owner if the Board approves the three applications... The ZEC Act allows the Applicants, who are merchant owners, to cover costs—including the cost of capital. [494]

The credits were to be available immediately, which will net approximately US$10/MWh amounting to US$100 million in subsidies per year for each reactor through 2022. The two units at Salem owned by Public Service Enterprise Group (PSEG) subsidiary PSEG Nuclear and 43 percent by Exelon are licensed by the Nuclear Regulatory Commission (NRC) to operate until 2036 and 2040. Hope Creek is licensed to operate until 2046.

For the third time in as many years, FirstEnergy Solutions has sought to secure state financing for its reactors in **Ohio**. Both Davis Besse and Perry reactors are long considered at risk of closure due to economic factors.[495] On 31 March 2018, FirstEnergy Solutions Corp. and six affiliated debtors each filed a voluntary petition for protection under Chapter 11 of the United States Bankruptcy Code in the Bankruptcy Court for the Northern District of Ohio.[496] The company is currently under petition at the NRC due to its failure to secure sufficient decommissioning funds for its three nuclear plants.[497] A 2017-estimate put decommissioning costs for the three nuclear plants at US$5.4 billion, with a current fund level of only US$2.5 billion.[498] In April 2018, First Energy filed official notification with the NRC of its bankruptcy and planned closure of Beaver Valley (Pennsylvania), as well as the two reactors at Davis Besse and Perry in Ohio.[499] First Energy noted: "We are actively seeking policy solutions at the state and federal level as an alternative to retiring these plants, which we believe still have a crucial role to play in the reliability and resilience of our regional grid."[500] but that "short of significant market changes... right now, we have nothing in front of us that allows us to rescind that deactivation notice."[501] FirstEnergy's debts amounted to US$2.8 billion.[502]

494 - Stefanie A. Brand, "In the Matter Of The Implementation Of L. 2018, C.16 Regarding The Establishment Of A Zero Emission Certificate Program For Eligible Nuclear Power Plants—Joint Certification Of Bob Fagan And Maximilian Chang On Behalf Of The New Jersey Division Of Rate Counsel", Division of Rate Counsel, Before the NJBPU, Docket No. EO18080899, 31 January 2019, see https://www.nj.gov/rpa/docs/EO18080899_ZEC_Chang_Fagan_Certification_REDACTED.pdf, accessed 29 May 2019..

495 - Mark Cooper, "Power Shift: The Deployment of a 21st Century Electricity Sector and the Nuclear War To Stop It", Institute for Energy and the Environment, Vermont Law School, 1 June 2015, see https://papers.ssrn.com/sol3/papers.cfm?abstract_id=2745357, accessed 28 May 2019.

496 - Robert Walton, "FirstEnergy Solutions files for bankruptcy after pushing for DOE emergency order", *Utility Dive*, 2 April 2018, see https://www.utilitydive.com/news/firstenergy-solutions-files-for-bankruptcy-after-pushing-for-doe- emergency/520371/; and FirstEnergy Solutions, "FirstEnergy Solutions Corp. (18-50757)", 31 March 2018, see https://cases.primeclerk.com/FES/Home-Index, both accessed 29 May 2019.

497 - Margrethe Kearney, Andrene Dabaghi, "Citizen Complaint and Request for Enforcement Action Regarding FirstEnergy Nuclear Facility Operations in Ohio and Pennsylvania", Environmental Law & Policy Center, Petition to Victor M. McCree, Executive Director for Operations, NRC, 27 March 2018, see http://elpc.org/wp-content/uploads/2018/03/001-ELPC-2.206-Petition-re-FirstEnergy.pdf, accessed 29 May 2019.

498 - Julia A. Moriarty, "2017 Nuclear Decommissioning Funding Study", Callan Institute, September 2017, see https://www.callan.com/wp-content/uploads/2017/09/Callan-2017-NDT-Survey.pdf, accessed 29 May 2019.

499 - Louise Lund, "Acknowledgment Of FirstEnergy Solutions, FirstEnergy Nuclear Generation, And FirstEnergy Nuclear Operating Company Bankruptcy Notification", Division of Licensing Projects, U.S.NRC, Letter to Donald A. Moul, President and Chief Nuclear Officer, FirstEnergy Solutions, 6 April 2018, see https://www.nrc.gov/docs/ML1809/ML18093B546.pdf, accessed 29 May 2019.

500 - David E. Hess, "FirstEnergy Files Letter With NRC Affirming Plans To Deactivate Beaver Valley, 2 Other Nuclear Power Plants", *PA Environment Digest*, 25 April 2018, see http://paenvironmentdaily.blogspot.com/2018/04/firstenergy-files-letter-with-nrc.html, accessed 29 May 2019.

501 - Nick Malawskey, "Clock ticks toward TMI shutdown", *PennLive*, 26 April 2018, see https://www.pennlive.com/news/2018/04/clock_ticks_toward_tmi_shutdow.html, accessed 29 May 2019.

502 - Jessie Balmert , "Energy overhaul: 'Clean Air Program' just for nuclear plants, not wind or solar", *Cincinnati.com*, 28 May 2019, see https://eu.cincinnati.com/story/news/politics/2019/05/27/ohio-energy-no-money-wind-solar-just-nuclear-plants/3739552002/J, accessed 12 July 2019.

The decision of FirstEnergy Solutions is a further signal that just because reactors have obtained 20-year license extensions does not mean they will operate through the full license period. The Beaver Valley Units 1 and 2 in 2009 were issued by the NRC 20-year license extensions to permit them to operate until 2036 and 2047 respectively.[503] FirstEnergy had notified the NRC only in May 2017 that it planned to file a license extension in 2020 for the one Perry reactor, whose current license expires in 2026. The 42-year-old Davis-Besse reactor was granted an NRC license extension in 2015, to operate through 2037.[504]

> *"Despite bankruptcy filings in 2018, FirstEnergy continued to spend millions of dollars on lobbying and advertising"*

FirstEnergy's power purchase agreement approved in March 2016[505] was blocked by the Federal Energy Regulatory Commission (FERC) a month later. Through 2016 and 2017, FirstEnergy then continued to lobby for the establishment of Zero Emission Nuclear (ZEN) legislation that would support their Davis Besse and Perry reactors, which could be worth an estimated US$300 million a year to their owners. In October 2017, a fresh bill was introduced, the ZEN resource program, aimed at saving the Davis Besse and Perry reactors, leading FirstEnergy to claim that it "would increase the likelihood of keeping the plants operational throughout the life of the program."[506] The bill reduces the amount FirstEnergy would receive over two consecutive periods of six years, from US$300 million in previous introduced legislation to US$180 million.[507] The Perry reactor was expected to operate at a profit of US$3.5/MWh during 2017–2019, with Davis Besse at US$4.5/MWh through the same period. These figures do not include the additional income if Ohio's emissions credits are finally approved.

The proposed legislation made no progress during the year 2018, despite appeals by the bill's sponsor to move forward following FirstEnergy's filing for bankruptcy.[508]

Despite bankruptcy filings in 2018, FirstEnergy continued to spend millions of dollars on lobbying and advertising in efforts to secure favorable legislative changes in Ohio and Pennsylvania.[509] In spring 2019, the Ohio legislature introduced the House Bill 6 or HB6, which would create the Ohio Clean Air Program and provide "clean energy" credits to zero-emission

503 - NRC, "Beaver Valley Power Station—License Renewal Application", Updated 13 December 2016, see https://www.nrc.gov/reactors/operating/licensing/renewal/applications/bvalley.html, accessed 29 May 2019.

504 - NRC, "Davis-Besse Nuclear Power Station, Unit 1—License Renewal Application", 20 April 2016, see https://www.nrc.gov/reactors/operating/licensing/renewal/applications/davis-besse.html, accessed 29 May 2019.

505 - John Funk, "FirstEnergy's Davis-Besse, Sammis power plants make money after all: FirstEnergy profits show", *Cleveland.com*, 27 April 2016, see http://www.cleveland.com/business/index.ssf/2016/04/firstenergys_davis-besse_sammi.html, accessed 29 May 2019.

506 - Ohio Legislature, "Senate Bill 128", Introduced by Senators Eklund, LaRose, 132nd General Assembly Regular Session 2017-2018, S. B. No. 128, see https://www.legislature.ohio.gov/legislation/legislation-documents?id=GA132-SB-128, accessed 29 May 2019; and Andrew Cass, "New Ohio House Bill aims to subsidize state's nuclear power plants", *The News Herald*, 13 October 2017, see http://www.news-herald.com/general-news/20171013/new-ohio-house-bill-aims-to-subsidize-states-nuclear-power-plants, accessed 29 May 2019.

507 - *NW*, "New Ohio legislation introduced to give financial support to nuclear plants", 19 October 2017.

508 - *Ohio Public Radio*, "Group Of FirstEnergy Employees Come To Columbus To Save Firm's Two Ohio Nuclear Power Plants", 3 April 2018, see http://wcbe.org/post/group-firstenergy-employees-come-columbus-save-firms-two-ohio-nuclear-power-plants, accessed 29 May 2019.

509 - Jessie Balmert , "Energy overhaul: 'Clean Air Program' just for nuclear plants, not wind or solar", *Cincinatti Enquirer*, 28 May 2019, see https://eu.cincinnati.com/story/news/politics/2019/05/27/ohio-energy-no-money-wind-solar-just-nuclear-plants/3739552002/, accessed 28 May 2019; and Dave Anderson, "Bankrupt FirstEnergy Solutions spends millions on bailout campaigns in Ohio and Pennsylvania", Energy and Policy Institute, 11 April 2011, see https://www.energyandpolicy.org/firstenergy-bailout/, accessed 12 July 2019.

power producers, including Davis Besse and Perry plants.[510] Financing is proposed through the Ohio Clean Air Fund. Amendments made to the Bill by Republican sponsors meant that by 28 May 2019 it was clear that the primary beneficiary of the legislation will be FirstEnergy. The estimated US$197.6 million that would be charged in new ratepayer fees would largely be paid to FirstEnergy. Renewable energy companies will not be able to access the Ohio Clean Air Program, with only small domestic wind turbines being eligible. Legislatures have also proposed terminating existing programs that encourage electricity providers to purchase renewable energy as well as energy efficiency programs. Finally, coal power with sequestration would be eligible for financing.

The proposed HB6 and its effective termination of support for significant renewable energy programs and energy efficiency—while instead supporting coal plants in Ohio—runs counter to those who have argued that ZEC support for nuclear plants is a necessary part of an eventual transition to renewable energy. This includes the United States Court of Appeals for the Second Circuit, which in September 2018 stated that in the case of New York, "the ZEC program aims to prevent nuclear generators that do not emit carbon dioxide from retiring until renewable sources of energy can pick up the slack."[511]

HB6 charges Ohioans a US$1 fee each month starting in January 2021 for nuclear energy. The fee is higher for businesses (US$15) and industrial customers (US$250 to US$2,500). The fees would in early versions of the legislation be applied for five years through 2026, but amendments by House Republicans would lock in the charges until 2030.[512] It has been estimated that these subsidies would net EnergySolutions US$320 million each year for its two nuclear plants. As reported in Ohio, the bailout of FirstEnergy is nothing new. Since 1999, FirstEnergy has received US$10.2 billion in state subsidies.[513]

Opposition to the legislation included the Chair of the Energy Generation Committee, and the Energy and Natural Resources Committee:

> This is a bailout plain and simple. What has happened is that First Energy and First Energy Solutions, they're in bankruptcy and they need a bailout. (...) Everyone will pay even if their electricity is not provided by nuclear power plants, everyone in Ohio will have to pay. First Energy has been bailed out before.[514]

On 13 May 2019, analysis of the economics of Davis Besse and Perry reactors argued that "The Ohio nuclear units are operating profitably in covering their going forward and avoidable costs and future capital expenditures. Consequently, there is no rational economic reason for them

510 - Ohio Legislature, "House Bill 6 Creates Ohio Clean Air Program", Reported by the House Energy and Natural Resources Committee, 133rd General Assembly, Regular Session Sub. H. B. No. 6, see https://www.legislature.ohio.gov/legislation/legislation-summary?id=GA133-HB-6, accessed 28 May 2019.

511 - United States Court of Appeals for the Second Circuit, "Coalition for Competitive Electricity, et al. v. Zibelman, et al., Case 17-2654, Document 224-1" 27 September 2018, op. cit.

512 - Jessie Balmert , "Energy overhaul: 'Clean Air Program' just for nuclear plants, not wind or solar", *Cincinatti Enquirer*, 28 May 2019, see https://eu.cincinnati.com/story/news/politics/2019/05/27/ohio-energy-no-money-wind-solar-just-nuclear-plants/3739552002/, accessed 28 May 2019

513 - Ibidem.

514 - *WFMJ*, "House Bill 6 - clean air or multi million dollar bailout paid by energy customers?", 21 May 2019, see http://www.wfmj.com/story/40506111/house-bill-6-clean-air-or-multi-million-dollar-bailout-paid-by-energy-customers, accessed 12 July 2019.

to retire."[515] The calculations of the reactors was based on unit specific costs, "whose relative accuracy has been verified by examining FirstEnergy financial statements in Securities and Exchange Commission (SEC) filings."[516] This is in contrast to the PJM that uses industry average single unit costs.

FirstEnergy rejected the analysis, citing that it "excludes critical cost components" including capital spending requirements and ignores the fact that the plants did not clear PJM's 2021/2022 capacity auction and will likely not clear future auctions. The power provider said that fixing the consultant's "obvious calculation errors" results in a net loss of more than $125 million/year versus a profit for the plants.[517]

The justification for the HB6 legislation was also challenged in a May 2019 analysis from the Institute for Energy Economics and Financial Analysis (IEEFA).[518] It concluded that "FirstEnergy's nuclear and coal plants are not needed to ensure electricity supply or reliability in Ohio", and that terminating the reactors is "unlikely to drive up electricity rates in Ohio—but reducing energy efficiency and renewable energy could have that effect." IEEFA contended that, "If Ohio is serious about providing low cost sources of clean energy, it would make more economic sense to invest in solar energy than to subsidize aging nuclear plants."[519]

On 28 May 2019, the HB6 legislation was passed by the Ohio House.[520] FirstEnergy was hoping that approval by the Senate would take place during June 2019, before the end of the current legislative sessions and when the utility was to decide whether to proceed with plans for refueling of the Davis Besse reactor, which was scheduled for closure in 2020. Securing HB6 would also likely see reversal of the decision to close Perry in 2021. While the legislature ended on 28 June 2019, before the Senate could vote on HB6, additional dates were added to the session. On 17 July 2019 the Senate passed HB6,[521] and on 23 July 2019 the House also voted to approve the Senate version of the legislation.[522] The Governor of Ohio signed the legislation into law the same day. Welcoming the legislation, FirstEnergy Solutions announced that it will "begin the process to rescind the deactivation orders for its Perry and Davis-Besse nuclear power stations and immediately resume preparation for the mandatory Davis-Besse refueling outage in the Spring."[523]

515 - Paul M. Sotkiewicz, "The Market and Financial Position of Nuclear Resources in Ohio", E-Cubed Policy Associates, 13 May 2019, see https://img1.wsimg.com/blobby/go/30b6d3a5-dffd-4a1b-9b4d-0bf3451282cd/downloads/OH%20Nuclear%20Analysis%20 20190513-final.pdf?ver=1559092681975, accessed 29 May 2019.

516 - Ibidem,

517 - Gavin Bade, "Ohio advances coal, nuclear subsidies after pressure from Trump campaign official", *Politico*, 29 May 2019, see https://www.politico.com/story/2019/05/29/ohio-coal-nuclear-trump-1347274, accessed 30 May 2019.

518 - David Schlissel, "Bailout Bill a Bonanza for FirstEnergy Solutions, but a Boondoggle for Ohio Consumers", IEEFA, May 2019, see http://ieefa.org/wp-content/uploads/2019/05/Bailout-Bill-a-Bonanza-for-FirstEnergy-Solutions_May-2019.pdf, accessed 12 July 2019.

519 - Ibidem.

520 - Gavin Bade, "Ohio advances coal, nuclear subsidies after pressure from Trump campaign official", *Politico*, 29 May 2019.

521 - Jim Provance, "Nuclear plant rescue clears Ohio Senate, but House punts", *The Blade*, 17 July 2019, see https://www.toledoblade.com/local/environment/2019/07/17/nuclear-plant-rescue-nears-final-votes/stories/20190717150, accessed 25 July 2019.

522 - John Funk, "Ohio Gov DeWine signs controversial nuke subsidy bill", *Utility Dive*, 23 July 2019, see https://www.utilitydive.com/news/breaking-ohio-passes-controversial-nuke-subsidy-bill-by-one-vote/559342/, accessed 25 July 2019.

523 - FirstEnergy Solutions, "FirstEnergy Solutions Applauds Enactment of HB6 Legislation", 24 July 2019, see https://www.prnewswire.com/news-releases/firstenergy-solutions-applauds-enactment-of-hb6-legislation-300890693.html, accessed 25 July 2019.

The final version of HB6 will mean that from April 2021 through 2027, FirstEnergy Solutions will receive quarterly payments that will net on average US$150 million each year from additional electricity charges on domestic and industrial customers. An additional nearly US$50 million a year will be received by Ohio Valley Electric Corp to operate two old coal plants in the state.[524] In addition, energy-efficiency standards will end for each utility in Ohio once it achieves a 17.5-percent power reduction while also reducing the state's renewable-energy target from a maximum of 12.5 percent by 2027 to 8.5 percent by 2026—the level that, under current law, utilities must reach by 2022.[525] The American Wind Energy Association stated: "Ohio consumers and manufacturers want greater commitment to renewable energy, not less… (it) won't make Ohio's air cleaner, but it will hike consumer electric bills and send both jobs and clean energy investment to Ohio's neighbors".[526] HB6 arguably sets a new standard for costly and asymmetrical state action to bail out failing coal and nuclear investments while disadvantaging efficiency and renewables.

In **Pennsylvania**, while legislative initiatives failed in 2018 to secure bailouts of nuclear plant operators, efforts continued during the past year. A contentious debate has been underway over the extent to which Exelon and FirstEnergy are seeking state support for their reactors in the state citing unfavorable market conditions, while at the same time failing to disclose detailed financial statements on grounds of commercial sensitivity. In May 2017, Exelon had announced that TMI-1, scheduled for closure in September 2019, and Quad Cities in Illinois, for the third year running, had not cleared the PJM base residual auctions. With FirstEnergy's Beaver Valley-1 and -2 planned closures in May and October 2021 respectively,[527] total closures in Pennsylvania would represent 25 percent of the state's nuclear generating capacity, but only 6 percent of the state's overall power generation.

One analysis released in March 2019 provided insight into the economics of TMI and Beaver Valley nuclear plants operating in Pennsylvania.[528] In the case of Exelon's TMI-1, it reported that losses for 2018 were likely to be in the range of US$73 million; FirstEnergy's twin Beaver Valley units were found profitable by US$23–96 million per year depending on whether they cleared the PJM auction, but could be as high as US$173 million if based on the day-ahead average Locational Marginal Price (LMP).

The PJM Interconnection in a 5 June 2019 analysis concluded that there would be "no reliability impact from the planned closures of the Davis Besse, Perry and Beaver Valley nuclear units… [however] it can reasonably be expected that imposing additional out-of-market subsidies to retain generation that would otherwise retire would have a chilling effect on new investment in the longer term."[529]

524 - Jeremy Pelzer, "Nuclear bailout bill passes Ohio legislature, signed by Gov. Mike DeWine", *Cleveland.com*, 23 July 2019, see https://www.cleveland.com/open/2019/07/nuclear-bailout-bill-passes-ohio-legislature.html, accessed 25 July 2019.

525 - Ibidem.

526 - AWEA, "Ohio House Bill 6 passage will lead to higher electric bills, fewer jobs, and lost clean energy investment", Press Statement, 23 July 2019, see https://www.awea.org/resources/news/2019/ohio-house-bill-6-passage, accessed 21 August 2019.

527 - David E. Hess, "FirstEnergy Files Letter With NRC Affirming Plans To Deactivate Beaver Valley, 2 Other Nuclear Power Plants", *PA Environment Digest*, 25 April 2018, see http://www.paenvironmentdigest.com/newsletter/default.asp?NewsletterArticleID=43293&SubjectID, accessed 28 May 2019.

528 - Andrew G. Place et al., "Analysis of Pennsylvania Nuclear Plants and Available Policy Alternatives", Pennsylvania Public Utility Commission, 6 March 2019, see https://assets.documentcloud.org/documents/5763986/Nuclear-Policy-Paper-PUC-Commissioner-Andrew-G.pdf, accessed 28 May 2019.

529 - *NW*, "PJM analysis shows significant power price drop if reactors retire", 13 June 2019.

Two legislative efforts were underway in the Pennsylvania House and Senate in early 2019.[530] In March 2019 an amendment was proposed to the 2004 Alternative Energy Portfolio Standards (AEPS) Act that would provide financial support to the state's nuclear plants, which were currently excluded.[531] The principal sponsor of the bill made the case that "If we lose one or more of these plants we might as well forget about all the time and money we've invested in wind and solar. [...] The Legislature can save Pennsylvania consumers money, keep our nuclear power plants open and keep our air clean."[532] In contrast, the Natural Resources Defense Council (NRDC) condemned the draft bill as

> ...nothing more than a windfall for aging, uneconomical nuclear power plants. It fails to limit carbon pollution or advance commonsense energy policy that transitions Pennsylvania away from nuclear power and dirty fossil fuels to renewable sources and energy efficiency.[533]

Hearings began in April 2019, with both proponents and opponents contesting the benefits and detriments of the legislation.[534] The state's Public Utility Commission (PUC) has estimated that the legislation if adopted would cost ratepayers between US$459 and US$551 million a year in subsidies to FirstEnergy and Exelon.[535] This estimate was on the basis that both TMI-1 and Beaver Valley would be operating, which will no longer be the case as Exelon Generation announced on 8 May 2019 that TMI-1 will permanently close by 30 September 2019.[536] As of 1 July 2019, legislation had yet to be approved.

530 - Pennsylvania State Senate, "Updating the Pennsylvania Alternative Energy Portfolio Standards (AEPS) Act", Senate Bill 510, Regular Session 2019–2020, 4 February 2019, see https://www.legis.state.pa.us//cfdocs/Legis/CSM/showMemoPublic.cfm?chamber=S&SPick=20190&cosponId=28189, accessed 29 May 2019.

531 - Pennsylvania General Assembly, "House Bill 11", Regular Session 2019-2020, Referred to Committee on Consumer Affairs, 12 March 2019, see https://www.legis.state.pa.us/cfdocs/billinfo/billinfo.cfm?sYear=2019&sInd=0&body=H&type=B&bn=11, accessed 28 May 2019.

532 - Marie Cusick, "Rep. Mehaffie talks up his nuclear bailout bill; opponents line up to trash it", *StateImpact Pennsylvania*, 11 March 2019, see https://stateimpact.npr.org/pennsylvania/2019/03/11/rep-mehaffie-talks-up-his-nuclear-bailout-bill-opponents-line-up-to-trash-it/, accessed 29 May 2019.

533 - NRDC, "Pennsylvania Lawmaker Introduces Regressive Bill to Prop Up Nuclear Power", Press Release, 11 March 2019, see https://www.nrdc.org/media/2019/190311-1, accessed 12 July 2019.

534 - Marie Cusick, "Political fight begins over bill to rescue Pennsylvania nuclear industry", *StateImpact Pennsylvania*, 8 April 2019, see https://stateimpact.npr.org/pennsylvania/2019/04/08/political-fight-begins-over-bill-to-rescue-pennsylvania-nuclear-industry/?_ga=2.28139580.1486885018.1559245881-6078996.1559245881, accessed 29 May 2019.

535 - Andrew G Place, Letter to the Senate Consumer Protection and Professional Licensure Committee, Public Utility Commission, 18 April 2019, see https://www.documentcloud.org/documents/5973561-Commissioner-Andrew-Place-memo-on-SB-510.html, accessed 29 May 2019; and Marie Cusick, "Pennsylvania utility regulator speaks out against state Senate's nuclear bailout bill", *StateImpact Pennsylvania*, 22 April 2019, see https://stateimpact.npr.org/pennsylvania/2019/04/22/pennsylvania-utility-regulator-speaks-out-against-state-senates-nuclear-bailout-bill/?_ga=2.257312011.1486885018.1559245881-6078996.1559245881, accessed 29 May 2019.

536 - Exelon Generation, "Three Mile Island Unit 1 To Shut Down By September 30, 2019", 8 May 2018, see https://www.exeloncorp.com/newsroom/Pages/Three-Mile-Island-Unit-1-To-Shut-Down-By-September-30,-2019.aspx, accessed 13 May 2019.

FUKUSHIMA STATUS REPORT

INTRODUCTION

Eight years have passed since the Fukushima accident began in March 2011. Spent fuel removal in Unit 3 has started following significant delays and the investigation to locate fuel debris in Unit 2 was finally conducted, but with uncertain results. Although the evacuation order of a part of the evacuation zone was lifted again, only few residents have returned.

The assessment of health consequences remains controversial. Thyroid cancer in children continues to increase, with ongoing controversies over the causal relationship with the accident.

Other areas analyzed in this chapter are remaining food contamination, storage of contaminated water and the management of decontamination wastes that continue to accumulate.

ONSITE CHALLENGES

Current Status Reactors[537]

Water injection into all three units with fuel debris—Units 1, 2 and 3—has been continuing; the temperature of the lower part of the reactor pressure vessels and the containment vessels is currently maintained at 15–25 degrees Celsius. According to the survey map[538] of radiation doses, the levels measured across most of the site are below 10 µSv/h (micro-sievert per hour) but there are locations with levels of 100 µSv/h near the buildings.[539] The dose inside the reactor buildings is still high; the level at some locations is more than 10 mSv/h.[540] The amount of radioactive materials released from the reactor building is about 5×10^{-12} Bq/cm³ for Cs-134 and about 3.5×10^{-11} Bq/cm³ for Cs-137 at the site boundary. These values are below the air concentration limits set by the Japanese government.[541]

In April 2019 the work of spent fuel removal finally re-started after having been halted since the work at Unit 4 was completed in December 2014.[542] Removal of spent nuclear fuel, comprising 566 fuel assemblies, at Unit 3 began on 15 April 2019. Since it was scheduled to start in the

537 - In this chapter, the following materials are used when there is no footnote: Secretariat of the Team for Countermeasures for Decommissioning and Contaminated Water Treatment, "Summary of Decommissioning and Contaminated Water Management", Ministry for Economy Trade and Industry, Government of Japan, 28 March 2019, see https://www.meti.go.jp/english/earthquake/nuclear/decommissioning/pdf/20190423_e.pdf, accessed 1 May 2019.

538 - TEPCO, "Results of the analysis of radioactive materials around Fukushima Daiichi Nuclear Power Station", Undated (in Japanese), see http://www.tepco.co.jp/decommission/data/surveymap/, accessed 1 May 2019.

539 - TEPCO, "Fukushima Daiichi Ground Survey Map (for April 3 and 4, 2019)", Undated (in Japanese), see http://www.tepco.co.jp/decommission/data/surveymap/pdf/2019/f1-sv2-20190425-j.pdf, accessed 1 May 2019.

540 - According to the results of the measurements made at Unit 1 from January to December 2018, the level at the first floor of the reactor building at one point was 12 mSv.: TEPCO, "The air dose rate in the building, Data collection period: January 1, 2018 – December 31, 2018 at Unit 1", 29 March 2019 (in Japanese), see http://www.tepco.co.jp/decommission/data/surveymap/pdf/2019/sv-u1-20190329-j.pdf, accessed 1 May 2019.

541 - Government-defined air concentration limits outside the perimeter monitoring area: 2.0×10^{-5} Bq/cm³ for Cs-134 and 3.0×10^{-5} Bq/cm³ for Cs-137.

542 - TEPCO, "About the start of fuel extraction from spent fuel pool at Unit 3", 15 April 2019 (in Japanese), see http://www.tepco.co.jp/decommission/information/newsrelease/reference/pdf/2019/1h/rf_20190415_1.pdf, accessed 1 May 2019.

middle of 2018 in the government's medium- and long-term roadmap,[543] this was a delay of about half a year.[544] It is reported that the plan was delayed due to malfunction of the machine that transfers the spent fuel to the transport container. The spent fuel will be moved to and stored in the common spent fuel pool. This work is scheduled to take about one year until FY 2020.

At Unit 1 the removal of debris, which is an obstacle to the removal of spent fuel, was finally completed in February 2019. As for Unit 2, the process is still at the stage of designing the fuel removal method. In the most recent Tokyo Electric Power Company (TEPCO) roadmap report,[545] the plan has been significantly revised. Instead of removing the roof and walls of Unit 2, the existing fuel handling machine is to be repaired, and then in combination with a new rig, spent fuel containers will be removed via the air lock platform newly installed in Unit 2.

In the roadmap, the removal of spent fuel in Unit 1 and 2 is scheduled to start in Financial Year (FY) 2023.

With regard to the removal of molten fuel debris, it is scheduled in the roadmap to determine the removal method for the first unit in FY 2019. However, as of 1 July 2019, there has been no official announcement. According to the Fukushima Daiichi decommissioning roadmap, the fuel debris removal from the first unit will start by 2021 and be completed within ten years. The timetable for the plan lacks credibility. The International Research Institute for Nuclear Decommissioning (IRID) has estimated a range of volumes of molten fuel in the three reactors:[546] for Unit 1, 232–357 tons, with a nominal value of 279 tons; Unit 2, 189–390 tons, with a nominal value of 237 tons; and Unit 3, 188–394 tons, with a nominal value of 364 tons. The reason that the corium mass is higher than the original fuel mass—69 tons in reactor 1, and 94 tons in each of reactors 2 and 3—is that corium contains, in addition to the original fuel, molten steel and concrete. Consequently, the corium masses are 2.5–4 times larger than the original fuel. The sum of the nominal quantities of corium is 880 tons, with the lower range being 609 tons, and upper estimate being 1,141 tons. This nominal value of 880 tons is 3.4 times more than the original fuel in the three reactors.

On 13 February 2019, for the first time, a survey robot made direct contact with material in the Reactor Pressure Vessel (RPV) of Unit 2.[547] The maximum measurement of the dose at

543 - Inter-Ministerial Council for Contaminated Water and Decommissioning Issues, "Mid-and-Long-Term Roadmap towards the Decommissioning of TEPCO's Fukushima Daiichi Nuclear Power Station", 26 September 2017, see https://www.meti.go.jp/english/earthquake/nuclear/decommissioning/pdf/20170926_01a.pdf, accessed 1 May 2019.

544 - The first version of the roadmap (announced in December 2011) stated that fuel extraction was to begin at the end of 2014. Therefore, this is a delay of four years in terms of this plan. Nuclear Emergency Response Headquarters Government and TEPCO Mid-to-Long Term Countermeasure Meeting, "Mid-and-long-Term Roadmap towards the Decommissioning of Fukushima Daiichi Nuclear Power Station Units 1-4", Provisional Translation, 21 December 2011, see https://www.meti.go.jp/english/earthquake/nuclear/decommissioning/pdf/111221_02.pdf, accessed 1 May 2019.

545 - TEPCO, "Spent fuel pool measures schedule", 30 May 2019 (in Japanese), see https://www4.tepco.co.jp/decommission/information/committee/roadmap_progress/pdf/2019/d190530_06-j.pdf, accessed 30 June 2019.

546 - IRID, "Estimation of fuel debris distribution by the analysis and evaluation", Japan Atomic Energy Society Fuel Debris Research Committee, 4 October 2016, see http://irid.or.jp/wp-content/uploads/2016/10/20161004.pdf (in Japanese), accessed 30 June 2019.

547 - TEPCO, "Results of the Internal Survey of Reactor Vessel in Unit 2 of Fukushima Daiichi Nuclear Power Station", Preliminary Report, 13 February 2019 (in Japanese), see http://www.tepco.co.jp/decommission/information/newsrelease/reference/pdf/2019/1h/rf_20190213_1.pdf, accessed 1 May 2019.

the bottom of the containment vessel remains a lethal 43 Sv/h.[548] While TEPCO had earlier predicted that the material at the bottom of the RPV was molten fuel debris, the result of the inspection has raised many questions as to the location and condition of the molten fuel in Unit 2. Radiation levels measured 30 cm from the material was recorded at 7 Sv/h, rather than several hundred Sv/h anticipated by TEPCO. This led to questions not just over the amount of molten fuel remaining in the RPV and therefore how much has exited the RPV into the basemat, but most significantly whether in fact all the molten fuel will in the end be removed. The material that was lifted by a robotic arm in the February 2019 survey comprised mostly of pebble-like sediment, with speculation that this included zirconium cladding. Further inspections are scheduled for the second half of 2019. As a result of the February inspection, Akira Ono, head of the Fukushima Daiichi decommissioning project, stated on 28 March 2019 that "At present, it is difficult to clearly say we are going to remove all fuel debris".[549,550]

The inspection results of Unit 2 prompted Naoyuki Takaki, professor of nuclear engineering at Tokyo City University, to state that "there could ultimately be a decision to stop debris removal after pulling out as much debris as possible. In that case, we would have no option but to consider building a sarcophagus like the one at the Chernobyl nuclear plant."[551] There has been no change to the planned decommissioning completion period, which is set at 2041 to 2051.

Contaminated Water Management

The implementation of response measures for the contaminated water[552] is still ongoing. With regards to the frozen soil walls (land-side impermeable walls[553]), for which feasibility and high cost were considered to be a problem, TEPCO claimed that the walls had almost been completed in March 2018.[554] Many measures—such as pumping up of groundwater before it flows into frozen soil walls and buildings—have reduced the amount of groundwater and rainwater flowing into buildings; as a result, the amount of newly generated contaminated water has decreased, but remains significant. The average quantity of contaminated water was about 470 m^3/day in FY 2014 and decreased to about 170 m^3/day in FY 2018.[555] In the roadmap, the goal is to curb the amount to 150 m^3/day by 2020.

548 - The maximum dose rate measured was 43 Gy/h. The assumption made here is 1 Gy/h = 1 Sv/h. See TEPCO, "Results of internal survey of Unit 2 reactor containment vessel", 19 March 2019 (in Japanese), p.11, see https://www.meti.go.jp/earthquake/nuclear/osensuitaisaku/committtee/genchicyousei/2019/0319_01_03.pdf, accessed 1 May 2019.

549 - Toshiyuki Suzuki, "Unclear debris map casts shadow over decommissioning of Fukushima plant", *The Mainichi*, 9 April 2019, see https://mainichi.jp/english/articles/20190409/p2a/00m/0na/021000c, accessed 30 June 2019.

550 - International Research Institute for Nuclear Decommissioning, "Decommissioning of Fukushima Daiichi Nuclear Power Station and R&D of IRID", 29 May 2018 (in Japanese), p.26, see http://www.irid.or.jp/_pdf/20180529.pdf, accessed 1 May 2019.

551 - Toshiyuki Suzuki, "Unclear debris map casts shadow over decommissioning of Fukushima plant", *The Mainichi*, 9 April 2019.

552 - Generic term for water contaminated with radioactive materials such as seawater injected at the time of the accident and groundwater flowing into the building and mixing with highly contaminated water.

553 - An ice wall is made by circulating a refrigerant (approximately –30 degrees Celsius) in piping buried underground to freeze the groundwater.

554 - TEPCO, "Current Status of Landside Impermeable Wall", 7 March 2018 (in Japanese), see https://www.meti.go.jp/earthquake/nuclear/osensuitaisaku/committtee/osensuisyori/2018/pdf/020_01_00.pdf, accessed 1 May 2019.

555 - Data until January 2019.

As for this contaminated water, the work for removing radioactive materials from the water has been continued using multi-nuclide removal equipment and other devices. The treated, still contaminated water—containing tritium in particular, the only material that is not planned to be removed—continues to be stored in storage tanks. As of 21 March 2019, the total storage volume in the tanks is about 1.12 million m^3. The current plan is to increase the total tank storage capacity to 1.37 million m^3 by the end of 2020.[556] If the capacity is enhanced, the difference would be 250,000 m^3, which would extend the capacity by about four years, at a production rate of 170 m^3/day. However, if the capacity of the storage tanks is 1,000 m^3 per tank, a new tank is still needed about every six days.

The Nuclear Regulatory Authority (NRA) recommends dumping the contaminated water into the ocean, but TEPCO has not decided on its final disposal method because of fear of backlash from local residents. The Ministry of Economy, Trade and Industry (METI) held public hearings on the future handling of treated water containing tritium in August 2018 in Fukushima Prefecture and Tokyo.[557] However, most of the participants including the representatives of the fishermen's co-op raised concerns about reputational damage and safety.[558]

A major setback to plans for discharge into the Pacific Ocean emerged in August 2018, when it was reported by *Kyodo News* that TEPCO's Advanced Liquid Processing System (ALPS) had not performed as had been widely reported otherwise.[559] On 28 September 2018, TEPCO admitted that of the 890,000 m^3 of water treated by the ALPS (as of September 2018) and stored in tanks, about 750,000 m^3 tons contained higher concentrations of radioactive materials than levels permitted by the safety regulations for release into the ocean.[560] In 65,000 m^3 of treated water, the levels of strontium-90 are more than 100 times above the safety standards, according to TEPCO. In some tanks, the levels are exceeding the limits by a factor of 20,000. These admissions contrast with earlier official statements on ALPS, claiming the system would reduce radioactivity levels "to lower than the permissible level for release".[561]

The disclosures from TEPCO further antagonized local communities. The METI contaminated-water task-force is currently reviewing the implications of these disclosures and how to proceed with management of the contaminated water. TEPCO indicated that it will be

556 - TEPCO, "Treated Water Portal Site", see http://www.tepco.co.jp/en/decommission/progress/watertreatment/index-e.html, accessed 1 May 2019.

557 - Sub-committee secretariat for handling of treated water by multi-nuclide removal equipment, "Holding of information sessions and public hearings about the handling of treated water by multi-nuclide removal equipment", METI, 31 July 2018 (in Japanese), see https://www.meti.go.jp/earthquake/nuclear/osensuitaisaku/committtee/takakusyu/setsumei-kochokai.html?platform=hootsuite, accessed 1 May 2019.

558 - Sub-committee secretariat for handling of treated water by multi-nuclide removal equipment, "Information sessions and public hearings", METI, October 2018 (in Japanese), see https://www.meti.go.jp/earthquake/nuclear/osensuitaisaku/committtee/takakusyu/pdf/010_02_00.pdf, accessed 1 May 2019.

559 - *The Japan Times*, "ALPS system at Fukushima No. 1 plant failing to remove more than tritium from toxic cooling water", 19 August 2018, see https://www.japantimes.co.jp/news/2018/08/19/national/alps-system-fukushima-no-1-plant-failing-remove-tritium-toxic-cooling-water/#.XRoxptNKjOQ, accessed 30 June 2019.

560 - TEPCO, "Collection of ALPS treated water data (outlet concentration levels)", METI, 17 October 2018 (in Japanese), see https://www.meti.go.jp/earthquake/nuclear/osensuitaisaku/committtee/takakusyu/pdf/010_04_05.pdf, accessed 1 May 2019; and *The Asahi Shimbun*, "Editorial: TEPCO bungles it again in dealing with Fukushima tainted water", 9 October 2018, see http://www.asahi.com/ajw/articles/AJ201810090025.html, accessed 30 June 2019.

561 - Division of Water Chemistry and Fusion Engineering Division, "Treatment of contaminated water stored in Fukushima Dai-ichi Nuclear Power Plant", Investigation Committee on the Nuclear Accident at the Fukushima Daiichi Nuclear Power Plant, Atomic Energy Society Japan, 10 September 2013, see http://www.aesj.or.jp/jikocho/Treatmentofcontaminatedwater.pdf, accessed 30 August 2019.

necessary to conduct further processing of the contaminated water, which could take several years.[562]

Coastal fishermen in Fukushima prefecture are currently voluntarily refraining from fishing activities within 10 km of the Fukushima Daiichi plant. However, identified marine products with levels exceeding the contaminated threshold (100 Bq/kg) are decreasing,[563] and the fishermen are currently operating on a trial basis, i.e., they are fishing and selling some fish species for which safety has been confirmed. Their concern is that a decision to release tritiated water into the Pacific would have a major impact on their attempts to restore their fragile fishing businesses.[564,565]

The International Atomic Energy Agency (IAEA) has reviewed METI for its decommissioning efforts. In the final report of its fourth review (5–13 November 2018),[566] the IAEA highlights that storage in tanks is only a temporary measure and that sustainable options are needed.[567] At the same time, the IAEA has long argued for a Pacific Ocean release.

Worker Exposure

According to TEPCO, the monthly average workers' radiation dose was about 0.36 mSv in FY 2017, a decline from about 0.59 mSv in FY 2015. The burden on employees of subcontractor companies is large. The number of workers in February 2019 was 7,264, of which 962 TEPCO employees and 6,302 employees from subcontractors.[568] The maximum effective dose for external exposure was 5.38 mSv for TEPCO employees and twice as high or 10.87 mSv for subcontractor employees.

According to the questionnaire survey involving workers other than TEPCO employees conducted by TEPCO and released in December 2018,[569] 41.9 percent of the workers responded that they felt "anxious." The reasons given for such anxiety included "the impact of [radiation] exposure on health." The Ministry of Health, Labor and Welfare (MHLW) supervised and gave guidance to 290 business operators who carried out decommissioning work, of which

562 - Shaun Burnie, "TEPCO Water Crisis", Greenpeace Germany, 22 January 2019, see https://storage.googleapis.com/planet4-japan-stateless/2019/06/eefof147-tepco_water_crisis.pdf, accessed 30 June 2019.

563 - According to the Fisheries Agency, only one sample exceeded the standard value of 100 Bq/kg (1,665 samples, excess rate is 0.1 percent) among the samples examined in the January to March 2019 survey. Fisheries Agency of Japan, "Results of the monitoring on radioactivity level in fisheries products—Summary of Monitoring on fishery products (as of Mar.31, 2019)", 31 March 2019 (in Japanese), see http://www.jfa.maff.go.jp/e/inspection/index.html, accessed 1 May 2019.

564 - Fukushima Prefecture Fisheries Cooperative Federation, "Approach to trial operation in Fukushima Prefecture", Undated (in Japanese), see http://www.fsgyoren.jf-net.ne.jp/siso/sisotop.html, accessed 1 May 2019.

565 - TEPCO, "Collection of ALPS treated water data (outlet concentration levels)", 1 October 2019 (in Japanese), see https://www.meti.go.jp/earthquake/nuclear/osensuitaisaku/committtee/takakusyu/pdf/010_04_05.pdf, accessed 1 May 2019.

566 - IAEA, "IAEA International Peer Review Mission on Mid-and-Long-Term Roadmap Towards the Decommissioning of TEPCO's Fukushima Daiichi Nuclear Power Station (Fourth Mission)", Mission Report to the Government of Japan, Mission from 5–13 November 2018, Report issued 31 January 2019, see https://www.iaea.org/sites/default/files/19/01/missionreport-310119.pdf, accessed 1 May 2019.

567 - Ibidem, p.8.

568 - TEPCO, "Evaluation situation of exposure dose of workers of Fukushima Daiichi Nuclear Power Station", 27 March 2019 (in Japanese), see http://www.tepco.co.jp/decommission/information/newsrelease/exposure/pdf/2019/exposure_20190327-j.pdf, accessed 1 May 2019.

569 - TEPCO, "Results of questionnaire for improvement of working environment (the ninth) and future direction of improvement", December 2018 (in Japanese), see https://www.meti.go.jp/earthquake/nuclear/decommissioning/committee/osensuitaisakuteam/2018/13/3-7-2.pdf, accessed 1 May 2019.

more than half (154) were in violation of labor laws. The rate of detected infringements was 53.1 percent, up from 38.4 percent in the previous fiscal year.[570] The most frequent type of violation was inadequate payment of premium wages.

According to multiple newspapers,[571] MHLW recognized the decommissioning work of the Fukushima accident as the cause of cancer developed by two workers. The causal relationship between radiation exposure and illness was recognized for one of them on 4 September 2018. This employee of a subcontractor company was in charge of radiation control at multiple nuclear power plants from 1980 to September 2015. After the Fukushima accident started in March 2011, he was in charge of measuring the radiation dose of locations slated for decontamination prior to implementation. He was diagnosed with lung cancer in February 2016 and subsequently died. His cumulative dose was estimated at 195 mSv, of which about 74 mSv was from exposure after 3/11.[572,573]

The other worker was also a subcontractor company employee for whom causal relationship between radiation exposure and illness was recognized on 12 December 2018. For about 11 years, between November 1993 and March 2011, he had been working in the maintenance of electrical facilities at several nuclear power plants. Immediately after 3/11, he started carrying out restoration work of the power supply. In June 2017, he was diagnosed with thyroid cancer. His cumulative exposure dose was estimated at 108 mSv of which about 100 mSv were due to post-3/11 exposure, including about 37 mSv calculated to be internal exposure.[574,575] As a result, so far the Fukushima events have been recognized by MHLW as the cause of cancer for six people: two cases of thyroid cancer, three cases of leukemia, and one case of lung cancer.

In addition, death caused by overwork also occurred. The cause of one worker's death was recognized by the MHLW as overwork in November 2018 while TEPCO had claimed at a press conference the day after his death in October 2017[576] that there was no causal relationship with the work.[577]

570 - MHLW, "Supervision instruction results of companies performing decommissioning work in Fukushima Daiichi Nuclear Power Station of TEPCO and companies performing decontamination work in Fukushima Prefecture (2018)", Press Release, 29 March 2019 (in Japanese), see https://www.mhlw.go.jp/content/11300000/000497488.pdf, accessed 1 May 2019.

571 - Currently, the MHLW has ceased to disclose these types of information to the general public through its website. We can find out only indirectly, through media reports.

572 - *The Asahi Shimbun*, "Occupational accident recognized for a man who died of lung cancer", 5 September 2018 (in Japanese), see https://digital.asahi.com/articles/ASL9524MNL95UBQU001.html?iref=pc_ss_date?iref=pc_extlink, accessed 5 May 2019.

573 - The MHLW has established criteria such as "cumulative 100 mm or more" and "period from exposure to onset of 5 years or more" for recognizing a worker's exposure as an occupational accident.

574 - *The Asahi Shimbun*, "Exposure during work after the nuclear accident causes cancer, 6th worker's occupational accident recognition", 13 December 2018 (in Japanese) see https://digital.asahi.com/articles/ASLDF42SBLDFUBQU009.html, accessed 1 May 2019.

575 - *The Japan Times*, "Tepco-linked firm employee's thyroid cancer caused by work after Fukushima nuclear plant meltdown, labor ministry admits", 13 December 2018, see https://www.japantimes.co.jp/news/2018/12/13/national/tepco-linked-firm-employees-thyroid-cancer-caused-work-fukushima-nuclear-plant-meltdown-labor-ministry-admits/#.XLwWky97F24, accessed 1 May 2019.

576 - *The Asahi Shimbun*, "Overwork death at Daiichi Nuclear Power Station, Man's bereaved family holds a press conference", 8 November 2018 (in Japanese), see https://digital.asahi.com/articles/ASLC73R7GLC7UGTB00B.html?iref=pc_ss_date, accessed 1 May 2019.

577 - TEPCO, "Progress of the medium- and long-term roadmap", 26 October 2017 (in Japanese), see https://www4.tepco.co.jp/library/movie/detail-j.html?catid=61693&video_uuid=t4cs581k, accessed 1 May 2019.

The MHLW has commissioned an epidemiological survey of workers.[578] As of April 2019, the first cycle of the baseline survey, which examines the health condition and smoking habits of the examinees, has finally ended. However, prospective subjects are reluctant to participate in the survey. As of 15 January 2018, out of the 19,808 prospective subjects, 6,873 have participated in the survey (34.7 percent), 3,432 have refused to participate (17.3 percent), 7,392 have not replied (37.3 percent), and the contact information was unavailable for 1,685 (8.5 percent).[579] According to media reports, it is believed that a strong distrust of TEPCO and the government is the main reason why the number of participants is so low.[580]

OFFSITE CHALLENGES

Current Status of Evacuation

As of 5 April 2019, 39,724 Fukushima residents are still living as officially designated evacuees (7,235 are living in the prefecture, 32,476 are living outside the prefecture, and 13 are missing).[581] According to Fukushima Prefecture, the peak level of evacuees was 164,865 (May 2012).[582] The official figures do not include the so-called "self-evacuees" who left areas of Fukushima that were outside the officially designated evacuation areas. As of October 2016, the official figure for these evacuees was 26,601.[583] Starting in 2017, Fukushima Prefecture no longer included these evacuees in its statistics.

The government has continued its policy of lifting evacuation orders in the remaining evacuation zones.[584] On 10 April 2019, for the first time in two years, evacuation orders were lifted for a Restricted Residence Zone[585] and a Zone in Preparation for Lifting the

578 - The emergency dose limit was raised from 100 mSv to 250 mSv from 14 March 2011 to 16 December 2011. During this time, it is estimated that about 20,000 people were engaged in emergency work, and 174 people were exposed to levels above 100 mSv, which is the 5-year dose limit under normal circumstances. In this study, it is said that the health effects of low-dose exposure will be followed up throughout the lives of all these approximately 20,000 emergency workers. See Radiation Effects Research Foundation, "Epidemiological study of the TEPCO Fukushima Daiichi Nuclear Power Station emergency workers", Joint Study (in Japanese), see https://news.rerf.or.jp/hp/top.html, accessed 1 May 2019.

579 - Radiation Effects Research Foundation, "Report of the epidemiological study of the TEPCO Fukushima Daiichi Nuclear Power Station emergency workers", March 2018 (in Japanese), see https://news.rerf.or.jp/hp/pdf/report_h29.pdf, accessed 1 May 2019.

580 - *NHK*, "Nuclear Power Plant Accident 'Heroes' Now—The actual situation regarding their refusal to participate in the radiation exposure survey", 6 March 2018 (in Japanese), see https://www.nhk.or.jp/gendai/articles/4105/index.html, accessed 1 May 2019.

581 - Fukushima Disaster Measures Headquarters, "Immediate report on damage caused by the 2011 Tohoku Region Pacific Coast Earthquake", Report No. 1752, Fukushima Prefecture (in Japanese), see https://www.pref.fukushima.lg.jp/uploaded/life/416950_1041904_misc.pdf, accessed 1 May 2019.

582 - Fukushima prefecture, "Steps for Revitalization Fukushima", 25 December 2018 (in Japanese), p.3, see https://www.pref.fukushima.lg.jp/uploaded/attachment/322728.pdf, accessed 1 May 2019.

583 - *The Mainichi*, "Voluntary nuclear evacuees to face housing assistance gap", 6 January 2017, see https://mainichi.jp/english/articles/20170106/p2a/00m/0na/007000c, accessed 30 June 2019.

584 - The conditions for lifting an evacuation order are: 1. It is certain that the annual accumulated value (estimated value) of air dose rate will be less than 20 mSv, 2. Recovery of infrastructure (electricity, gas, etc.) and life services (medical, postal, etc.) essential for daily life. Decontamination of children's living environment and so on will sufficiently progress, 3. Sufficient consultation with prefectures, municipalities and residents. See METI, "Requirements for lifting an evacuation order", December 2011 (in Japanese), see https://www.meti.go.jp/earthquake/nuclear/kinkyu/hinanshiji/2017/pdf/0310_01e.pdf, accessed 1 May 2019.

585 - The area where levels may exceed the annual accumulated value of 20 mSv one year after the accident.

Evacuation Order[586]. The location where the evacuation orders were lifted this time is a part of Okuma Town, one of the host towns for the Fukushima Daiichi plant.[587]

However, population numbers have not significantly increased in areas where evacuation orders have been lifted. According to the latest residents' intention survey by the Reconstruction Agency, for example, only 4.9 percent of the residents of Namie Town[588] have returned and 49.9 percent of the residents have already decided not to return to the town.

The treatment of voluntary evacuees[589] is worsening. Fukushima Prefecture stopped providing free housing for voluntary evacuees at the end of March 2017 and although the prefecture subsequently started providing rent assistance for low-income households, this assistance was also terminated at the end of March 2019[590]. Once the free housing offer is terminated, they are no longer considered as voluntary evacuees and they disappear from the statistics of evacuees. The Governor of Fukushima Prefecture has not given a clear answer to the question from a reporter regarding the necessity of conducting a fact-finding investigation into their situation.[591] These voluntary evacuees may eventually consider returning to Fukushima as a result of being denied the right to evacuate, something the government and Fukushima Prefecture are effectively trying to force on tens of thousands of Japanese citizens. In its recovery plan, Fukushima Prefecture has set a goal to reduce the number of evacuees inside and outside the prefecture to zero within FY 2020.[592] On current trends it will miss this target by a wide margin.

On 25 October 2018, at the UN General Assembly, Special Rapporteurs from the UN Human Rights Commission criticized the Japanese government's policies as it relates to evacuees.[593] The UN Rapporteurs pointed out that the conditions for lifting evacuation orders should be a radiological situation limiting exposure to 1 mSv/year instead of the government-designated 20 mSv/year. In addition, they expressed strong concerns about evacuees being pressured to return due to the termination of free housing support. However, the Japanese Ministry of Foreign Affairs has argued that, "The Government of Japan is seriously concerned about such claims, as it could unnecessarily inflame public anxiety, cause confusion, and further trouble people suffering from reputational damage in disaster-hit areas."[594]

586 - The area where it is certain that annual accumulated value will be less than 20 mSv one year after the accident.

587 - METI, "Conceptual diagram of evacuation zones", 5 April 2019 (in Japanese), see https://www.meti.go.jp/earthquake/nuclear/kinkyu/hinanshiji/2019/sanko1gainenzu.pdf, accessed 1 May 2019.

588 - In this town, all areas became evacuation zones after the accident, but some evacuation orders were lifted on 31 March 2017.

589 - People who lived outside the evacuation zones but evacuated voluntarily.

590 - *The Mainichi*, "Voluntary nuclear evacuees to face housing assistance gap", 6 January 2017.

591 - Fukushima Prefecture, "Governor Press Conference", 17 December 2018 (in Japanese), see https://www.pref.fukushima.lg.jp/site/chiji/kaiken20181217.html#1, accessed 1 May 2019.

592 - Fukushima Prefecture, "Fukushima restoration plan (the third)", December 2015 (in Japanese), see https://www.pref.fukushima.lg.jp/uploaded/attachment/152267.pdf, accessed 1 May 2019.

593 - Office of the High Commissioner for Human Rights, "Japan must halt returns to Fukushima, radiation remains a concern, says UN rights expert", United Nations, 25 October 2018, see https://www.ohchr.org/EN/NewsEvents/Pages/DisplayNews.aspx?NewsID=23772&LangID=E, accessed 1 May 2019.

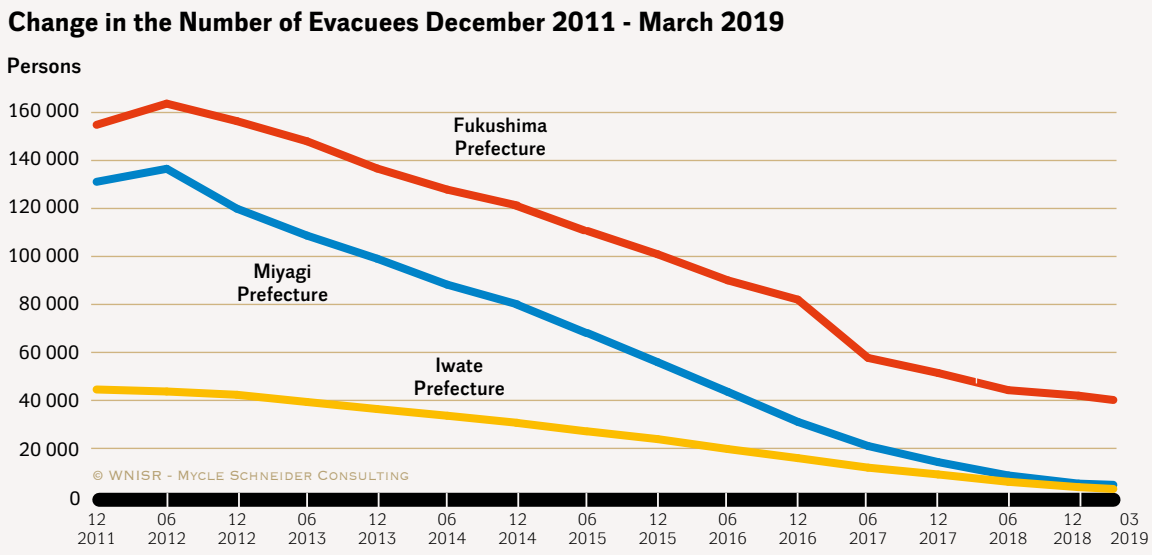
594 - Ministry of Foreign Affairs, "Response to the Joint Communication from two UN Special Rapporteurs from the Government of Japan concerning the Tokyo Electric Power Company Fukushima Daiichi Nuclear Power Station accident", 6 November 2018, see https://www.mofa.go.jp/fp/hr_ha/page25e_000260.html, accessed 1 May 2019.

In August 2018, UN Special Rapporteurs also raised multiple issues of human rights violations around the Fukushima Daiichi plant, including families with children, and involving decontamination workers.[595]

According to the Reconstruction Agency, as of the end of March 2019, there were approximately 51,000 evacuees of the Great East Japan Earthquake in Japan as a whole, including the 39,000 official "nuclear" evacuees.[596] Evacuees were primarily from Miyagi, Iwate and Fukushima Prefectures, which were seriously damaged by this magnitude 9 earthquake and tsunami. Although time has passed since the earthquake and these prefectures are in the process of restoration, Fukushima Prefecture alone has different characteristics from the other two prefectures. The total number of evacuees in and outside the prefecture decreased to 4,466 in Iwate Prefecture and 6,159 in Miyagi Prefecture as of the end of March 2019. However, the pace of reduction has been slow in Fukushima Prefecture; the prefecture still counts 41,454 evacuees. As shown in **Figure 34**, the number of evacuees reported in Fukushima Prefecture fell sharply in 2017 when, as noted above, free housing for voluntary evacuees was cut off and they were removed from the database.

Indirect but disaster-related deaths remain a cause of major concern.[597] Fukushima Prefecture is still showing an increasing trend (see **Figure 35**).[598]

Figure 34 | Change in the Number of Evacuees



Source: Compiled by Tadahiro Katsuta, based on Reconstruction Agency, "Change in the number of evacuees", 2019.

595 - Greenpeace Japan, "On the Frontline of the Fukushima Nuclear Accident: Workers and Children—Radiation risks and human rights violations", March 2019, see https://storage.googleapis.com/planet4-japan-stateless/2019/03/b12d8f83-frontfksm_en.pdf, accessed 30 June 2019.

596 - Reconstruction Agency, "Change in the number of evacuees", Government of Japan, 26 April 2019 (in Japanese), see http://www.reconstruction.go.jp/topics/main-cat2/sub-cat2-1/20190329_hinansha_suii.pdf, accessed 1 May 2019.

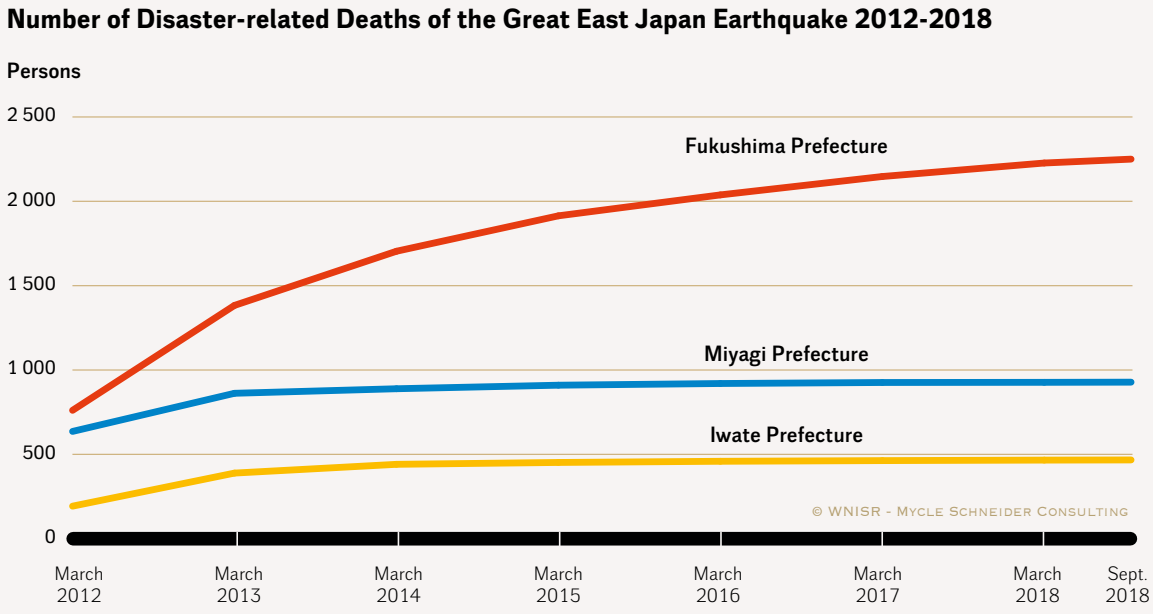
597 - In comparison to deaths due to direct damages caused by the tsunami or earthquake, deaths due to indirect damages (such as poor physical condition or stress) that occur as a result of living as an evacuee following the disaster.

598 - The Figure is based on the compilation of annual data starting from Reconstruction Agency, "Number of disaster-related deaths of the Great East Japan Earthquake (as of 31 March 2012)", announced 11 May 2012 (in Japanese), see http://www.reconstruction.go.jp/topics/main-cat2/sub-cat2-6/20140526131634.html, accessed 1 May 2019.

The termination of the compensation for damages is also a problem. For example, according to the guidelines for damages set forth by the Dispute Reconciliation Committee for Nuclear Damage Compensation,[599] compensations paid for psychological damages end one financial year after a relevant evacuation order is lifted (for restricted residential zones and zones in preparation for lifting the evacuation order). For example, in Tomioka-cho, for which the evacuation order was lifted two years ago, the compensation ended in March 2019.

Victims of the nuclear accident can file a claim with the Alternative Dispute Resolution (ADR) Center for Nuclear Damage Dispute Settlement. The ADR Center proposes to victims and TEPCO a settlement compromise (settlement amount). TEPCO is still paying compensation for damages, and as of 19 April 2019, the total payment has reached approximately 8,972 billion yen (US$81.5 billion[600]).[601] The total number of claims for damages from individuals and corporations is about 3 million.

Figure 35 | Number of Disaster-related Deaths of the Great East Japan Earthquake



Source: Compiled by Tadahiro Katsuta, based on Reconstruction Agency, "Number of disaster-related deaths of the Great East Japan Earthquake", 2019.

TEPCO has made three pledges in its business plan: "Complete compensation payments up to the very last person", "rapid and thorough compensation" and "respect of intermediate settlement proposals".[602] However, TEPCO continues to reject the settlement proposals of many collective complaints against the company's compensation practice. For example,

599 - MEXT, "Guideline for judgment on the range of nuclear damage by the TEPCO's Fukushima Daiichi and Daini Nuclear Power Station accident", Undated, in Japanese, see http://www.mext.go.jp/component/a_menu/science/detail/__icsFiles/afieldfile/2014/02/04/1329116_1_1.pdf, accessed 1 May 2019.

600 - Calculated at 110 yen per US$, as of the end of April 2019. The same conversion rate is used hereafter.

601 - TEPCO, "Payment of compensation", as of the end of March 2019 (in Japanese), see http://www.tepco.co.jp/fukushima_hq/compensation/results/, accessed 1 May 2019.

602 - Nuclear Damage Compensation and Decommissioning Support Organization, "New special comprehensive business plan (third plan)", TEPCO, Certification Application, 11 May 2017 (in Japanese), see http://www.tepco.co.jp/press/release/2017/pdf1/170511j0102.pdf, accessed 1 May 2019.

Namie Town filed a collective complaint in 2013 on behalf of more than 15,000 town inhabitants. The complaint called for a uniform increase, noting that the amount of compensation was not appropriate for the reality of peoples' damages. However, as TEPCO continued to reject the settlement proposal, the settlement mediation by the ADR Center was discontinued in April 2018.[603] In November 2018, Namie Town filed a lawsuit against TEPCO and the Japanese government.[604]

As a result of persistent efforts of lawyers representing 13,000 Japanese citizens, criminal trials have been held since 2017 against three former TEPCO executives (the former Chair of TEPCO and two former vice presidents) on charges of professional negligence resulting in death and injury. The trial has been ongoing, with sentencing scheduled for 19 September 2019.[605] If found guilty, the executives could see five-year prison sentences (though unlikely). Such an outcome would have widespread ramifications in Japan, not just for ongoing legal actions, but for the future prospects for TEPCO's nuclear operations now centered on the Kashiwazaki Kariwa reactors.

Radiation Exposure and Health Effects

Fukushima Prefecture has been continuing its thyroid cancer examination program for children who were under 18 years old at the time of the accident.[606] As of April 2019, the number of patients diagnosed with a malignant tumor or suspected of having a malignant tumor is 212; 169 individuals underwent surgery (see **Table 10**).[607]

Even now, the Prefectural Oversight Committee Meeting for Fukushima Health Management Survey does not recognize the causal relationship between the occurrence of thyroid cancer and radiation exposure post-3/11. However, analysis based on previous examinations is being carried out. In February 2019, referring to the report of the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), the oversight committee reported that there would be no increase in cancer detection rate associated with the increase in radiation dose.[608] However, due to the high uncertainty of this UNSCEAR report, the oversight committee decided to continue the analysis instead of drawing any final conclusions.

603 - Namie Town, "Namie Town ADR Group Appeal, briefing session on discontinuation", 20 April 2018 (in Japanese), see https://www.town.namie.fukushima.jp/soshiki/1/18360.html, accessed 1 May 2019.

604 - *The Asahi Shimbun*, "TEPCO and state slapped with new lawsuit over nuclear crisis", 28 November 2018, see http://www.asahi.com/ajw/articles/AJ201811280053.html, accessed 1 May 2019.

605 - For example, the progress report of the trial is summarized below: *NHK*, "TEPCO criminal trial 'The truth of the nuclear accident'" (in Japanese), see https://www3.nhk.or.jp/news/special/toudensaiban/, accessed 1 May 2019.

606 - Radiation Medical Science Center for the Fukushima Health Management Survey, "Report of the Fukushima Health Management Survey", Revised Version, Fukushima Medical University, 5 December 2018, see http://kenko-kanri.jp/en/pdf/report_e.pdf, accessed 1 May 2019.

607 - Fukushima Prefecture, "Status of thyroid examination results", The 34th Prefectural Oversight Committee Meeting for Fukushima Health Management Survey, 8 April 2019 (in Japanese), see https://www.pref.fukushima.lg.jp/uploaded/attachment/320844.pdf, accessed 1 May 2019.

608 - Fukushima Prefecture, "Relationship between UNSCARE Estimated Thyroid Absorbed Dose by Municipalities and the Detection Rate of Malignant Tumors or Suspected Malignant Tumors", The 12th Thyroid Examination Evaluation Section Meeting, 22 February 2019 (in Japanese), see https://www.pref.fukushima.lg.jp/uploaded/attachment/311587.pdf, accessed 1 May 2019.

Table 10 | Thyroid Cancer Statistics in Fukushima Prefecture

Number of people diagnosed with a malignant tumor or suspected of having a malignant tumor, and surgical case [number of people]					
Survey (Year executed)	**Subjects (Number of examinees)**	**Number of examinees diagnosed with a malignant tumor or suspected of having a malignant tumor (Comparison of males and females)**	**Number of operations performed**	**Surgical cases**	**Note**
Preliminary survey (FY2011-FY2013)	367,637 (300,472)	116 (Male 39, Female 77)	102	Benign nodule: 1 Papillary carcinoma:100 Poorly differentiated cancer:1	As of 31 March, 2018
Full-scale survey -Second survey- (Fy2014-Fy2015)	381,244 (270,529)	71 (Male 32, Female 39)	52	Papillary carcinoma:51 Other thyroid cancer:1	As of 31 March, 2018
Full-scale survey -Third survey- (Fy2016-Fy2017)	336,669 (217,530)	21 (Male 8, Female 13)	15	Papillary carcinoma:15	As of 31 December, 2018
Full-scale survey -Forth survey- (Fy2018-Fy2019)	293,945 (76,979)	2 (Male 1, Female 1)	0	-	As of 31 December, 2018
Survey for age 25 (FY2018)	22,653 (2,005)	2 (Male 1, Female 1)	0	-	As of 31 September, 2018
Total	**-**	**212**	**169**	**-**	**-**

Source: Compiled by WNISR based on Fukushima Prefecture, "The 34th Prefectural oversight committee meeting for Fukushima health management survey, Reference 1, Status of thyroid test results", 8 April 2019 (in Japanese).

Food Contamination

During the year ending March 2019, according to the official statistics, among 299,500 sample measurements conducted for food contamination across the country, 313 food items were identified that exceeded the threshold.[609, 610] Fukushima Prefecture has the highest number of those detections (125 items). For example, some bamboo shoots and wild boar meat exceeded the threshold. The number of detected items has increased compared to that of FY 2017 (200 items). According to the Ministry of Health, Labor and Welfare (MHLW), inspections have been conducted prior to shipment and most of the contaminated food items have been found in areas under shipment restriction.

The Consumer Agency continues to investigate reputational damage. According to a March 2019 survey, among those who care about the production area at the time of food purchase, the portion of people wishing to buy food stuffs that do not contain radioactive substances was 15.6 percent, a significant drop from 27.9 percent in February 2013.[611] However, on the other hand, the number of people who are not aware of food inspections such as shipping restrictions

609 - Standard value established by the Ministry of Health, Labor and Welfare (MHLW): The level of radioactive cesium is 100 Bq/kg for food, 10 Bq/kg for drinking water, 50 Bq/kg for milk, and 50 Bq/kg for infant food.

610 - MHLW, "Public inspection result FY 2018 (outline)", Preliminary Value, 28 March 2019 (in Japanese), see https://www.mhlw.go.jp/content/11135000/000502940.pdf, accessed 1 May 2019.

611 - The survey wording was: "If you answered that you 'care' or 'somewhat care' about the food production area when shopping in your daily life, please answer this question. Why are you worried about where the food was produced?" In March 2019, only 15.6 percent answered: "Because I want to buy foods that do not contain radioactive substances." See Consumer Agency, "The fact-finding of consumer awareness about reputational damage (the 12th)", 6 March 2019 (in Japanese), see https://www.caa.go.jp/disaster/earthquake/understanding_food_and_radiation/pdf/understanding_food_and_radiation_190306_0003.pdf, accessed 1 May 2019.

increased from 22.4 percent in 2015 to 44.8 percent. The reduction in reputational damage, as demonstrated by these results, may be because people's memory of the Fukushima accident itself has faded, or that they have given up on safety, rather than a consequence of people gaining a better understanding of radioactivity.

On the other hand, the impact of 3/11 on food exports is still severe. The Japanese government filed a complaint with the World Trade Organization (WTO) on the grounds that South Korea would arbitrarily and unfairly discriminate when importing Japanese food.[612] Japan's request was granted at the first trial held in 2018, but Japan lost the case at the Appeals tribunal on 11 April 2019.[613] As a result, South Korea has been able to continue its import restrictions on food produced in Japan.

After 3/11, 54 countries had imposed import restrictions and as of April 2019, the regulations remain in force in 23 countries. In particular, eight countries including South Korea, China, and the U.S. do not import from Fukushima Prefecture.[614]

Decontamination[615,616]

Decontamination of the Special Decontamination Area[617] managed by the Japanese government in Fukushima Prefecture ended in March 2018, and work in the Intensive Contamination Survey Area[618] ended already in March 2017. According to the Ministry of the Environment (MoE), a budget of about ¥2.9 trillion (US$26 billion) was spent on decontamination resulting in about 16.5 million m^3 of contaminated soil and other waste.[619] However, it cannot be said that dose rates in Fukushima Prefecture have returned to the situation prior to the Fukushima accident.[620] The difficult-to-return zones have not been subject to decontamination. However, decontamination testing has been carried out.[621]

612 - MoFA, "WTO dispute resolution 'Restriction on import of Japanese marine products by Korea', issuance of report of senior committee", 12 April 2019 (in Japanese), see https://www.mofa.go.jp/mofaj/press/danwa/page4_004887.html, accessed 1 May 2019.

613 - WTO, "Korea — Import Bans, and Testing and Certification Requirements for Radionuclides", Dispute Settlement, DS495, Reports Adopted 26 April 2019, see https://www.wto.org/english/tratop_e/dispu_e/cases_e/ds495_e.htm, accessed 1 May 2019.

614 - The policy varies from country to country. China, for example, stopped importing all food from multiple prefectures, including Fukushima Prefecture. South Korea banned food imports that are also restricted in Japan as well as fishery products from several prefectures, including Fukushima. Singapore stopped importing forest products from Fukushima Prefecture. See Ministry of Agriculture, Forestry and Fisheries, "Elimination and relaxation of food and other food import restrictions in foreign countries and regions due to the nuclear accident", as of 15 April 2019 (in Japanese), see http://www.maff.go.jp/j/export/e_info/pdf/kisei_gaiyo_ja.pdf, accessed 1 May 2019.

615 - MoE, "Environmental Remediation", Homepage, Undated, see http://josen.env.go.jp/en/, accessed 1 May 2019.

616 - MoE, "Environmental Remediation in Affected Areas in Japan", 26 March 2019, see http://josen.env.go.jp/en/pdf/environmental_remediation_1903.pdf, accessed 1 May 2019.

617 - A high dose area within a 20 km radius of the power plant, located around the difficult-to-return zone.

618 - It covers all eight prefectures, including Fukushima Prefecture, except for the Special Decontamination Area managed by the government.

619 - MoE, "Current Status of Efforts to Revitalize the Environment of Disaster-Stricken Areas", 2 March 2018 (in Japanese), see https://www.env.go.jp/jishin/rmp/conf/19/mat04.pdf, accessed 1 May 2019.

620 - Fukushima Prefecture, "Results of the environmental radioactivity measurement (provisional value)", as of 26 April 2019 (in Japanese), see http://www.pref.fukushima.lg.jp/sec_file/monitoring/kakuchihou.pdf, accessed 1 May 2019.

621 - It is considered as an area where residence will be restricted well into the future. However, decontamination work to enable residence is currently being carried out in some areas. See MoE, "Specified Restoration and Revitalization Base", Undated (in Japanese), see http://josen.env.go.jp/kyoten/index.html, accessed 1 May 2019.

On 16 August 2018, the Special Rapporteur of the UN Human Rights Commission issued a statement warning that workers engaged in the cleanup of the Fukushima accident were at risk from radiation exposure and serious exploitation.[622]

The work of transferring contaminated soil from a temporary storage site in Fukushima Prefecture to an intermediate storage facility[623] has been in progress since FY 2015. Although land acquisition for the facility has not yet ended, storage has begun in some areas.[624] According to the MoE, the decontaminated soil to be transported is about 14 million m^3. As of 19 April 2019, approximately 2.7 million m^3 of decontaminated soil had been moved.[625] In other words, only about 20 percent has been transported during the four-year period.

No plans have been developed for the final disposal of decontaminated soil out outside Fukushima Prefecture after 30 years of storage. The MoE plans reutilization of decontaminated soil, for example, on agricultural land as it is difficult to find a disposal site outside the prefecture. A demonstration project was planned to reuse the soil in road construction as embankment in Nihonmatsu City, Fukushima Prefecture, but it was canceled in June 2018 due to local opposition.[626]

As for contaminated soil outside the prefecture, 329,104 m^3 of removed soil is stored at 28,026 locations and 142,859 m^3 of waste is stored at 9,320 locations as of the end of March 2019.[627] These are to be disposed of in landfills. As of March 2019, a demonstration test of landfill disposal is being conducted for about 641 m^3 of soil/waste at the Tokai-mura Japan Atomic Energy Agency (JAEA) site in Ibaraki Prefecture, and about 217 m^3 of soil/waste at an open space in Nasu Town, Tochigi Prefecture.[628]

CONCLUSION ON FUKUSHIMA STATUS

The Japanese government and TEPCO are promoting highly controversial policies. Decommissioning work is leading to occupational diseases; evacuation orders are lifted but people do not wish to return; decontamination waste (soil)—collected by decontamination workers who were exposed—shall be reused. Thus Japan's policies regarding the ongoing crisis at Fukushima, supposed to protect its people, appear to be implemented at the expense of its people.

622 - Office of the High Commissioner for Human Rights, "Japan: Fukushima clean-up workers, including homeless, at grave risk of exploitation, say UN experts", United Nations, 16 August 2018, see https://www.ohchr.org/EN/NewsEvents/Pages/DisplayNews.aspx?NewsID=23458&LangID=E, accessed 1 May 2019.

623 - Until final disposal, facilities store removed soil, waste, incinerated ash with levels exceeding 100,000 Bq/kg, etc. that were generated from decontamination activities in Fukushima Prefecture.

624 - MoE, "Interim Storage Facility", Undated, see http://josen.env.go.jp/en/storage/, accessed 1 May 2019.

625 - MoE, "Accumulated (From 2015) Transportation Status", as of 23 April 2019 (in Japanese), see http://josen.env.go.jp/chukanchozou/transportation/#section01, accessed 1 May 2019.

626 - *Sankei Shimbun*, "Difficult situation for treatment of decontamination soil in Fukushima, 'This is not what we were promised' Residents' backlash", 7 March 2019 (in Japanese), see https://www.sankei.com/affairs/news/190307/afr1903070050-n1.html, accessed 1 May 2019.

627 - MoE, "Number of storage locations and storage amount of removed soil and other materials in the Key Contamination Survey Area (outside Fukushima Prefecture)", as of the end of March 2018 (in Japanese), see http://josen.env.go.jp/zone/pdf/removing_soil_storage_amount_h30_03.pdf, accessed 1 May 2019.

628 - MoE Decontamination Team, "Result of demonstration project concerning landfill disposal of removed soil (interim report)", March 2019, see http://www.env.go.jp/press/t04_mat01.pdf, accessed 1 May 2019.

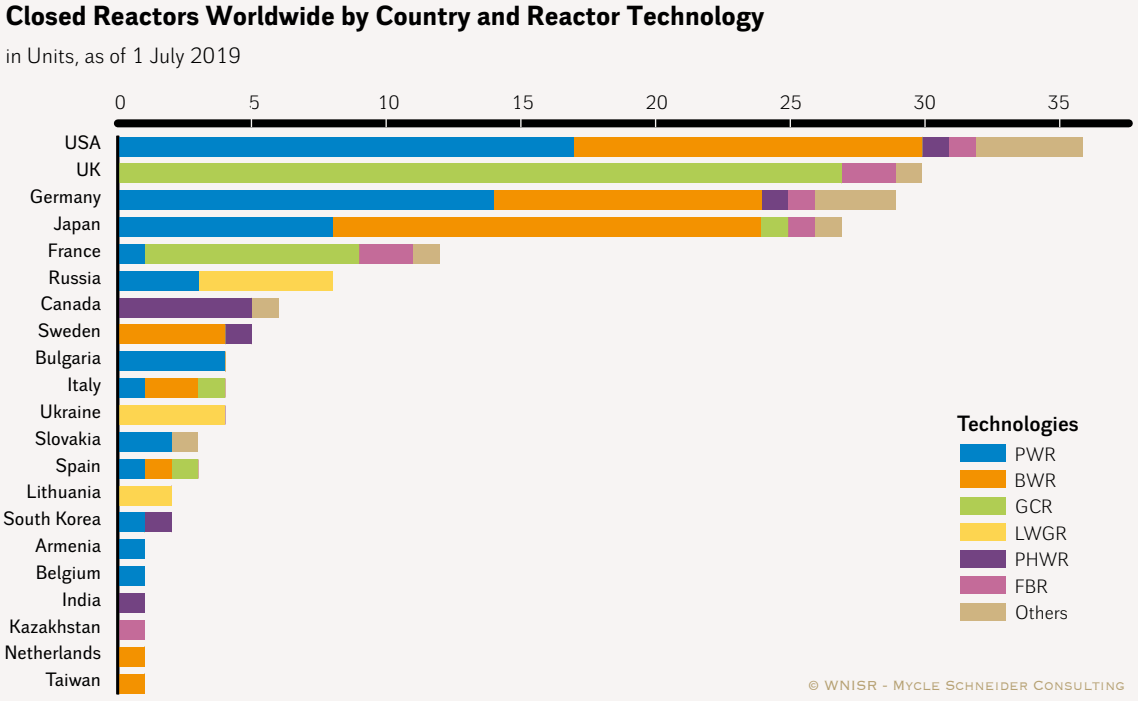
DECOMMISSIONING STATUS REPORT 2019

INTRODUCTION AND OVERVIEW

Decommissioning Worldwide

The defueling, deconstruction, and dismantling—summarized by the term decommissioning—are the final steps in the life cycle of a nuclear power plant. The process is technically complex and poses major challenges in terms of long-term planning, execution and financing. Decommissioning was rarely considered in the reactor design, and the costs for decommissioning at the end of the lifetime of a reactor were usually discounted away, and thus, subsequently, largely ignored. However, as an increasing number of nuclear facilities either reach the end of their operational lifetimes or are already closed, the challenges of reactor decommissioning are coming to the fore, and also attract increasing public attention.

Figure 36 | Closed Reactors Worldwide by Country and Reactor Technology



Sources: compiled by WNISR, 2019

Note: PWR = Pressurized Water Reactor, BWR = Boiling Water Reactor, GCR = Gas Cooled Reactor, LWGR = Light Water Gas-Cooled Reactor, PHWR = Pressurized High Water Reactor, FBR = Fast Breeder Reactor.

The cluster "other" includes the reactor technologies: High-Temperature Gas-Cooled Reactor (HTGR), Heavy Water Gas Cooled Reactor (HWGCR), Steam Generating Heavy Water Reactor (SGHWR), Heavy Water Light Water Reactor (HWLWR), and yet "others".

As of 1 July 2019, worldwide, there are 181 closed reactors totaling 78.1 GW of capacity. Since WNISR2018, eight additional reactors (4.5 GW) have been officially closed: two each in Japan, Russia and the U.S., and one each in South Korea and Taiwan. Close to 60 percent of the closed

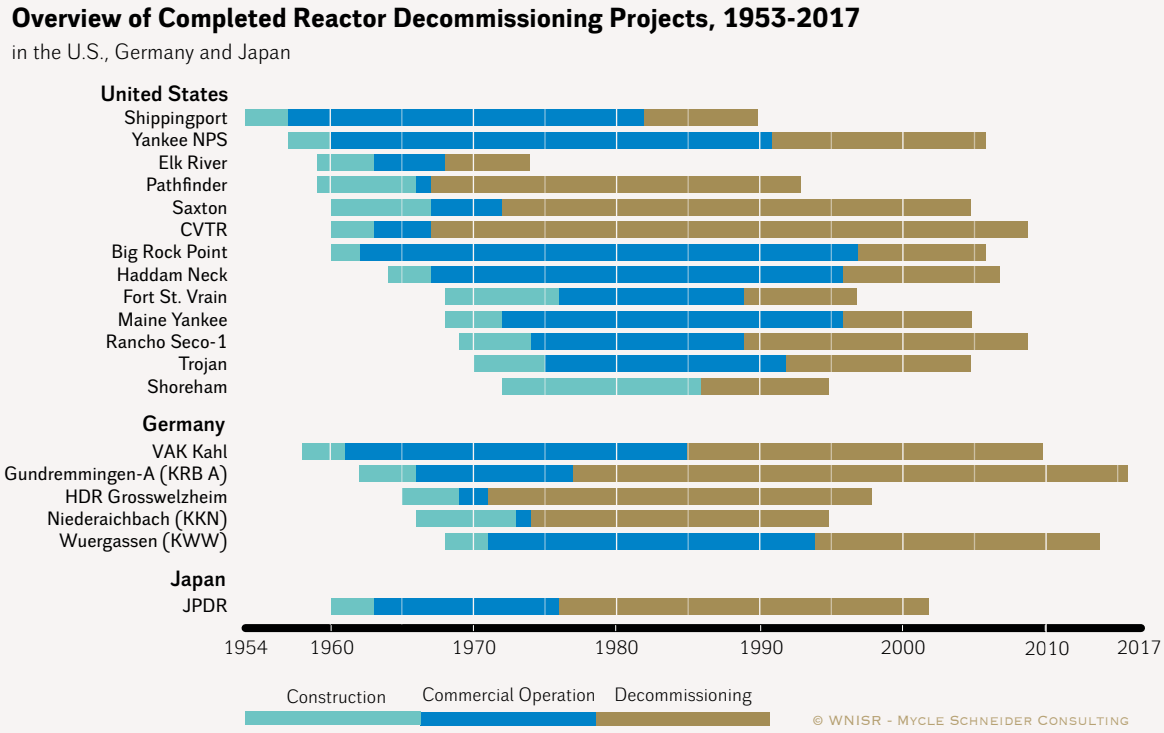
units are located in Europe (85 in Western Europe and 23 in Central and Eastern Europe), followed by North America (42) and Asia (31). Around 78 percent or 140 reactors are using three reactor technologies: Pressurized Water Reactors or PWRs (30 percent or 54 units), Boiling Water Reactors or BWRs (27 percent or 48 units), and the Gas-Cooled Reactors or GCRs (21 percent or 38 units). Of the latter, the majority (27 reactors) are located in the U.K.

Figure 36 gives an overview of the closed reactors by country and reactor technology. The U.S. and Germany each have six different reactor types, the highest diversity among the countries with closed reactors. Spain has only three closed reactors but three different reactor types to dismantle.

Decommissioning is only at its very beginnings. Assuming a 40-year average lifetime, a further 207 reactors will close by 2030 (reactors connected to the grid between 1979 and 1990); and an additional 125 will be closed by 2059; this does not even account for the 85 reactors which started operating before 1979, an additional 28 reactors in Long-term Outage (LTO) and the 46 reactors under construction as of mid-2019.

Overview of Reactors with Completed Decommissioning

Figure 37 | Overview of Completed Reactor Decommissioning Projects, 1953–2017



Source: WNISR and IAEA-PRIS, 2018-19

As of the first quarter of 2019, 162 units are globally awaiting or in various stages of decommissioning, eight more than in the first quarter of 2018. No reactor completed decommissioning worldwide since WNISR2018 (see Figure 37). Overall, only 19 reactors,

with a capacity of 6 GW, were fully decommissioned, i.e. only 8 percent of the total 78.1 GW withdrawn from the grid. Of the 19 decommissioned reactors, only 10 have been returned to greenfield sites. The average duration of the decommissioning process, independent of the chosen strategy, is around 19 years, with a very high variance: the minimum of six years for the 22-MW Elk River plant, and the maximum of 42 years for the 17-MW CVTR (Carolinas-Virginia Tube Reactor), both in the U.S.

ELEMENTS OF NATIONAL DECOMMISSIONING POLICIES

When analyzing decommissioning policies, one needs to distinguish between the process itself (in the sense of the actual implementation), and the financing of decommissioning. The technological process can generally be divided into three main stages, which are briefly described hereunder (for more details, see WNISR2018).

- The **Warm-up-stage** comprises the post-operational stage, the dismantling of systems that are not needed for the decommissioning process. Also, the dismantling of higher contaminated system parts begins. An indicator for the progress of this stage is the defueling of the reactor as it is crucial for further undertakings: defueling means removing the spent fuel from the reactor core and the spent fuel pools.
- The **Hot-zone-stage** comprises the dismantling activities in the hot zone, i.e. dismantling of highly contaminated or activated parts, e.g. the reactor pressure vessel (RPV) and its internals (RVI), and the biological shield.
- The **Ease-off-stage** comprises removal of operating systems as well as decontamination of the buildings. This stage ends ideally with the demolition of the buildings and the release of the reactor site as a greenfield for unrestricted use but the release as a brownfield is allowed in some countries, which means that the buildings can also be further used, for nuclear or other purposes.

With respect to financing, four main approaches are observable: Public budget, external segregated fund, internal non-segregated fund, and internal segregated fund (for more details, see WNISR2018).

CASE STUDIES NORTH AMERICA, EUROPE, AND ASIA

WNISR2019 contains case studies of decommissioning in North America (U.S. and Canada), Europe, and Asia and counted 140 closed reactors in the U.S., Canada, France, Germany, Japan, and the U.K. that represent almost 79 percent of the worldwide total closed fleet. The country case-studies suggest that both duration and costs have been largely underestimated. In nearly all the cases, the few started decommissioning projects encounter delays as well as cost increases.

The U.S. have decommissioned the highest number of reactors (13), followed by Germany (5), and Japan (1). By contrast, the early nuclear states U.K., France and Canada have not fully decommissioned one single reactor. Table 11 reflects the little progress that the entire decommissioning process is making: between July 2018 and June 2019, no additional reactor

was completely decommissioned, and little progress can be reported for the rest of the reactors undergoing decommissioning.

In **Germany**, Neckarwestheim-1 and Philippsburg-1 were defueled.[629] In **France**, it was announced that the decommissioning of the small 80 MW Brennilis reactor will be further delayed, with the earliest possible completion in 2038. The decree formalizing that timeframe is expected to be signed by 2021.[630] In **Japan**, Genkai-2 and Onagawa-1 have been officially closed; WNISR2018 already counted these two reactors in Longt-Term Outage (LTO). In 2019, Japan Atomic Power Company (JAPC), which owns the two Tokai and the two Tsuruga reactors—all four are either closed or in LTO—announced that it considers setting up a subsidiary for decommissioning its reactors together with EnergySolutions as operator.[631] JAPC is decommissioning the GCR Tokai-1 as well as Tsuruga-1 since 2017 and supports decommissioning works for the Fukushima Daiichi plant. Already in 2016, EnergySolutions and JAPC signed a cooperation agreement and JAPC members visited the Zion site in the USA.[632]

In the **U.S.**, there was no tangible progress in reactor decommissioning, but it seems that the new organizational model of selling the license to a decommissioning contractor, identified in WNISR2018, gains popularity. In December 2018, the Vermont Public Utility Commission approved the operating license transfer from Entergy to Northstar, mainly due to the accelerated decommissioning plan, Northstar would start with decommissioning no later than 2021.[633] The transfer also includes the dry storage facility.[634] In June 2019, Duke Energy announced that it plans to sell the operating license for Crystal River-3, which is currently in Long Time Enclosure (LTE), to the Northstar and Orano joint-venture.[635] Before this deal, the model was already applied to three reactors (Zion-1, Zion-2 and Lacrosse); here the license was sold to waste-management company EnergySolutions, which seems to be involved in most if not all decommissioning projects. In early 2019, Omaha Public Power District (OPPD), owner and operator of Fort Calhoun-1, signed a contract with EnergySolutions for technical support for decommissioning the reactor, although no details about the contract, including its value, have been disclosed.[636] The strategy has been changed to immediate dismantling, and OPPD estimates that decommissioning costs could be reduced by US$200 million (i.e. a total cost

629 - Deutscher Bundestag, "Kernbrennstofffreiheit und Rückbau deutscher Atomkraftwerke", Drucksache 19/6177, Antwort der Bundesregierung auf die Kleine Anfrage 19/5710, Beantwortet vom Bundesministerium für Umwelt, Naturschutz und nukleare Sicherheit, 29 November 2018.

630 - Commission Locale d'Information des monts d'Arrée, "Réunion plénière de la CLI des monts d'Arrée du jeudi 5 juillet 2018", Press Release, 17 July 2018 (in French), see https://www.finistere.fr/content/download/36289/573127/file/2018-07-17%20CP%20Réunion%20plénière%20de%20la%20CLI%20des%20Monts%20d'Arrée%20du%205-07-2018.pdf, accessed 26 June 2019.

631 - *Japan Times*, "Japan Atomic Power considers launching unit that specializes in scrapping nuclear plants", 16 April 2019, see https://www.japantimes.co.jp/news/2019/04/16/national/japan-atomic-power-considers-launching-unit-specializes-scrapping-nuclear-plants/#.XRN1q498JO8, accessed 26 June 2019.

632 - EnergySolutions, "EnergySolutions Signs Japan Commercial Nuclear Reactor Decommissioning Agreement", Press Release, 20 April 2016, see https://www.energysolutions.com/energysolutions-signs-japan-commercial-nuclear-reactor-decommissioning-agreement/, accessed 26 June 2019.

633 - John Dillon, "Vermont Yankee transfer approved, Northstar will decommission plant", *Vermont Public Radio*, 6 December 2018, see https://www.vpr.org/post/vermont-yankee-transfer-approved-northstar-will-decommission-plant, accessed 11 August 2019.

634 - U.S.NRC, "NRC Approves License Transfer for Vermont Yankee", *NRC News*, No.18-047, 12 October 2018, see https://www.nrc.gov/reading-rm/doc-collections/news/2018/18-047.pdf, accessed 9 May 2019

635 - *WNN*, "Accelerated decommissioning for Crystal River", 31 May 2019, see http://world-nuclear-news.org/Articles/Accelerated-decommissioning-for-Crystal-River, accessed 10 June 2019.

636 - *WNN*, "EnergySolutions to decommission Fort Calhoun", 30 April 2019, see http://world-nuclear-news.org/Articles/EnergySolutions-to-decommission-Fort-Calhoun, accessed 9 May 2019.

of around US$1.1 billion or US$2,250/kW). Contrary to other cases, EnergySolutions does not take over the license and the funds but OPPD retains full ownership, control and regulatory accountability.[637] EnergySolutions estimated that it will finish decommissioning Lacrosse and the two Zion units in late 2019.[638]

The two units San Onofre-2 and -3 are not yet defueled but this is scheduled to be completed by the end of 2019. Underground storage vaults were installed to this end. Defueling might be delayed, however, as the Nuclear Regulatory Commission (NRC) is currently evaluating an incident at the station, where staff came close to dropping 18 feet (6 meters) a container containing 50 tons of spent fuel. One canister got stuck and was not properly inserted, which the operator Southern California Edison (SCE) first failed to note; only after radiation protection registered unusually high radiation was the problem realized and solved.[639] SCE has come under pressure recently with a San Diego attorney calling for criminal investigations by the FBI[640] and congressmen announcing new legislation amid serious environmental and safety concerns.[641]

On 17 September 2018, Oyster Creek, a 619 MW GE BWR-2 (Mark 1) reactor and the first "commercial" and then oldest reactor in the U.S., was closed after 49 years of operation, 11 years before its license expires in 2029. Exelon will now defuel the plant with plans to sell it to the newly created joint venture Comprehensive Decommissioning International consisting of Holtec International (U.S. waste management company) and SNC-Lavalin (Canadian engineering company). The company plans to acquire the decommissioning licenses of two Entergy reactors in the coming years: Pilgrim, closed on 31 May 2019 and Palisades, planned to close definitely in 2022.[642]

Thus, of the ten reactors undergoing decommissioning, six were sold to decommissioning companies, only four—the Humboldt Bay station and the San Onofre plant (three units)—were not. As reported in WNISR2018, there is a need for a high level of scrutiny to these models, as in most cases the decommissioning funds are also transferred to the new licensee. In the case of Oyster Creek, the latest reported decommissioning fund contained US$888.5 million as of late 2016 with a site-specific cost estimate of around US$1,083 million for decommissioning including spent fuel management.[643] These developments are problematic as limited-liability companies are only financially liable—in the case of an accident or other legal dispute—up to the value of their assets. Therefore, if the decommissioning funds are exhausted, such a third-party company could declare bankruptcy, leaving the bill to the taxpayer.

637 - OPPD, "OPPD Contracts with EnergySolutions to Support Nuclear Decommissioning", 29 April 2019, see https://www.oppd.com/news-resources/news-releases/2019/april/oppd-contracts-with-energysolutions-to-support-nuclear-decommissioning/, accessed 9 May 2019.

638 - *WNN*, "EnergySolutions to decommission Fort Calhoun", 30 April 2019.

639 - U.S.NRC, "Special Inspection Activities Regarding Cask Loading Misalignment", Updated 2 August 2019, see https://www.nrc.gov/reactors/operating/ops-experience/songs-spec-insp-activities-cask-loading-misalignment.html, accessed 11 August 2019.

640 - Alison St John, "Criminal Investigation Sought Into Nuclear Waste Handling At San Onofre", *kpbs*, 2 January 2019, see https://www.kpbs.org/news/2019/jan/02/criminal-investigation-sought-nuclear-waste-handli, accessed 10 May 2019.

641 - *abc7*, "San Onofre nuclear power plant decommission under fire amid safety concerns", 17 April 2019, see https://abc7.com/politics/san-onofre-nuclear-power-plant-decommission-safety-in-question/5255934/, accessed 10 May 2019.

642 - *WNN*, "Oyster Creek retires after 49 years", 18 September 2018, see http://www.world-nuclear-news.org/Articles/Oyster-Creek-retires-after-49-years, accessed 26 June 2019.

643 - U.S.NRC, "2017 Decommissioning Funding Status Report for Operating Power Reactor Licenses (December 31, 2016)", 21 August 2018, see https://www.nrc.gov/docs/ML1809/ML18096B543.pdf.

Table 11 | Update Decommissioning Status in Three Selected Countries

Status	USA		Germany			Japan	
	May 2018	May 2019	2015	May 2018	May 2019	May 2018	May 2019
"Warm-up-stage"	4	6	10	10	10	20	26[a]
of which defueled	*1*	*1*	*0*	*2*[b]	*4*	*0*	*0*
"Hot-zone-stage"	0	0	3	4	4	0	0
"Ease-off-Stage"	5	5	9	8	8	0	0
"Long-Term Enclosure"	12	12	2	2	2	0	0
Finished	13	13	4	5	5	1	1
of which greenfield	*6*	*6*	*3*	*3*	*3*	*1*	*1*
Total Closed Reactors	34	36	28	29	29	25	27

Sources: compiled by WNISR, 2018, 2019

Notes

a – includes the four Fukushima Daini reactors, not included in 2018

b - corrected from WNISR2018

CASE STUDIES: WESTERN EUROPE, CENTRAL AND EASTERN EUROPE, AND ASIA

The following section provides an in-depth review of developments in five countries in Western Europe, Central and Eastern Europe, and Asia with 19 closed reactors (6 PWR, 3 BWR, 2 GCR, 7 LWGR and 1 PHWR) in Spain, Italy, Lithuania, Russia, and South Korea. Together with the six case studies reviewed in WNISR2018 and updated in WNSIR2019, we cover a total of 159 closed reactors, representing almost 87 percent of the worldwide closed fleet. In Spain, Italy, Lithuania, Russia, and the Republic of Korea 19 reactors are currently awaiting or are in various stages of decommissioning, while none of the observed countries has yet fully decommissioned one reactor. In Lithuania, an RBMK reactor is for the first time undergoing decommissioning.

Spain

Decommissioning Monitoring

As of mid-2019, Spain had three closed reactors with a combined capacity of 1,067 MW. The first was José Cabrera-1, a 241 MW Westinghouse Pressurized Water Reactor or PWR (1-Loop), which was closed in 2006. It was the first Spanish reactor to start and it operated for 37 years east of Madrid. Decommissioning was started after a "transition period" in 2010. Between 2013 and 2015 Westinghouse performed the segmentation (underwater mechanical cutting) and packaging of the reactor pressure vessel as well as the reactor internals.[644] The vessel and some internals were transported to the Cabril Waste Repository, while some internals are still stored

644 - Joseph Boucau, "Special Constraints During Reactor Dismantling Projects", Westinghouse, Presentation at the 3rd World Nuclear Decommissioning & Waste Management Congress (Europe), 18 September 2018.

with the spent fuel on-site in the interim storage facility.[645] The reactor is currently in the ease-off-stage and decommissioning is expected to be completed by 2020. The original budget for decommissioning including site restoration was approximately €150 million or €1,400/kW (US$169 million or US$1,600/kW).[646] In 2016, the cost estimate for the project had nearly doubled to around €259 million or €1,800/kW (US$292 million or US$2,100/kW).[647]

The second reactor to be decommissioning is Vandellos-1, a 480 MW GCR (or UNGG for Uranium Naturel Graphite Gaz) designed and supplied by the French state agency CEA. The GCR was operational from 1972 on and closed in 1990, following an incident in which one of its turbo generators was damaged. The owner of Vandellos-1, Hifrensa, defueled the reactor, conditioned the operational wastes, and extracted the wastes from the graphite silos. After this, Enresa took over decommissioning in 1998 and removed unnecessary conventional structures. The pressure vessel was confined and covered by a protective structure. Dismantling of the vessel and remaining internals is expected to begin in 2028, after an enclosure period of 25 years.[648] At the lower floor of the reactor building a temporary graphite storage facility was installed, where some 1,100 tons of graphite from the sleeves of the fuel used during operation are stored.[649] In 2018, a contract between Enresa and EDF was signed covering a four-year period of engineering support for the enclosure period, the contract includes the preparation of technical and licensing documentation.[650] Although some decommissioning work was done, WNISR considers the reactor as in Long Term Enclosure (LTE), as the main decommissioning work will be carried out after an enclosure period of 25 years.

The third closed reactor is the GE BWR at the Santa Maria de Garoña station, which was operational from 1971 until 2012. Iberdrola has no intentions of bringing the reactor back online, as Garona is not economically viable, and the necessary investments were described as potentially ruinous to the utility (see WNISR2018). The 446 MW BWR will now enter the decommissioning stage. The operator, Nuclenor (a joint venture of Endesa and Iberdrola), will have to defuel the reactor and transfer the spent fuel to the interim storage facility as well as condition the operational wastes. Then, Enresa will take over the ownership of the plant. Enresa estimates that decommissioning will take about ten years.[651] The reactor is currently in the "warm-up-stage". **Table 12** shows the current status of reactor decommissioning in Spain.

645 - Enresa, "Experiences and Lessons Learned: Jose Cabrera NPP Decommissioning Project", Spanish Radioactive Waste Management Agency, Spanish Ministry for the Ecological Transition, 23 January 2018, see https://ec.europa.eu/jrc/sites/jrcsh/files/experiences_and_lessons_learned_jose_cabrera_npp_decommissioning_project.pdf.

646 - Laura Gil, "Tying up loose ends: Spain's successful decommissioning project", *IAEA Bulletin*, 2016, see https://www.iaea.org/sites/default/files/5710607-spain.pdf, accessed 30 August 2019.

647 - NEA/OECD, "Costs of Decommissioning Nuclear Power Plants", Nuclear Energy Agency, Organisation for Economic Co-operation and Development, *OECD/NEA Publishing*, NEA No.7201, 2016.

648 - Enresa, "Dismantling of the Vandellós I Nuclear Power Plant", Undated, see http://www.enresa.es/eng/index/activities-and-projects/dismantling-and-environmental-restoration/dismantling-of-vandellos-i-nuclear-power-plant, accessed 30 April 2019.

649 - Enresa, "Vandellos I Nuclear Power Plant Decomissioning Report 1998-2003", Empresa Nacional de Residuos Radiactivos, 2007.

650 - *WNN*, "Contract awarded for Vandellós 1 engineering support", 22 February 2018, see http://world-nuclear-news.org/Articles/Contract-awarded-for-Vandellos-1-engineering-suppo, accessed 30 April 2019.

651 - *NEI*, "Spain to close its oldest reactor", 4 August 2017, see https://www.neimagazine.com/news/newsspain-to-close-its-oldest-reactor-5891433, accessed 30 April 2019.

Table 12 | Current Status of Reactor Decommissioning in Spain (as of May 2019)

Spain	May 2019
"Warm-up-stage"	1
of which defueled	0
"Hot-zone-stage"	0
"Ease-off-stage"	1
LTE	1
Finished	0
of which greenfield	0
Total Closed Reactors	**3**

Sources: various, compiled by WNISR, 2019

Organizational Challenges

Spain has a national policy for decommissioning its reactors, which is specified by the official government document, the periodically updated "General Radioactive Waste Plan". In this plan, all decommissioning and waste management activities are developed by Enresa. While the long-term enclosure strategy is applied for the GCR Vandellos-1, all Light Water Reactors (LWRs) are bound to be immediately dismantled to a greenfield site. Spain describes decommissioning and waste management as an essential public service and assigns these tasks to the state-owned company Empresa Nacional de Residuos Radiactivos S.A. (Enresa).[652] The operator of the reactor is responsible for spent fuel, or must otherwise provide a spent fuel management plan, as this task falls under activities prior to decommissioning (e.g. defueling the reactor, conditioning of operational wastes).[653] Once these activities are completed, the decommissioning plan set up by Enresa must be approved, before the site is temporarily transferred to Enresa which then becomes the decommissioning licensee.[654] In general, this transition period of conditioning the waste, defueling the reactor and transferring the license is expected to last three years, while the decommissioning works are estimated to last 10 years. Although this seems short compared to the average of 19 years for decommissioned reactors, if Enresa did finish the ease-off stage of the José Cabrera-1 reactor by 2020, decommissioning would indeed have lasted only 10 years. When decommissioning is complete and the "Closure Declaration" has been issued by the regulatory body—the Nuclear Safety Council or CSN[655]—the site will be returned to its former owner.[656]

Enresa is also responsible for managing the funds and liabilities for decommissioning. The external segregated fund is fed by two fees, the rate of which is regulated. The first fee is included in the electricity prices and used to finance waste management decommissioning

652 - By Article 38 bis of Law 25/1964 of the Nuclear Energy Act.

653 - IAEA, "Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management—Sixth Spanish National Report", Report drafted by the Spanish Ministry of Energy, Tourism and the Digital Agenda, the Nuclear Safety Council, the Spanish Radioactive Waste Management Agency, and the Spanish Electrical Industry Association, October 2017, see https://www.iaea.org/sites/default/files/national_report_of_spain_for_the_6th_review_meeting_-_english.pdf, accessed 11 August 2019.

654 - Ibidem.

655 - CSN stands for Consejo de Seguridad Nuclear.

656 - Nuclear Energy Agency, "Radioactive Waste Management and Decommissioning in Spain", Organisation for Economic Co-operation and Development, October 2018, see https://www.oecd-nea.org/rwm/profiles/Spain_report.pdf, accessed 11 August 2019.

activities for those reactors closed prior to 2010 (José Cabrera and Vandellos-1). The second fee is for the reactors that were operating beyond 2010 and stems from the income from operating the reactors.[657] After decommissioning starts, there are no more payments to the fund and in the case of a shortfall, it would be the full responsibility of the decommissioning licensee Enresa and hence the taxpayer to cover these costs.[658]

Italy

Decommissioning Monitoring

Following a referendum on the use of nuclear power in November 1987, triggered by the Chernobyl accident in April 1986, Italy no longer generated nuclear electricity.[659] The Pressurized Water Reactor (PWR) Enrico Fermi (Trino) produced its last kilowatt-hours in March 1987, the GCR Latina and the BWR Caorso in 1986 and the BWR Garigliano in 1978. Caorso is the only larger BWR (860 MW) Italy has to dismantle. The construction projects for the Heavy Water Light Water Reactor (HWLWR) Cirene and the two Boiling Water Reactors (BWRs) at Montalto Di Castro were mothballed after the referendum.

In 2017, Italy estimated the cost to decommission the four reactors that did operate and the consequent waste management at €7.2 billion (US$8.1 billion).[660] While this estimate does not include the disposal of high-level waste, it takes into account interim storage as well as the disposal of low- and intermediate-level waste. The estimate has almost doubled since 2004, when the total estimate was around €4 billion (US$4.5 billion), and more than tripled since the closure of the reactors, when decommissioning of the four reactors was projected to cost €2 billion (US$2.3 billion).[661] In 2004, it was estimated that Sogin (Società Gestione Impianti Nucleari SpA)[662] would decommission the four reactors by 2024.[663] Although Italy has only four units to dismantle, they have to deal with all three major reactor types.

The decommissioning license for **Enrico Fermi** (Trino) was issued in 2012; although, prior to this, some dismantling activities were already carried out, e.g. demolishment of the cooling towers, decontamination of the steam generators and dismantling of turbine components. Since 2015, the spent fuel pools have been defueled. Enrico Fermi is currently in

657 - IAEA, "Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management—Sixth Spanish National Report", Report drafted by the Spanish Ministry of Energy, Tourism and the Digital Agenda, the Nuclear Safety Council, the Spanish Radioactive Waste Management Agency, and the Spanish Electrical Industry Association, October 2017.

658 - NEA/OECD, "Costs of Decommissioning Nuclear Power Plants", *OECD/NEA Publishing*, NEA No.7201, 2016, op. cit.

659 - WNISR considers the day of the last electricity generation as the closure date.

660 - David Dalton, "Italy's €7.2 Billion Decommissioning Cost Estimate Is Robust And Thorough, Says IAEA", *NucNet*, 21 September 2017, see https://www.nucnet.org/all-the-news/2017/09/21/italy-s-7-2-billion-decommissioning-cost-estimate-is-robust-and-thorough-says-iaea, accessed 3 May 2019.

661 - Wolfgang Irrek et al., "Comparison among different decommissioning funds methodologies for nuclear installations—Country Report Italy", Final Report, Wuppertal Institute for Climate, Environment and Energy, on behalf of the Directorate-General Energy & Transport of the European Commission, 2007, see https://epub.wupperinst.org/frontdoor/deliver/index/docId/2596/file/2596_EUDecommFunds_IT.pdf, accessed 11 August 2019.

662 - Sogin is the Italian state-owned company responsible for the decommissioning of Italian nuclear plants and the management of radioactive waste.

663 - Wolfgang Irrek et al., "Comparison among different decommissioning funds methodologies for nuclear installations—Country Report Italy", Wuppertal Institute for Climate, Environment and Energy, on behalf of the DG Energy & Transport of the EU-Commission, 2007.

the "warm-up-stage" and Sogin expects to conclude decommissioning by 2031.[664] The waste generated during operation as well as from decommissioning are stored on-site awaiting the opening of the national repository.

The pools of **Garigliano** have been defueled since 1987, when the last fuel elements were sent for reprocessing to the U.K. or for storage to the centralized interim storage facility Avogadro in Saluggia. The decommissioning license for Garigliano was issued in 2012, although Sogin has carried out some decommissioning work since 2000, e.g. demolition of the chimney and decontamination of the internal systems. In 2012, calls for tender were issued for dismantling the internal systems of the reactor and turbine buildings and Garigliano should soon enter the "hot-zone-stage". Sogin expects to conclude decommissioning by 2026.[665] The waste generated during operation as well as from decommissioning are stored on-site until a national repository opens.

The decommissioning license for **Caorso** was issued in 2014. As for the other light water reactors, some dismantling works have been carried out prior to the issuing of the license, in the case of Caorso since 2004, e.g. decontamination works, demolition of the auxiliary cooling towers, underwater decontamination and extraction of the contaminated materials in the plant's pool. The reactor has been defueled since 2010, when the spent fuel was sent to France for reprocessing. Caorso is currently in the "warm-up-stage" and Sogin expects to conclude decommissioning by 2031.[666]

Table 13 | Current Status of Reactor Decommissioning in Italy (as of May 2019)

Italy	May 2019
"Warm-up-stage"	4
of which defueled	*4*
"Hot-zone-stage"	0
"Ease-off-stage"	0
LTE	0
Finished	0
of which greenfield	*0*
Total Closed Reactors	**4**

Sources: various, compiled by WNISR, 2019

The only GCR in Italy, **Latina**, has been defueled in the early 1990s and the spent fuel sent to the U.K. for reprocessing. The decommissioning license for Latina was expected in 2018 but had not yet been granted as of mid-2019. Since 2006, some decommissioning works have been carried out, e.g. dismantling of the upper pipelines of the primary circuit, dismantling of the turbine and of the building. Sogin currently expects to finish decommissioning up

664 - Sogin, "Trino nuclear power plant Vercelli - Decommissioning", 2019, see https://www.sogin.it/en/closureoftheitaliannuclearcycle/italian-nuclear-sites/trinonuclearpowerplant/Pagine/default.aspx, accessed 6 May 2019.

665 - Sogin, "Garigliano nuclear power plant Caserta - Decommissioning", 2019, see https://www.sogin.it/en/closureoftheitaliannuclearcycle/italian-nuclear-sites/gariglianonuclearpowerplant/Pagine/default.aspx, accessed 6 May 2019.

666 - Sogin, "Caorso nuclear power plant Pacenza - Decommissioning", 2019, see https://www.sogin.it/en/about-us/environmental-remediation-of-nuclear-sites/where-we-are/caorso-nuclear-power-plant-%e2%80%93-piacenza.html, accessed 6 May 2019.

to the brownfield stage with waste storage on-site by 2027.[667] Then it will start with the decommissioning of the reactor building until it reaches the stage of greenfield site. As with all of the other reactors, wastes are currently stored on-site, but the GCR Latina depends more than any other reactor on the opening of a national repository as the dismantling of the reactor will produce around 2,000 tons of highly radioactive graphite. **Table 13** shows the current status of reactor decommissioning in Italy.

Organizational Challenges

In 1999, the state-owned Sogin (Società Gestione Impianti Nucleari SpA) was established during the privatization process of Enel with the task to decommission Italy's nuclear power plants as well as finding a national waste storage site. The shareholder of Sogin is the Ministry of Economy and Finance, while the strategic and operational directives come from the Ministry of Economic Development. At the same time, the initial strategy of long-term enclosure was changed to immediate dismantling. As there is no disposal facility available, the national decommissioning strategy is divided into two distinct phases with an estimated endpoint set at 2035:

- First phase: Decommissioning up to brownfield level: dismantling and waste treatment activities have been completed and the waste is stored on-site. The duration of this phase depends on the availability of the disposal facility.
- Second phase: Decommissioning of the reactor itself up to greenfield level: transferal of all the wastes to the repository and release of the site from regulatory control.

Italian legislation allows to authorize specific dismantling activities before the overall decommissioning plan is approved, if these activities benefit safety and radiation protection, some of which are underway (e.g., decontamination works, conditioning, construction of interim storages).[668] In 2018, Sogin signed a €28 million (US$31.6 million) contract with Cyclife, an EDF subsidiary, for waste treatment for three reactors worth.[669] As opposition to on-site interim storage of spent fuel was strong, Italy signed an agreement with France to send its 235 tons of spent fuel to France for reprocessing. Shipments from Caorso were completed in 2010, those from Enrico Fermi in 2015. All of the fuel has been reprocessed at the Orano plant at La Hague. High- and intermediate-level waste will have to be returned to Italy.

Until 1987, during the operation of the nuclear power plants, the operator ENEL set aside internal, non-segregated funds. The early closure of the reactors prevented the operator of accumulating the total and needed amount of decommissioning funding. The funds, around €800 million (US$904 million), were transferred to Sogin after its creation in 1999; they were part in cash and assets and part in credits from the public entity CCSE[670], a national fund that

667 - Sogin, "Latina nuclear power plant Latina - Decommissioning", 2019, see https://www.sogin.it/en/closureoftheitaliannuclearcycle/italian-nuclear-sites/latinanuclearpowerplant/Pagine/default.aspx, accessed 21 August 2019.

668 - ISPRA, "Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management—Fifth Italian National Report", Joint Report, National Centre for Nuclear Safety and Radiation Protection of the Institute for the Environmental Protection and Research, on behalf of the Italian Government, October 2017, see https://www.iaea.org/sites/default/files/6rm-italy.pdf, accessed 12 August 2019.

669 - *WNN*, "EDF subsidiary wins Italian waste reduction contract", 7 February 2018, see http://www.world-nuclear-news.org/Articles/EDF-subsidiary-wins-Italian-waste-reduction-contra, accessed 6 May 2019.

670 - CCSE which stands for La Cassa conguaglio per il settore elettrico, is now Cassa per i servizi energetici e ambientali, or CSEA.

pays for all decommissioning costs occurring at Sogin.[671] Since then, decommissioning funds are accumulated through a levy on the electricity price at a level set by the electricity market regulator.[672] The levy is allocated by the distribution companies and transferred bimonthly to the national fund. The levy and the decommissioning programs are reviewed every three months and any decommissioning shortfall is addressed by adjusting the levy on the electricity bill.[673] CSEA supposedly pays all decommissioning costs of Sogin, but independent experts highlight that it is not transparent how much money has already been paid to Sogin in total.[674] The resources are still held in internal and unrestricted funds, only they are now in state hands and money has been partly used for purposes of public interest other than decommissioning; the state is free to use the money being paid to CCSE for any purpose. However, in the end the state and hence the taxpayer remains responsible for all decommissioning and waste disposal costs.

Lithuania

Decommissioning Monitoring

Lithuania operated two Soviet-Style RBMK-1500 reactors at the Ignalina station. The two 1,185 MW (each) reactors were closed in 2004 and 2009 as a requirement for Lithuania to join the European Union. The two reactor cores are defueled, but the spent fuel in the pools has not yet been evacuated as the interim storage facility is delayed by more than 10 years.[675] The transferal of all spent fuel to the on-site dry interim-storage facility is a prerequisite for the decommissioning license.[676] Although no license has yet been granted, decommissioning work (e.g., in the turbine building or auxiliary buildings) is being carried out. All the hot-zone work still lies ahead and even plans for the dismantling of the reactor cores or primary circuit have not yet been completed, 18 years after closure.[677] The decommissioning end date has, since 2011, been postponed by further 9 years to 2038. It is planned to decommission Ignalina to "brownfield" status.[678] **Table 14** shows the current status of reactor decommissioning in Lithuania.

671 - Wolfgang Irrek et al., "Comparison among different decommissioning funds methodologies for nuclear installations—Country Report Italy", Wuppertal Institute for Climate, Environment and Energy, on behalf of the Directorate-General Energy & Transport of the European Commission, 2007, see https://epub.wupperinst.org/frontdoor/deliver/index/docId/2596/file/2596_EUDecommFunds_IT.pdf, accessed 11 August 2019.

672 - NEA/OECD, "Costs of Decommissioning Nuclear Power Plants", *OECD/NEA Publishing*, NEA No.7201, 2016, op. cit.

673 - Ibidem.

674 - Wolfgang Irrek et al., "Comparison among different decommissioning funds methodologies for nuclear installations—Country Report Italy", Final Report, Wuppertal Institute for Climate, Environment and Energy, on behalf of the Directorate-General Energy & Transport of the European Commission, 2007, op. cit.

675 - ENSREG, "Lithuania", Updated 6 February 2019, see http://www.ensreg.eu/country-profile/Lithuania, accessed 20 June 2019.

676 - Ignalina Nuclear Power Plant, "The list of documents of the State Enterprise Ignalina NPP required to issue a license for decommissioning and the schedule for their submission were agreed", 6 December 2018, see https://www.iae.lt/en/the-list-of-documents-of-the-state-enterprise-ignalina-npp-required-to-issue-a-license-for-decommissioning-and-the-schedule-for-their-submission-were-agreed/323, accessed 20 June 2019.

677 - European Court of Auditors, "EU nuclear decommissioning assistance programmes in Lithuania, Bulgaria and Slovakia: some progress made since 2011, but critical changes ahead", Special Report, No.22, 2016, see https://www.eca.europa.eu/Lists/ECADocuments/SR16_22/SR_NUCLEAR_DECOMMISSIONING_EN.pdf, accessed 12 August 2019.

678 - Ibidem.

Table 14 | Current Status of Reactor Decommissioning in Lithuania (as of May 2019)

Lithuania	May 2019
"Warm-up-stage"	2
of which defueled	0
"Hot-zone-stage"	0
"Ease-off-stage"	0
LTE	0
Finished	0
of which greenfield	0
Total Closed Reactors	**2**

Sources: various, compiled by WNISR, 2019

Funding Challenges

Due to high decommissioning costs and the fear of rising electricity prices, the EU decided to financially support decommissioning in Lithuania until 2020. Starting in 1999, the EU had already provided financial and technical assistance to EU candidate countries under the PHARE program.[679] The European Commission entrusts budget implementation to the European Bank for Reconstruction and Development (EBRD). With the Ignalina International Decommissioning Support Fund (IIDSF), the EU committed to assist Lithuania in implementing decommissioning, with specific emphasis on managing radiological safety challenges. The EU covers more than half of the costs for the decommissioning of Ignalina. A 2016 report by the European Court of Auditors concluded that the EU funding programs for decommissioning have not created the right incentives for timely and cost-effective decommissioning. The auditors conclude that the funding programs should be discontinued after 2020, when EU support for Lithuania will have totaled €1.8 billion (US$2 billion).[680]

Between 2010 and 2015, costs increased by 67 percent to an estimated total of €3.4 billion (US$3.8 billion) and, as of 2015, the country faced a financing gap of €1.6 billion (US$1.8 billion). If high-level waste management and spent fuel disposal were included, the total costs were estimated at €6 billion (US$6.8 billion) and the financing gap would more than double to €4.2 billion (US$4.7 billion).[681]

Actual decommissioning work is carried out by the state enterprise INPP (Ignalina Nuclear Power Plant). Further delays are likely, as the construction of the above-surface facility for low- and medium-level wastes is still in the design phase, while the buffer storage facility was already 80 percent full in 2015. In addition, Lithuania faces a lack of qualified engineers for decommissioning, as this is the first RBMK decommissioning project anywhere; qualified international experts are also missing.

679 - In addition, the Central Project Management Agency, a national public-sector body, acts as a second implementing body, and performs the same functions as the European Bank for Reconstruction and Development (EBRD).

680 - European Court of Auditors, "EU nuclear decommissioning assistance programmes in Lithuania, Bulgaria and Slovakia: some progress made since 2011, but critical changes ahead", Special Report, No.22, 2016.

681 - Ibidem.

Russia

Decommissioning Monitoring

As of mid-2019, Russia had eight closed reactors with a combined capacity of 2,107 MW consisting of two different reactor types: five first-generation light-water gas-cooled reactors (LWGR)—among them one Chernobyl-style reactor—and three Soviet-style Pressurized Water Reactors (PWRs).

In 1983, Russia officially closed its first reactor with **Beloyarsk-1**, a 102 MW LWGR (AMB-100), 19 years after it was first connected to the grid. The closure of **Beloyarsk-2**, a 146 MW LWGR, followed seven years later in 1990 after 23 years of operation. The two reactors were defueled and put into long-term enclosure.[682] At the same site, the only two Russian Fast Breeder Reactors (FBRs) remain in operation.

Two Soviet-style PWRs, Unit 1 (197 MW) and 2 (336 MW) of **Novovoronezh** were closed in 1988 and 1990 respectively. In 2011, the preparation for the long-term enclosure started. Although some equipment was already dismantled in the machinery hall, actual dismantling work was planned to start in 2055 and be completed in 2060.[683] Spent fuel pools have been dismantled, as the station has an operating independent storage facility.[684] As this constitutes the first Russian VVER decommissioning project, Rosatom created a pilot and demonstration engineering center for decommissioning at the site to test and probe decommissioning technologies.[685] In 2016, Unit 3, the first VVER-440 was closed, four months after Novovoronezh 2-1 was connected to the grid. The reactor had been operational for 45 years, 15 years longer than originally envisaged.[686] In 2017, the head of decommissioning of Rosatom announced at a forum that the immediate dismantling strategy would bring decommissioning cost down by 20 percent; this might mean that decommissioning could be accelerated for economic reasons.[687] However, in 2019, it is still unclear if the strategy will be long-term enclosure or immediate dismantling. Therefore, the reactors are classified as LTE as long as there is no clear evidence of decommissioning progress.

APS-1 Obninsk was the first European reactor and often described as the worldwide first reactor for commercial production of electricity. The reactor is located at the Obninsk Institute for Nuclear Power Engineering, which was turned into a museum. In 2002, the 5 MW LWGR AM-1 reactor was closed after 48 years of operation. Six years later, in 2008, the reactor was

682 - Oskar Njaa, Nils Bøhmer and Charles Digges, "Russian Nuclear Power 2018", Bellona, 2018, see https://network.bellona.org/content/uploads/sites/2/2018/08/Russian-Nuclear-Power-2018.pdf, accessed 12 August 2019.

683 - Artem Izmestev, "Russian Strategy for Decommissioning of NPPs", presented at the International Conference on Nuclear Decommissioning, 18 May 2015.

684 - Russian Federation, "The Fifth National Report of the Russian Federation on Compliance with the Obligations of the Joint Convention on the Safety of Spent Fuel Management and the Safety of Radioactive Waste Management", Drafted by Rosatom, the Federal Environmental, Industrial and Nuclear Supervision Service, the Nuclear Safety Institute of the Russian Academy of Science, and the Federal State-Funded Institution Scientific and Engineering Center for Nuclear and Radiation Safety, Prepared for the Sixth Review Meeting of the Joint Convention, IAEA, 2017, see https://www.iaea.org/sites/default/files/russian-federation-eng-jc.pdf, accessed 12 August 2019.

685 - Artem Izmestev, "Russian Strategy for Decommissioning of NPPs", presented at the International Conference on Nuclear Decommissioning, 18 May 2015.

686 - Charles Digges, "Russia's first VVER-440 reactor shuts for decommissioning", Bellona, 12 January 2017, see https://bellona.org/news/nuclear-issues/2017-01-russias-first-vver-440-reactor-shuts-for-decommissioning, accessed 26 June 2019.

687 - Oskar Njaa, Nils Bøhmer and Charles Digges, "Russian Nuclear Power 2018", Bellona, 2018, op. cit.

defueled but no information is given on the amount and condition of the stored spent fuel. Decommissioning is expected to last until 2080 and is "hobbled by bumbling secrecy"; in addition, it turned out at a public hearing that the company that owns the reactor does not have a decommissioning license.[688] Considering the very distant decommissioning completion date, the WNISR classifies the reactor as LTE.

Leningrad-1 was the first RBMK-1000 reactor. The 925 MW LWGR was closed on 22 December 2018 after 45 years of operation. All NPPs with RMBK1000 reactors have independent storage facilities[689] and defueling is estimated to last until 2023.[690] The RBMK reactors were not constructed with decommissioning in mind and the 2000 tons of heavy graphite stacks, where fuel is fed into via channels, pose particular technological challenges. How to safely dismantle the graphite seems unanswered, not only in Russia but worldwide. It is estimated that decommissioning will last at least 50 years and dismantling all four reactors at the Leningrad station would cost around US$820 million.[691] This figure is of course highly speculative and seems an underestimate, especially if compared to the two reactors in Lithuania, where the estimated costs have increased by 67 percent in the last five years to more than €3 billion (US$3.7 billion) for just two reactors. The remaining three RBMK-1000 reactors at the Leningrad station are expected to be closed between 2021 and 2026.[692] The only comparable project in Russia is the decommissioning of the five graphite moderated plutonium production reactors at the Mayak site, where, according to leaked documents, Russia intends to bury these reactors onsite, rather than dismantling and safely managing the graphite stacks.[693]

In January 2019, decommissioning of **Bilibino**, a small 11 MW light-water gas-cooled reactor, was approved after it had remained shut down since March 2018. WNISR classifies the reactor as LTE, unless contradicting evidence emerges, considering the anticipated long decommissioning duration of 50 years and the fact that the dominating strategy for graphite-moderated reactors in the world is LTE.

Organizational Challenges

In Russia, enterprises and organizations are expected to have earmarked finances to cover the costs associated with decommissioning; for this purpose "special reserve funds" were established within the state corporation Rosatom.[694] Information about the Russian

688 - Charles Digges, "Russia's decommissioning of historic reactor hobbled by bumbling secrecy", Bellona, 12 April 2018, see https://bellona.org/news/nuclear-issues/2018-04-russias-decommissioning-of-historic-reactor-hobbled-by-bumbling-secrecy, accessed 26 June 2019.

689 - Russian Federation, "The Fifth National Report of the Russian Federation on Compliance with the Obligations of the Joint Convention on the Safety of Spent Fuel Management and the Safety of Radioactive Waste Management", Prepared for the Sixth Review Meeting of the Joint Convention, IAEA, 2017.

690 - Charles Digges, "Russia retires Reactor No 1 at the Leningrad nuclear plant", Bellona, 9 January 2019, see https://bellona.org/news/nuclear-issues/2019-01-russia-retires-reactor-no-1-at-the-leningrad-nuclear-plant, accessed 26 June 2019.

691 - Charles Digges, "Decommissioning Russia's RBMK reactors by waiting for better days", Bellona, 14 January 2019, see http://bellona.org/news/nuclear-issues/2019-01-decommissioning-russias-rbmk-reactors-by-waiting-for-better-days, accessed 15 January 2019.

692 - *NEI*, "What's next for Leningrad?", see https://www.neimagazine.com/features/featurewhats-next-for-leningrad-7183813/, accessed 12 July 2019.

693 - Charles Digges, "Decommissioning Russia's RBMK reactors by waiting for better days", Bellona, 14 January 2019, op. cit.

694 - Russian Federation, "The Fifth National Report of the Russian Federation on Compliance with the Obligations of the Joint Convention on the Safety of Spent Fuel Management and the Safety of Radioactive Waste Management", Prepared for the Sixth Review Meeting of the Joint Convention, IAEA, 2017.

decommissioning fund has been inconclusive and contradictory; the terms "reserve" and "funds" have different institutional components.[695] The first phase of decommissioning regulation started in 1995, under Boris Yeltsin, with the adaptation of the Russian Federation Law on the use of nuclear energy. With this the responsibility for establishing a system for financing decommissioning was assigned to the government and the organization of decommissioning to the operating utility, i.e. Rosatom, who should also create a fund within its budget for decommissioning.[696] In 2002, it was established that Rosatom should transfer money to a "reserve" and that this amount should be 1.3 percent of the gross income generated by the sale of electricity. Independent experts argue that the substitution of the word 'fund' by 'reserve' may lead to a weaker control of how Rosatom can manage the allocated finances.[697] In addition, money flow into the fund for decommissioning also comes from regional and federal budget sources, but it is unclear how much.[698] As only 8 of the 43 operational and closed reactors started operation after 2002, the majority of the reactors did not generate allocations to decommissioning themselves, and money from the reserves is already spent on current decommissioning projects, though it is not clear how much.[699] In 2012, the percentage of revenues that has to be put aside into the funds was increased to 3.2 percent.[700] According to Rosatom, around €160 million (US$182 million) were accumulated in the fund by 2015.[701] To put the amount into perspective, this is roughly a fifth of the estimated decommissioning costs for the four Leningrad reactors. In addition, if the numbers from Lithuania's Ignalina site are taken as reference, the decommissioning of the four Leningrad RBMKs will cost more likely around €6 billion (US$6.7 billion). It is obvious that in addition to technological challenges with dismantling, Russia has not set aside appropriate finances for decommissioning and heavily underestimates decommissioning costs. It is unclear how Russia will handle this challenge in the future. One way out would be the long-term enclosure of the closed reactors, while other units still generate income. A much riskier strategy that Russia has apparently adopted consists in the building of new reactors dedicated to generate income to replace ageing, life-extended units,[702] pushing the financing challenge further into the future.

South Korea

Decommissioning Monitoring

South Korea is operating a large nuclear program, including 26 power reactors. As of mid-2019, two commercial reactors had been closed: South Korea's oldest unit Kori-1 (576 MW) was taken

695 - Kjersti Album et al., "Report 2006—Status of Russia's decommission fund", Decommission, Green World, Naturvernforbundet/Friend of the Earth Norway, et al., May 2006.

696 - Ibidem.

697 - Ibidem.

698 - Ibidem.

699 - Kjersti Album, et al., "How to pay?—Financing decommissioning of nuclear power plants", Naturvernforbundet/Friends of the Earth Norway, May 2017, see https://naturvernforbundet.no/getfile.php/13122760/Bilder/International%20projects/Report%20How%20To%20Pay%202017.pdf, accessed 26 June 2019.

700 - Ibidem.

701 - Ibidem.

702 - Oskar Njaa, Nils Bøhmer and Charles Digges, "Russian Nuclear Power 2018", Bellona, 2018, op. cit.

offline in June 2017, and Wolsong-1, that ceased operation in May 2017, officially terminated its commercial operation in June 2018.[703]

In 2016, the operator Korea Hydro and Nuclear Power (KHNP) submitted an application to decommission Kori-1, the first reactor to enter the decommissioning phase in the country. A final and detailed decommissioning plan is being developed and has to be submitted by KHNP to the regulator by 2021. In June 2018, the decision was taken to close Wolsong-1, which had not generated power since 2017 (see **South Korea Focus** for details).

Decommissioning of Kori-1 is estimated to start in mid-2022, last until 2032, and cost around US$570 million or US$990/kW.[704] According to the Moon administration's policy, South Korea will implement a nuclear phase-out policy in the long run. Existing capacity will not be extended after the completion of the units under construction and operating licenses not be granted beyond a reactor's design lifetime. Kori-2 is the next unit to be closed in 2023, followed by nine additional ones prior to 2030 (see **Table 6**). In the next decades, South Korea is expected to build up its own decommissioning industry. Meanwhile, the Korean Atomic Energy Research Institute (KAERI) is taking steps to enhance decommissioning expertise and a series of contracts were signed to develop suitable technologies.

CONCLUSION ON REACTOR DECOMMISSIONING

Decommissioning is only at its very beginnings. Assuming a 40-year average lifetime, a further 207 reactors will close by 2030 (reactors connected to the grid between 1979 and 1990); and an additional 125 will be closed by 2059; this does not even account for the 85 reactors which started operating before 1979, additional 28 reactors in Long-term Outage (LTO) and 46 units under construction as of mid-2019. Around 60 percent of the closed reactors are located in Europe (85 in Western Europe and 23 in Central & Eastern Europe), followed by North America (42 reactors), and Asia (31 reactors). As of the first quarter of 2019, 162 units are globally awaiting or in various stages of decommissioning, eight more than in the first quarter of 2018. No reactor completed decommissioning worldwide since WNISR2018. Still, only 19 reactors, with a capacity of 6 GW were fully decommissioned. The average duration of the decommissioning process, independent of the chosen strategy, is around 19 years. Again, of these 19 reactors only 10 have been released as so-called greenfield sites.

Around three-quarters of the closed reactors are in the three major reactor technology streams: Pressurized Water Reactor, Boiling Water Reactor and Gas-Cooled Reactor. Not one graphite-moderated reactor has yet been decommissioned (see case studies on France and the U.K. in WNISR2018); this also holds true for Light Water Cooled and Graphite Moderated Reactors such as the Chernobyl-type RBMK. How to safely dismantle graphite reactors has yet to be demonstrated, not only in Russia but worldwide. The internationally preferred strategy is long-term enclosure, although some countries, including Italy and Lithuania, appear to be opting for immediate dismantling. This remains to be seen, as the reactors are still in the warm-up stage and the Ignalina reactors in Lithuania are not even yet fully defueled.

703 - KHNP, "Nuclear Power Operation - Plant Status", 31 December 2018, see http://cms.khnp.co.kr/eng/content/529/main.do?mnCd=EN03020101, accessed 27 March 2019.

704 - Jane Chung, "South Korea to complete dismantling of oldest nuclear reactor by 2032", *Reuters*, 19 June 2017, see https://www.reuters.com/article/us-southkorea-nuclear-idUSKBN19A02R, accessed 26 June 2019.

The U.S. is still the most advanced in decommissioning reactors but since last year there was no tangible progress. A new organizational model of selling decommissioning licenses to a contractor is gaining popularity. Of the ten reactors undergoing decommissioning in 2019, a majority of six were sold to decommissioning companies. The waste management company EnergySolutions seems to be involved in most if not in all U.S. decommissioning projects and plans to enter the Japanese market. Limited-liability decommissioning companies appear to operate according to business incentives that are starting to attract regulatory and legal attention.

In Spain, a national policy is in place and a public enterprise is taking over decommissioning and managing the funds. With one reactor in the ease-off stage, Spain is close to finishing one decommissioning project. While 30 years after abandoning nuclear, Italy is just starting decommissioning. Since closure, cost estimates have increased threefold. In Lithuania, the European Union is covering more than half of the costs for the worldwide first decommissioning of RBMK reactors. A report by the European Court of Auditors concludes that the EU funding programs for decommissioning have not created the right incentives for timely and cost-effective decommissioning and that the funding programs should be discontinued after 2020.

As other early nuclear countries France, Canada, and the UK, Russia has not yet decommissioned one single reactor (see overview in **Table 15**). Overall decommissioning experience seems to be scarce, as apparently all Russian closed reactors are going into long-term enclosure. Russia especially faces challenges concerning the decommissioning of its 11 RBMK reactors. Information about the Russian decommissioning fund has been inconclusive and contradictory.

Table 15 | Overview of Reactor Decommissioning in 11 Selected Countries (as of May 2019)

Country	Closed Reactors	Decommissioning Process				
		Warm-up	Hot Zone	Ease-off	LTE	Completed
Canada	6	0	0	0	6	0
France	12	3	1	0	8	0
Germany	29	10	4	8	2	5 [17%]
Japan	27	26	0	0	0	1 [4%]
United Kingdom	30	0	0	0	30	0
USA	36	6	0	5	12	13 [36%]
Spain	3	1	0	1	1	0
Italy	4	4	0	0	0	0
Lithuania	2	2	0	0	0	0
Russia	8	0	0	0	8	0
South Korea	2	2	0	0	0	0
Total	**159**	**54**	**5**	**14**	**67**	**19**

Sources: various, compiled by WNISR, 2019

POTENTIAL NEWCOMER COUNTRIES

On 26 June 1954, the Obninsk reactor in Russia became the first nuclear reactor connected to a grid to supply electricity. By 1985, 20 additional countries generated power by nuclear fission and 65 years after the first one, only 31 ountries host power reactors—16 percent of the United Nations' 193 Member States. Only four new countries (Mexico, China, Romania, Iran) started up power reactors over the past 30 years, while three (Italy, Kazakhstan and Lithuania) have closed down their programs (see **Figure 1**).

Nuclear power continues to be slowly deployed or developed in a number of additional countries for the first time. The World Nuclear Association (WNA) suggests that there are 30 countries in which nuclear energy is being considered, planned or being built for the first time, with an additional 20 countries that have "at some time" expressed an interest in developing nuclear power. The WNA further categorizes those countries in which nuclear power is being planned into five separate groups[705]:

- Power reactors under construction: Bangladesh, Belarus, Turkey and United Arab Emirates (UAE).
- Contracts signed, legal and regulatory infrastructure well-developed or developing: Lithuania, Poland and Vietnam (but deferred).
- Committed plans, legal and regulatory infrastructure developing: Egypt and Jordan.
- Well-developed plans but commitment pending: Kazakhstan, Indonesia, Thailand, Saudi Arabia, Uzbekistan; or commitment stalled: Italy.
- Developing plans: Israel, Nigeria, Kenya, Laos, Malaysia, Morocco, Algeria.

The main difference from previous years is that the WNA has removed Chile from the list of countries with well-developed plans and added Uzbekistan.

This section of the report will look at the countries where the WNA considers nuclear plans are at least "well developed". The WNA-classification is debatable, as can be seen in the analysis hereunder.

705 - WNA, "Emerging Nuclear Energy Countries - New Nuclear Build Countries", March 2019, see http://www.world-nuclear.org/information-library/country-profiles/others/emerging-nuclear-energy-countries.aspx, accessed 18 April 2019.

UNDER CONSTRUCTION

Bangladesh

On 30 November 2017, Bangladesh officially began construction of the first unit of the Rooppur nuclear plant.[706] Unit 1 is scheduled to begin operation in 2023 followed by unit 2 in 2024.[707] The construction license for Unit 2 was granted in July 2018.[708] The idea of building nuclear reactors at Rooppur goes back to even before Bangladesh became an independent country, to a 1963 plan by the Pakistan Atomic Energy Commission (PAEC) to build one reactor in West Pakistan and one in East Pakistan, as Bangladesh was then called.[709]

The current reactor deal dates back to November 2011 when the Bangladeshi Government announced that it was prepared to sign a deal with the Russian Government for two 1,000 MW units—the first of which was to start up between 2017 and 2018—at a total cost of US$1.5–2 billion.[710] Since then, although negotiations have reportedly been ongoing, the start-up date has been continually postponed and the expected construction cost has risen sharply.

By 2015, the Bangladeshi Finance Minister was quoted as saying the project was then expected to cost US$12.65 billion.[711] However, even this is not likely to be the final cost with suggestions that this is not a fixed-price contract, but a "cost-plus-fee" contract, so "the vendor has the right to come up with any cost escalation (plus their profit margin) to be incorporated into the contract amount" and that the eventual cost of generating power would be "at least 60 percent higher than the present retail cost" of electricity in Bangladesh.[712] The size of the loan is extremely large and is roughly half of Bangladesh's outstanding external debt, estimated at US$26 billion, to which the nuclear debt will be added.[713]

If and when completed, the reactors would have a major impact on the electricity supply mix in the country, whose installed capacity in 2018 was about 16 GW.

The December 2015 agreement was said to be signed between the Bangladesh Atomic Energy Commission (BAEC) and Rosatom for 2.4 GW of capacity, with work then expected to begin in 2016 and operation to start in 2022 and 2023.[714] According to the deal, Russia would provide

706 - WNISR, "Construction Start at First Nuclear Power Plant in Bangladesh", 2 December 2017, see https://www.worldnuclearreport.org/Construction-Start-at-First-Nuclear-Power-Plant-in-Bangladesh.html, accessed 29 June 2018.

707 - *NEI*, "Work begins on foundation for unit 1 of Bangladesh NPP", 6 April 2018, see http://www.neimagazine.com/news/newswork-begins-on-foundation-for-unit-1-of-bangladesh-npp-6107152/, accessed 22 April 2018.

708 - *NEI*, "Construction licence granted for second Bangladesh reactor", 10 July 2018, see https://www.neimagazine.com/news/newsconstruction-licence-granted-for-second-bangladesh-reactor-6239837/, accessed 18 April 2019.

709 - IAEA, "Country Nuclear Power Profiles—Bangladesh", Updated 2012, see https://www-pub.iaea.org/mtcd/publications/pdf/cnpp2012_cd/countryprofiles/Bangladesh/Figures/Bangladesh%20CNPP.pdf, accessed 8 May 2018.

710 - Srinivas Laxman, "Bangladesh & Russia Sign N-Plant Deal For Two Reactors At Rooppur", *Asian Scientist*, 4 November 2011, see https://www.asianscientist.com/2011/11/topnews/rooppur-nuclear-power-project-bangladesh-russia-sign-nuclear-agreement-2011/, accessed 22 April 2018.

711 - *WNN*, "Bangladesh, Russia ink $12.65 billion Rooppur plant deal", 29 December 2015, see http://www.world-nuclear-news.org/NN-Bangladesh-Russia-ink-12.65-billion-Rooppur-plant-deal-29121501.html, accessed 22 April 2018.

712 - A Rahman, "Ruppur Nuclear Power Plant: Bangladesh's Potential Blackhole", *The Daily Star*, 31 December 2015, see http://www.thedailystar.net/op-ed/politics/ruppur-nuclear-power-plant-bangladeshs-potential-blackhole-194017, accessed 22 April 2018.

713 - Rakesh Shama, "Is Bangladesh Ready for Nuclear?", *NIW*, 22 December 2018.

714 - *WNN*, "Bangladesh, Russia Ink $12.65 Billion Rooppur Plant Deal", 29 December 2015.

90 percent of the funds on credit at an interest rate of Libor plus 1.75 percent. Bangladesh will have to pay back the loan in 28 years with a 10-year grace period. As in other countries, Russia has offered to take back the spent fuel for reprocessing.[715] In late May 2016, negotiations were concluded over the US$12.65 billion project, with Russia making available US$11.385 billion.[716] The Bangladesh government allocated just US$77.62 million for "phase 1" of the project and in December 2018 announced that it was allocating US$42.33 million for "phase 2.[717] The government of Bangladesh has exempted the project from all taxes and duties, including regulatory duty, advanced VAT import duty, VAT and supplementary duty on all imported goods, parts and machinery.[718]

In late June 2016, the Atomic Energy Regulatory Authority issued a site license and then a few days later the country's cabinet approved the May Intergovernmental Agreement.[719] In April 2017, Tass, the Russian news agency, reported that permission to start construction had been granted and that work would commence in the second half of 2017.[720] In January 2019, the Government of Bangladesh signed a nuclear support contract with Russia for the supply of fuel during the operational life of the reactor,[721] with all used fuel to be sent back to Russia.[722]

There is growing concern about the project and the lack of information over the impact on water use. Pressing concerns have also been raised over the lack of preparedness of emergency planning and possible terrorist acts against the facility.[723] Others have pointed to the unsuitability of the site, with concerns over flooding, earthquakes and shifting alluvial soil, plus water shortages and high water temperatures that could affect cooling.[724] Critics of the project also claimed that Bangladesh lacks the skilled labor and adequate regulators to oversee the operation of the nuclear power plant.[725] Bangladesh clearly wants help from other countries, which might explain why it appointed India's Global Centre for Nuclear Energy Partnership (GCNEP) in 2017 to oversee the development and operation of the Rooppur nuclear facilities.[726]

715 - *NW*, "Bangladesh will begin construction of first nuclear unit in August 2017: official", 14 April 2016.

716 - *NEI*, "Russia initials credit agreement with Bangladesh for Rooppur NPP", 30 May 2016, see http://www.neimagazine.com/news/newsrussia-initials-credit-agreement-with-bangladesh-for-rooppur-npp-4907672/, accessed 22 April 2018.

717 - *NEI*, "Bangladesh allocates budget for Rooppur", 7 December 2018, see https://www.neimagazine.com/news/newsbangladesh-allocates-budget-for-rooppur-6896443/, accessed 18 April 2019.

718 - Khondaker Golam Moazzem, "The Power and Energy Sector of Bangladesh: Challenges of Moving beyond the Transition Stage", Center for Policy Dialogue, March 2019, see https://cpd.org.bd/wp-content/uploads/2019/03/The-Power-and-Energy-Sector-of-Bangladesh.pdf, accessed 11 June 2019.

719 - *WNN*, "Bangladesh moves forward with Rooppur", 28 June 2016, see http://www.world-nuclear-news.org/NN-Bangladesh-moves-forward-with-Rooppur-2806167.html, accessed 24 April 2018.

720 - *TASS*, "Rosatom plans to launch construction of Ruppur power plant in Bangladesh", 19 April 2017, see http://tass.com/economy/942156.

721 - Energy Bangla, "Nuclear Fuel Supply Deal signed with Russia for RNPP", 31 January 2019, see http://energybangla.com/nuclear-fuel-supply-deal-signed-with-russia-for-rnpp/, accessed 11 June 2019.

722 - WNA, "Nuclear Power in Bangladesh", Updated April 2019, see http://world-nuclear.org/information-library/country-profiles/countries-a-f/bangladesh.aspx, accessed 11 June 2019.

723 - Petr Topychkanov, "Why the Bangladeshi public has concerns over the Rooppur nuclear project", *Russian Beyond*, 27 February 2017, see https://www.rbth.com/blogs/south_asian_outlook/2017/02/27/why-the-bangladeshi-public-has-concerns-over-the-rooppur-nuclear-project_709866, accessed 22 April 2018.

724 - Rakesh Shama, "Is Bangladesh Ready for Nuclear?", *NIW*, 22 December 2018.

725 - *NIW*, "Bangladesh", Nuclear Intelligence Weekly, 1 December 2017.

726 - WNA, "Nuclear Power in Bangladesh", Updated April 2019, op. cit.

The project's economics have been widely questioned. Earlier in 2017, a retired nuclear engineer who had been involved in advising the BAEC argued in one of the leading English-language newspapers in Bangladesh that the country was "paying a heavy price" for BAEC not having "undertaken a large-scale programme of recruitment, and training of engineers"; he also charged that Bangladesh was buying reactors at the "unreasonable and unacceptable" price of US$5,500/kW because its "negotiators didn't have the expertise to properly scrutinise the quoted price".[727]

Construction of both units is said to be going according to schedule and Rooppur-1 is currently scheduled to go on line in 2023 followed by Rooppur-2 in 2024.[728] There have been reports about corruption in the construction of the nuclear plant, although these allegations largely revolve around materials for housing of plant workers and their families.[729]

In recent years, Bangladesh has been rapidly expanding its solar energy installations, with capacity going from 18 MW in 2009 to 201 MW in 2018.[730] In March 2019, the World Bank approved a US$185 million grant to expand renewable energy capacity in Bangladesh.[731]

Belarus

Construction started in November 2013 at Belarus's first nuclear reactor at the Ostrovets power plant, also called Belarusian-1. Construction of a second 1200 MWe AES-2006 reactor started in June 2014. In November 2011, the Russian and Belarusian governments agreed that Russia would lend up to US$10 billion for 25 years to finance 90 percent of the contract between Atomstroyexport and the Belarus Directorate for Nuclear Power Plant Construction. In July 2012, the contract was signed for the construction of the two reactors for an estimated cost of US$10 billion, including US$3 billion for new infrastructure to accommodate the remoteness of Ostrovets in northern Belarus.[732] The project assumes liability for the supply of all fuel and repatriation of spent fuel for the life of the plant. The fuel is to be reprocessed in Russia and the separated wastes returned to Belarus. In August 2011, the Ministry of Natural Resources and Environmental Protection of Belarus stated that the first unit would be commissioned in 2016 and the second one in 2018.[733] These dates were revised, and when construction began, the reactors were scheduled to be completed by 2018 and 2020 respectively.[734] In May 2016, the

727 - Abdul Martin, "The economics of the Rooppur Nuclear Power Plant", *The Daily Star*, 2 March 2017, see https://www.thedailystar.net/op-ed/economics/the-economics-the-rooppur-nuclear-power-plant-1369345, accessed 22 April 2018.

728 - *WNN*, "Rooppur 1 achieves first construction milestone", 5 April 2018, see http://www.world-nuclear-news.org/NN-Rooppur-1-achieves-first-construction-milestone-05041801.html, accessed 24 April 2018.

729 - *The Daily Star*, "Rooppur Power Plant: HC asks ministry to submit report on 'irregularities'", 21 May 2019, see https://www.thedailystar.net/frontpage/news/rooppur-power-plant-hc-asks-ministry-submit-report-irregularities-1746547, accessed 13 June 2019.

730 - IRENA, "Renewable Capacity Statistics 2019", International Renewable Energy Agency, March 2019, see https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2019/Mar/IRENA_RE_Capacity_Statistics_2019.pdf, accessed 13 June 2019.

731 - World Bank, "World Bank Helps Bangladesh Expand Renewable Energy", Press Release, 1 March 2019, see http://www.worldbank.org/en/news/press-release/2019/03/01/world-bank-helps-bangladesh-expand-renewable-energy, accessed 14 June 2019.

732 - *NIW*, "Belarus, Aided by Russia and Broke, Europe's Last Dictatorship Proceeds With NPP", 28 September 2012.

733 - WNA, "Nuclear Power in Belarus", Updated October 2017, see http://www.world-nuclear.org/information-library/country-profiles/countries-a-f/belarus.aspx, accessed 21 April 2018.

734 - *WNN*, "Ostrovets plant meets construction safety rules", 7 November 2014, see http://www.world-nuclear-news.org/NN-Ostrovets-plant-meets-construction-safety-rules-07111401.html, accessed 21 April 2018.

respective startup months were specified as November 2018 and July 2020.[735] In August 2016, the reactor pressure vessel of unit one slipped during installation and fell two meters to the ground. This led to an eight-month delay, while it was replaced.[736] In March 2018, the head of the reactor division at the power plant said that first electricity supply to the grid would be expected in the 4th quarter of 2019 with the second unit online in July 2020.[737] The start of the Commissioning process for the 1st unit was begun in April 2019,[738] with an expectation of full power by the end of the year. Almost simultaneously the Government announced a restructuring of the energy industry, which may lead to the establishment of two national energy companies, one for gas and the other for electricity.

The official cost of the project has risen by 26 percent, to 56 billion Russian rubles in 2001-prices (US$$_{2001}$1.8 billion).[739] However, the falling exchange rate of the ruble against the dollar significantly affects the dollar price of the project.

The project is the focus of international opposition and criticism, with formal complaints from the Lithuanian government[740] which has published a list of fundamental problems of the project. These include that there have been major construction problems, the site is considered non-suitable, and Belarus has been found to be in noncompliance with some of its public engagement obligations concerning the construction of the plant, according to the meeting of the Parties of the Espoo Convention.[741] Belarus was in 2017 also found in non-compliance with the Aarhus Convention for harassing members of civil society campaigning against the project.[742] Then, in April 2019, a meeting of the Espoo Convention voted 30-6 that Belarus had violated the convention's rules while choosing Ostrovets as the site for the country's first nuclear power plant.[743]

In April 2017, an accord was signed by all parties in the Lithuanian Parliament noting that all necessary measures should be taken to stop the construction of Ostrovets and "at least to ensure that the electricity produced in this nuclear power plant will not be allowed into Lithuania nor will it be allowed to be sold on the Lithuanian market under any circumstances ".[744] To allay European concerns about Ostrovets, the Belarussian government submitted the project

735 - *WNN*, "Reactor vessel assembly completed for second Belarusian unit", 26 May 2016, see http://www.world-nuclear-news.org/NN-Reactor-vessel-assembly-completed-for-second-Belarusian-unit-26051601.html, accessed 21 April 2018.

736 - *NIW*, "Briefs—Belarus", 7 April 2017.

737 - *Belarus News*, "Belarusian nuclear power plant to give electricity to national power grid in Q4 2019", 28 March 2018, see http://eng.belta.by/economics/view/belarusian-nuclear-power-plant-to-give-electricity-to-national-power-grid-in-q1-2019-110418-2018/, accessed 21 April 2018.

738 - *WNN*, "Commissioning starts at first Belarus unit", 8 April 2019, see https://www.world-nuclear-news.org/Articles/Commissioning-starts-at-first-Belarus-unit, accessed 14 April 2019.

739 - *Charter 97*, "Astravets NPP Becomes 12 Billion More Expensive In One Day", 30 December 2016, see https://charter97.org/en/news/2016/12/30/236059/, accessed 21 April 2018.

740 - Bryan Bradley, "Lithuania Urges Belarus to Halt Nuclear Project on Safety Issues", *Bloomberg*, 20 August 2013, see https://www.bloomberg.com/news/articles/2013-08-20/lithuania-urges-belarus-to-halt-nuclear-project-on-safety-issues, accessed 22 April 2018.

741 - MoFA, "Fundamental problems of the Astravets Nuclear Power Plant under construction in Belarus", Ministry of Foreign Affairs of the Republic of Lithuania, 29 March 2018, see http://lv.mfa.lt/default/en/news/fundamental-problems-of-the-astravets-nuclear-power-plant-under-construction-in-belarus-, accessed 22 April 2018.

742 - UNECE, "Findings and recommendations with regard to communication ACCC/C/2014/102 concerning compliance by Belarus", United Nations, Economic and Social Council, 24 July 2017, see https://www.unece.org/fileadmin/DAM/env/pp/compliance/CC-58/ece.mp.pp.c.1.2017.19.e.pdf, accessed 22 May 2018.

743 - *NIW*, "Briefs Belarus", 15 February 2019.

744 - Lithuanian Parliament, "Accord between the Parliamentary Political Parties of the Republic of Lithuania on Joint Actions Against the Unsafe Nuclear Power plant in Astraveyets", April 2017.

to a post-Fukushima nuclear stress test that produced in 2017 a national report, submitted to peer-review by a commission from the European Nuclear Safety Regulators Group (ENSREG) and the European Commission. In July 2018, the European Commission announced that the ENSREG peer-review report had been presented to the Belarussian authorities and the executive summary was made public, which concludes that "although the report is overall positive, it includes important recommendations that necessitate an appropriate follow up". For example, on the topic of assessment of severe accident management, it says, "the overall concept of practical elimination of early and large releases should be more explicitly reflected in an updated plant safety case." It also gave recommendations for better seismic robustness.[745] The next step is these recommendations need to be incorporated into the next draft of the National Action Plan.[746] In May 2019, Lithuanian Minister of Energy Žygimantas Vaičiūnas made an appeal to the European Commission to take strong leadership and a principled position to ensure that Belarus does not launch the Ostrovets nuclear power plant until the stress test recommendations are implemented.[747]

Belarus has historically been an importer of electricity from Russia and Ukraine. But in May 2018, Deputy-Prime Minister Vladimir Semashko stated: "In 2018 we stopped electric energy import, because we had upgraded our own power grid. We are self-reliant and can provide ourselves with our own electric energy."[748] In fact, Semashko claims that in the first four months of 2018, Belarus exported 0.4 TWh. The startup of the Ostrovets nuclear plant would significantly increase excess capacity. Lithuania has said it will not accept any electricity from Belarus and is trying to get its neighbors to follow the ban and it will use the Espoo ruling to add weight to its claim. Currently this has not been successful, although there has been an agreement to introducing an electricity import tax.[749] The sale of electricity to the West will be vital for the economics of the project, as increasing domestic consumption or even sale back to Russia will raise significantly lower revenues, due to lower prices.

Russia is currently upgrading its grid connection between the Leningrad and Smolensk nuclear power stations, potentially also enabling a better connection of Ostrovets to the West-Russian electricity grid, circumventing the Baltic States. Vice-Premier Semashko is confident: "Our energy is cheaper and it will be on demand on this market."[750]

745 - ENSREG, "Belarus Stress Tests Peer Review—Executive summary", European Nuclear Safety Regulators Group, July 2018, see http://www.ensreg.eu/sites/default/files/attachments/hlg_p2018-36_156_belarus_stress_test_prt_report_-_executive_summary_0.pdf, accessed 5 July 2018.

746 - European Commission, "Comprehensive risk and safety assessments of the Belarus nuclear power plant completed", Press Release, 3 July 2018, see http://europa.eu/rapid/press-release_IP-18-4347_en.htm, accessed 4 July 2018.

747 - Ministry of Energy of the Republic of Lithuania, "Lithuania has formally applied to the European Commission to demand that implementation of the Astravets NPP stress test recommendations be ensured", 7 May 2019, see http://enmin.lrv.lt/en/news/lithuania-has-formally-applied-to-the-european-commission-to-demand-that-implementation-of-the-astravets-npp-stress-test-recommendations-be-ensured, accessed 11 June 2019.

748 - *BelTa*, "Belarus ramps up electricity export in 2018", *Belarusian Telegraph Agency*, 14 May 2018, see http://eng.belta.by/economics/view/belarus-ramps-up-electricity-export-in-2018-111638-2018/, accessed 3 July 2018.

749 - *Reuters*, "Baltics to cooperate on Belarus nuclear power tax", 14 December 2017, see https://www.reuters.com/article/baltics-energy/baltics-to-cooperate-on-belarus-nuclear-power-tax-idUSL8N1OC3QD, accessed 22 April 2018.

750 - *BelTa*, "Belarus ramps up electricity export in 2018", 14 May 2018, op. cit.

On the other hand, Belarus' energy minister Viktor Karankevich announced on 25 April 2019 that a total of 916 MW of Ostrovets' capacity will be used in electric district heating plants.[751]

Turkey

In Turkey, three separate projects are being or have been developed over the past decades with three different reactor designs and three different financing schemes. Despite this, in early 2018, construction formally only began on the first of these projects.

Akkuyu

Some four decades after the first ideas came up for a nuclear power plant at Akkuyu, in the province of Mersin on Turkey's Mediterranean coast, construction started in April 2018, one day before President Putin of Russia visited Turkey for the official launch of the project.[752] The power plant is to be implemented by Rosatom of Russia under a Build-Own-Operate (BOO) model.

Only two months prior to the official construction start, Rosatom's Turkish partners quit. The consortium of private companies Cengiz Holding, Kolin Insaat Turizm Sanayi ve Ticaret and Kalyon Insaat Sanayi ve Ticaret was to hold 49 percent of the shares.[753]

JSC Akkuyu Nuclear has been established to ensure construction of the project and has been designated as the Strategic Investor. Although Rosatom initially was supposed to completely own the project, according to the establishing agreement, at least 51 percent of shares in the finished project should belong to Russian companies and up to 49 percent of shares can be available for sale to outside investors. Negotiations with potential Turkish investors continue after the three prospective partners withdrew because they expected too little benefit from the project.[754] However, Rosatom has stated that it would be able to complete the project even if it is unable to attract local investors.[755] As the Strategic Investor, the project will be able to claim tax reductions and exemptions (including from income tax and value added tax), as well as custom duties exemption.[756] In April 2019, Rosatom stated that it was in talks with both state-run and private Turkish companies seeking to sell 49 percent of the project.[757]

751 - *BelTa*, "Integration of Belarusian nuclear power plant into national power grid in progress", 25 April 2019, see https://eng.belta.by/society/view/integration-of-belarusian-nuclear-power-plant-into-national-power-grid-in-progress-120629-2019, accessed 4 May 2019.

752 - Tuvan Gumrukeu, Orhan Coskun, "Turkey grants Rosatom construction license for first unit of Akkuyu nuclear plant", *Reuters*, 2 April 2018, see https://www.reuters.com/article/us-turkey-russia-nuclearpower/turkey-grants-rosatom-construction-license-for-first-unit-of-akkuyu-nuclear-plant-idUSKCN1H91OY, accessed 22 May 2018.

753 - *AFP*, "Un consortium turc se retire du projet de la centrale nucléaire d'Akkuyu", *Agence France Presse*, 6 February 2018 (in French), see https://www.romandie.com/news/887776.rom, accessed 4 July 2018.

754 - Rosatom, "JSC Akkuyu Nuclear designated strategic investor in Turkey", 2 April 2018, see http://www.rosatom.ru/en/press-centre/news/jsc-akkuyu-nuclear-designated-strategic-investor-in-turkey/, accessed 20 April 2018.

755 - *Reuters*, "Russia capable of building Akkuyu plant without partners: Minister", published in *Hurriyet Daily News*, 6 April 2018, see http://www.hurriyetdailynews.com/russia-is-able-to-complete-akkuyu-nuclear-power-plant-construction-russian-minister-129886, accessed 6 April 2018.

756 - Rosatom, "JSC Akkuyu Nuclear Designated Strategic Investor in Turkey", 2 April 2018.

757 - *Ahval*, "Russia's Rosatom in talks to sell 49 pct stake in Akkuyu nuclear plant", 15 April 2019, see https://ahvalnews.com/akkuyu/russias-rosatom-talks-sell-49-pct-stake-akkuyu-nuclear-plant, accessed 18 April 2019.

An agreement was signed in May 2010 for four VVER-1200 reactors (Generation III+), with construction originally expected to start in 2015. At the heart of the project is a 15-year Power Purchase Agreement (PPA), which includes 70 percent of the electricity produced from units 1 and 2 and 30 percent of units 3 and 4. Therefore 50 percent of the total power from the station is to be sold at a guaranteed price for the first 15 years, with the rest to be sold on the market. Currency fluctuation, and in particular the fall in the value of the Turkish lira, makes the price guarantees in dollars (US$123.50/MWh) particularly problematic.[758]

The former CEO of Akkuyu JSC (the project company set up by Russia's Rosatom), Alexander Superfin, said in October 2013 that the project was going to be operational by mid-2020.[759] However, further delays have occurred, as the Akkuyu JSC's Environmental Impact Assessment was rejected by the Ministry of Environment when submitted in July 2013. When it was eventually approved in December 2014, it was said that the commissioning of the first unit was likely to be in 2021.[760] As a result of these domestic developments and financing problems, it was reported in November 2015 that the operation would now occur only in 2022[761] at an estimated budget of US$20 billion. Site preparation work started in April 2015[762] and it was estimated that US$3 billion had been spent as of autumn 2015.[763] On 3 March 2017, Akkuyu JSC applied for a construction license.[764] Rosatom stated: "According to the Intergovernmental Agreement, the commissioning of the first power unit must take place no later than 7 years after the issuance of all permits for construction by the Republic of Turkey."[765]

In July 2017 the European Parliament adopted a resolution calling on the Turkish Government to halt the plans for the construction of the Akkuyu project due to its location in a region prone to severe earthquakes and called on "the Turkish Government to involve, or at least consult, the governments of its neighboring countries, such as Greece and Cyprus."[766] In May 2019, as part of Turkey's accession process, the European Commission published a review of progress on meeting the EU's acquis. On nuclear power it noted that

> given Turkey's plan to have a first nuclear power reactor commissioned and operational by 2023, the legal and institutional framework should be improved rapidly to align with the EU's nuclear legislation and ensure nuclear safety in line with the Euratom Treaty.

758 - Phil Chaffee, "New Build, Revised 2023 Milestone for Akkuyu", *NIW*, 29 March 2019.

759 - Orhan Coskun, "Turkey's first nuclear plant facing further delays - sources", *Reuters*, 7 February 2014, see https://uk.reuters.com/article/uk-turkey-nuclear-delay/turkeys-first-nuclear-plant-facing-further-delays-sources-idUKBREA160P220140207, accessed 22 April 2018.

760 - *WNN*, "Akkuyu project EIA gets ministry approval", 1 December 2014, see http://www.world-nuclear-news.org/NN-Akkuyu-project-EIA-gets-ministry-approval-01121401.html, accessed 22 April 2018.

761 - *Sputnik News*, "First Reactor of Turkey's Akkuyu Nuclear Plant to Start Operating by 2022", 19 November 2015, see https://sputniknews.com/middleeast/201511191030420598-akkuyu-nuclear-plant-start-2022/, accessed 22 April 2018.

762 - *WNN*, "Ground broken for Turkey's first nuclear power plant", 15 April 2015, see http://www.world-nuclear-news.org/NN-Ground-broken-for-Turkeys-first-nuclear-power-plant-1541501.html, accessed 22 April 2018.

763 - *Hurriyet Daily News*, "$3 billion spent on Akkuyu power plant so far: CEO", 29 September 2015, see http://www.hurriyetdailynews.com/3-bln-spent-on-akkuyu-power-plant-so-far-ceo.aspx?pageID=238&nID=89154&NewsCatID=348, accessed 22 April 2018.

764 - *WNN*, "Akkuyu project receives production licence", 16 June 2017, see http://www.world-nuclear-news.org/NN-Akkuyu-project-receives-production-licence-16061701.html, accessed 22 April 2018.

765 - Orhan Coskun, "Turkey's first nuclear plant facing further delays - sources", *Reuters*, 7 February 2014.

766 - European Parliament, "2016 Report on Turkey— European Parliament resolution of 6 July 2017 on the 2016 Commission Report on Turkey (2016/2308(INI))", Texts Adopted 6 July 2017, see http://www.europarl.europa.eu/sides/getDoc.do?pubRef=-//EP//NONSGML+TA+P8-TA-2017-0306+0+DOC+PDF+V0//EN, accessed 22 April 2018.

The Commission further stated that

> there is a need of additional legal and technical assurance that the Turkish nuclear power plants will be constructed, commissioned, and operated safely and in line with the Euratom Treaty and EU secondary legislation.[767]

No such consultations took place. In April 2018, a construction license was awarded, the first concrete was poured, with first electricity expected to be generated in 2023 (the 100th anniversary of the founding of the modern state of Turkey), with all four units to be operational by 2025.[768] The Government of Cyprus has protested about the start of construction, citing safety concerns and potential impact, as the power plant is only a few dozen kilometers from the northern coast of Cyprus.[769]

In March 2019, the project management announced that it had finished the concreting of the basemat for the nuclear island for the first unit and that it was now expected that Unit 1 would be physically completed in 2023, with generation coming at a later date.[770] A limited works license was issued for Unit 2 in October 2018, with a full construction license expected in mid-2019.

Some international experts have raised concerns over the political stability of the deal, and Aaron Stein of the Washington-based Atlantic Council warned that a potential barrier to completion was the political relationship between the two countries: "Russia has shown that it will stop construction if it's upset with Turkey."[771]

In May 2019, it was reported that construction had been "held up" due to the discovery of cracks in the foundations. Apparently, the cracks were first discovered in July 2018 leading to re-laying of the concrete. However, further cracks were then discovered in the re-laid concrete with the consequence that a larger section of the foundations had to be redone.[772]

Sinop

Sinop is on Turkey's northern coast and was planned to host a 4.4 GW power plant of four units of the ATMEA reactor-design. If completed, these would be the first reactors of this design, jointly developed by Japanese Mitsubishi and French AREVA.[773] In April 2015, Turkish

767 - European Commission, "Commission Staff Working Document, Turkey 2019 Report - SWD(2019) 220 final - Accompanying the Document 'Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions - 2019 Communication on EU Enlargement Policy - COM 2019, 260 Final'", May 2019, see https://ec.europa.eu/neighbourhood-enlargement/sites/near/files/20190529-turkey-report.pdf, accessed 10 June 2019.

768 - *NEI*, "Construction of Turkey's Akkuyu NPP begins", 4 April 2018, see http://www.neimagazine.com/news/newsconstruction-of-turkeys-akkuyu-npp-begins-6102914/, accessed 22 April 2018.

769 - *ekathimerini.com*, "Nicosia to protest construction of Akkuyu nuclear plant", 5 April 2018, see http://www.ekathimerini.com/227454/article/ekathimerini/news/nicosia-to-protest-construction-of-akkuyu-nuclear-plant, accessed 22 April 2018.

770 - Phil Chaffee, "New Build, Revised 2023 Milestone for Akkuyu", *NIW*, 29 March 2019.

771 - Phil Chaffee, "Putin-Erdogan Relationship Key to Akkuyu Progress", *NIW*, 6 April2018.

772 - *Ahval*, "Cracks discovered during construction of Turkey's first nuclear plant", 6 May 2019, see https://ahvalnews.com/akkuyu/cracks-discovered-during-construction-turkeys-first-nuclear-plant, accessed 11 June 2019.

773 - *WNN*, "Turkish utility eyes large stake in Sinop project", 12 May 2015, see http://www.world-nuclear-news.org/C-Turkish-utility-eyes-large-stake-in-Sinop-project-12051501.html, accessed 22 April 2018.

President Erdogan approved parliament's ratification of the intergovernmental agreement with Japan.[774]

The estimated cost of the project was initially US$22 billion and involves a consortium of Mitsubishi, AREVA (now known again as Framatome), GDF-Suez (now known as Engie), and Itochu, who between them will own 51 percent of the project, with the remaining 49 percent owned by Turkish companies including the State-owned electricity generating company EÜAS.[775]

The division between the international partners remains in fact undecided. The ongoing financial problems of new-old Framatome after the absorption by EDF are affecting its ability to invest in the project, as does the review by Engie of its involvement in nuclear projects across its portfolio. Furthermore, concerns remain about site suitability given its seismic conditions, which have led to discussions about putting the station on pads to reduce possible ground movement.[776] According to AREVA, in September 2016, AREVA NP signed a "preliminary engineering contract with MHI [Mitsubishi Heavy Industry] to support the technical and cost feasibility study for the proposed construction and operation of four ATMEA1 reactors at the Sinop site".[777] The project is complicated by the region's lack of large-scale demand and the existing coal power stations, so 1,400 km of transmission lines would be needed to take the electricity to Istanbul and Ankara.

In January 2018, an Environmental Impact Assessment application was made to the Environment and Urban Planning Ministry. However, in March 2018, reports from Japan suggested that the expected cost of the project had doubled to US$37.5 billion and that it would be difficult to see completion by 2023. It was suggested that the Japanese side informed its Turkish partner of the expected cost increase.[778] Then in April 2018, press reports from Japan suggested that Itochu would no longer be willing to participate due to the exploding cost estimates, which had risen to more than JPY5,000 billion (US$46.2 billion) from JPY2,000 billion (US$19 billion) in 2013.[779]

By the end of 2018, the project was all but killed off, with announcements that the Japanese Government was asking its Turkish counterpart for additional funds to support the project, knowing that the demand would be rejected.[780] Then in December 2018 the *Nikkei*, an economic paper in Japan, reported that Mitsubishi Heavy Industries had withdrawn from the project, finally ending the project.[781]

774 - *WNN*, "Ground broken for Turkey's first nuclear power plant", 15 April 2015, see http://www.world-nuclear-news.org/NN-Ground-broken-for-Turkeys-first-nuclear-power-plant-1541501.html, accessed 22 April 2018.

775 - *WNN*, "Turkish Utility Eyes Large Stake in Sinop Project", 12 May 2015.

776 - *NIW*, "Akkuyu's Prospects Pull Past Sinop", 22 July 2016.

777 - AREVA, "Reference Document 2006", April 2017, see http://www.sa.areva.com/finance/liblocal/docs/doc-ref-2016/AREVA_DDR2016_EN_2.pdf, accessed 22 April 2018.

778 - Yasuaki Oshika, "Japan's nuclear export to Turkey in doubt as costs estimate doubles", *The Asahi Shimbun*, 15 March 2018, see http://www.asahi.com/ajw/articles/AJ201803150046.html, accessed 22 April 2018.

779 - *NEI*, "Japan's Itochu pulls out of Turkish nuclear project", 30 April 2018, see http://www.neimagazine.com/news/newsjapans-itochu-pulls-out-of-turkish-nuclear-project-6133206, accessed 15 May 2018.

780 - *Mainichi Daily News*, "Gov't to give up plan to export nuclear power reactors to Turkey", 4 January 2019, see https://mainichi.jp/english/articles/20190104/p2a/00m/0bu/011000c, accessed 18 April 2019.

781 - Matsukubo Hijime, "Mitsubishi Heavy Industries withdraws from the NPP project in Sinop, Turkey ~NPP makers need to switch to realistic track in the age of decommissioning~", Citizens' Nuclear Information Center, 30 January 2019, see http://www.cnic.jp/english/?p=4271, accessed 11 June 2019.

İğneada

In October 2015, the Turkish government suggested it was aiming to build a third nuclear power plant, at the İğneada site. The most likely constructors would be Westinghouse and the Chinese State Nuclear Power Technology Corporation (SNPTC). Chinese companies have been said to "aggressively" pursuing the contract, reportedly worth US$22–25 billion. In September 2016, China and Turkey signed a nuclear co-operation agreement similar to the mechanism used to develop the country's other nuclear projects. However, their financial collapse of makes Westinghouse's current involvement in the project unlikely.

United Arab Emirates

In the United Arab Emirates (UAE), building is ongoing at the Barakah nuclear project, 300 km west of Abu Dhabi, where there are four reactors under construction. At the time of the contract signing in December 2009 with Korean Electric Power Corporation (KEPCO), the Emirates Nuclear Energy Corp (ENEC), said that "the contract for the construction, commissioning and fuel loads for four units equaled approximately US$20 billion, with a high percentage of the contract being offered under a fixed-price arrangement".[782]

The original financing plan for the project was thought to include US$10 billion from the Export-Import Bank of Korea, US$2 billion from the Ex-Im Bank of the U.S., US$6 billion from the government of Abu Dhabi, and US$2 billion from commercial banks.[783] However, it later transpired that the total cost of the project is at least €24.4 billion (US$28.2 billion). Reportedly, its financing was US$16.2 billion from Abu Dhabi's Department of Finance, equity financing US$4.7 billion, US$2.5 billion through a loan from the Export-Import Bank of Korea, with loan agreements from the National Bank of Abu Dhabi, First Gulf Bank, HSBC and Standard Chartered making up the remainder.[784] In October 2016, KEPCO took an 18 percent equity stake in Nawah Energy Company that owns the four reactors, with ENEC holding the remaining 82 percent. [785]

In July 2010, a site-preparation license and a limited construction license were granted for four reactors at Barakah, 53 kilometers from Ruwais,[786] 40 km from the border with Saudi Arabia and 100 km from Qatar. A tentative schedule published in late December 2010, and not publicly altered since, suggested that Barakah-1 would start commercial operation in May 2017 with unit 2 operating from 2018, unit 3 in 2019, and Unit 4 in 2020.

782 - ENEC, "UAE Selects Korea Electric Power Corp, as Prime Team as Prime Contractor for Peaceful Nuclear Power", Emirates Nuclear Energy Corporation, 27 December 2009, see https://www.enec.gov.ae/news/uae-selects-korea-electric-power-corp-as-prime-team-as-prime-contractor-fo/, accessed 22 April 2018.

783 - Kim San-Baik, "Case Studies On Financing And Electricity Price Arrangements—The Barakah Nuclear Power Plants, The United Arab Emirates", OECD/NEA, 19 September 2013, see http://www.oecd-nea.org/ndd/workshops/wpne/presentations/docs/4_2_KIM_%20Barakah%20presentation.pdf, accessed 22 April 2018.

784 - *NIW*, "Kepco takes 18% of Barakah", 21 October 2016.

785 - *NEI*, "Kepco and Enec set up joint venture for Barakah NPP", 25 October 2016, see http://www.neimagazine.com/news/newskepco-and-enec-set-up-joint-venture-for-barakah-npp-5647366/, accessed 22 April 2018.

786 - *Arabian Business*, "ENEC Welcomes Regulator's License Approval", 11 July 2010, see http://www.arabianbusiness.com/enec-welcomes-regulator-s-licence-approvals-306150.html, accessed 22 April 2018.

Construction of Barakah-1 officially started on 19 July 2012, of Barakah-2 on 28 May 2013, of Barakah-3 on 24 September 2014 and Unit 4 on 30 July 2015.[787] In May 2016, ENEC stated that Barakah-1 was about 87 percent complete, while Barakah-2, -3 and -4 had reached 68 percent, 47 percent and 29 percent completion respectively.[788] As late as October 2016, the South Korean press was reporting unit 1 to be still scheduled for completion by May 2017.[789] Then, in May 2017, *Reuters* suggested that the startup of the first reactor was delayed, potentially until the end of 2017, due to a lack of locally trained and licensed domestic personnel.[790] The same month ENEC announced it had "completed initial construction activities for Unit 1" and the "handover of all systems for commissioning"; the plant as a whole would be 81 percent complete, with Barakah-1 at 95 percent finished. At the same time, ENEC stated: "The timeline includes an extension for the start-up of nuclear operations for Unit 1, from 2017 to 2018, to ensure sufficient time for international assessments and adherence to nuclear industry safety standards, as well as a reinforcement of operational proficiency for plant personnel."[791] In March 2018, the extent of the delay was confirmed with Nawah reporting that the startup of Unit 1 would only be in 2019.[792] But only a few months later, in July 2018, a new delay was announced, so that startup of Unit 1 would be in late 2019 or early 2020[793], with commercial operation would not be effective until 2020, three years behind schedule. Despite this, an official ceremony was held on 26 March 2018 to mark the end of construction of the first reactor. Apparently, a key reason for the delay remains the lack of trained staff and the multiplicity of cultures and languages among new personnel.[794] As a recognition of the scale of the ongoing problem, EDF signed an agreement with ENEC to provide services to support "operating and maintaining" the plant in November 2018.[795]

South Korean media reported that there have been a number of serious accidents at the construction site, resulting in deaths of workers. An assessment undertaken by Bechtel on behalf of KEPCO indicated that its "contractors largely failed to ensure worker safety".[796]

Another type of serious problem came up in the form of "voids" that have been found in the containment concrete of Units 2 and 3, although ENEC said that these weren't a safety risk,

787 - Ibidem.

788 - *NIW*, "United Arab Emirates", 20 May 2016.

789 - Lee Hyo-sik, "KEPCO to operate UAE nuclear plant for 60 years", *The Korean Times*, 20 October 2016, see http://www.koreatimes.co.kr/www/news/biz/2016/10/123_216466.html, accessed 22 April 2018.

790 - Jane Chung, "UAE delays launch of first nuclear power reactor", *Reuters*, 4 May 2017, see https://www.reuters.com/article/us-kepco-emirates-nuclearpower-exclusive/exclusive-uae-delays-launch-of-first-nuclear-power-reactor-idUSKBN1801ZD, accessed 22 April 2018.

791 - ENEC, "ENEC Announces Completion of Initial Construction Work for Unit 1 of Barakah Nuclear Energy Plant & Progress Update Towards Safety-led Operations", Emirates Nuclear Energy Corporation, 5 May 2017, see https://www.enec.gov.ae/enec-announces-completion-of-initial-construction-work-barakah-unit-1-progress-update/, accessed 22 April 2018.

792 - Nawah, "Next phase of preparations for Barakah Unit 1 Nuclear Operations starts", Press Release, 28 May 2018, see http://www.nawah.ae/en/news/NextphaseofpreparationsforBarakah.html, accessed 29 May 2018.

793 - *Arabian Business*, "UAE further delays launch of first nuclear reactor", 4 July 2018, see https://www.arabianbusiness.com/energy/400041-uae-further-delays-launch-of-first-nuclear-reactor, accessed 8 July 2018.

794 - Stephanie Cook, "The Challenge of Barakah's Multicultural Workforce", *NIW*, 23 March 2018.

795 - EDF, "EDF and Nawah Energy Company sign operations and maintenance assistance agreement for Barakah Nuclear Energy Plant, United Arab Emirates", 22 November 2018, see https://www.edf.fr/en/the-edf-group/dedicated-sections/journalists/all-press-releases/edf-and-nawah-energy-company-sign-operations-and-maintenance-assistance-agreement-for-barakah-nuclear-energy-plant-united-arab-emirates, accessed 9 April 2019.

796 - Lee Hyo-sik, "KEPCO hit by safety lapses at UAE nuke plant site", *The Korean Times*, 22 February 2017, see http://www.koreatimes.co.kr/www/biz/2017/02/367_224498.html, accessed 22 April 2018.

had been repaired, and shouldn't delay construction.[797] It was not clear how big these voids are, but a similar problem has been experienced in the 1990s at the Hanbit reactor in Yeonggwang, South Jeolla Province in South Korea, revealing holes large enough for a small child. The problems were found following the discovery of bulges in concrete due to movement in grease within the empty spaces and settling in gaps near the exterior wall[798]—the grease is used to lubricate the adjustable metal cables that run through the containment walls to strengthen it.

Cracks were also found in the containment building of unit 2, with conflicting reports as to whether or not similar cracking in the containment building of unit 3 had also been found. Even if these are easily repaired, the discovery raises two concerns: firstly, the containment building is a crucial barrier to stop potentially radioactive emissions escaping in the event of an accident, and secondly, this is a further indication that construction has not gone as smoothly as suggested by ENEC.

Further difficulties are emerging with the APR 1400 design, with problems around the reactor's pilot-operated safety relief valve (POSRV). This is designed to protect the pressurizer against overpressure and has been seen to be a problem for the design since 2016 when it inadvertently opened, allowing cooling water to leak during start-up of Shin-Kori-3 in South Korea. Then, possibly during testing, in November 2017 the same problem occurred at Unit 1 at Barakah, and as a result the regulator said that the valve didn't meet its safety acceptance criteria.[799]

The UAE released a long-term energy plan in February 2017, which proposes that by 2050 renewable energy will provide 44 percent of the country's electricity, with natural gas 38 percent, "clean fossil fuels" 12 percent and nuclear 6 percent.[800] The nuclear share is in line with expected output from the Barakah nuclear power plant, so it seems that no further nuclear power plants are envisaged at this point. In September 2017, Government officials confirmed that there were no plans to build a second plant.[801]

There are concerns that the Barakah plant maybe a target in the ongoing conflict with the Houthi rebels based in Yemen. They have claimed, although the Emirati state denied, that they had successfully fired a cruise missile at the power plant. The UAE stated that they have the defensive capabilities to deal with any such threats and that the "Barakah reactor is immune."[802] However the plant remains the source of diplomatic tension, and in March 2019 Qatar wrote to the International Atomic Energy Agency (IAEA) asking them to intervene in the project saying that "the lack of any international co-operation with neighboring states regarding disaster planning, health and safety and the protection of the environment pose a serious threat to

797 - Geert De Clerco, "Exclusive: Qatar asks IAEA to intervene over 'threat' posed by UAE nuclear plant", *Reuters*, 20 March 2019, see https://www.reuters.com/article/us-qatar-emirates-nuclearpower-exclusive/exclusive-qatar-asks-iaea-to-intervene-over-threat-posed-by-uae-nuclear-plant-idUSKCN1R120L, accessed 9 April 2019.

798 - Choi Ha-yan, "Controversy over Barakah power plant construction fiasco continues", *Hankyoreh*, 18 December 2018, see http://english.hani.co.kr/arti/english_edition/e_international/874896.html, accessed 9 April 2019.

799 - Stephanie Cook, "Shared POSRV Nightmares for KHNP and Enec", *NIW*, 15 March 2019.

800 - LeAnne Graves, "UAE Energy Plan aims to cut CO2 emissions 70% by 2050", *The National*, 10 January 2017, see https://www.thenational.ae/uae/uae-energy-plan-aims-to-cut-co2-emissions-70-by-2050-1.51582, accessed 22 April 2018.

801 - Amena Bahr, "UAE Abu Dhabi Unlikely to Build a Second Nuclear plant", *NIW*, 29 September 2017.

802 - *NIW*, "Briefs—Saudi Arabia", 22 September 2017.

the stability of the region and its environment".[803] Qatar said that the region's environmental concerns will rise further if and when Saudi Arabia's nuclear program becomes active.

"CONTRACTS SIGNED"

The World Nuclear Association (WNA) has put Lithuania, Poland and Vietnam in a category of "contracts signed". However, in none of these cases does there seem to have been any notable progress over the past twelve months; rather they are either dormant—in the case of Lithuania and Vietnam—or any expected operational date is moving backwards, as in the case of Poland.

Lithuania

Although Lithuania signed a memorandum of understanding with Hitachi-GE for the construction of a new nuclear power station at Visaginas, it never signed a contract and the project was cancelled following a no-vote in a referendum earlier in 2012.

Lithuania had two large RBMK (Graphite-Moderated Reactor—Chernobyl Type) reactors at Ignalina, which were closed in 2004 and 2009, a requirement for joining the European Union after the 1992 G7 Summit in Munich concluded the reactors were not sufficiently upgradable. Since then there have been ongoing attempts to develop a replacement project, either unilaterally or with neighboring countries. (See earlier editions of the WNISR for an annual account). However, in October 2012, a consultative national referendum on the future of nuclear power was held and 63 percent voted against new nuclear construction, with sufficient turnout to validate the result.[804] Prior to his appointment as Prime Minister, Algirdas Butkevicius stated that legislation prohibiting the project would be submitted once the new parliament convenes and that "the people expressed their wish in the referendum, and I will follow the people's will".[805] In early 2016, the Energy Minister of Lithuania, Rokas Masiulis, said that the project had been shelved indefinitely, due to unfavorable market conditions.[806] No significant changes have been reported since, whereas opposition against the Ostrovets nuclear project in Belarus, 20 km from the Lithuanian border (see **Belarus section** above), has increased opposition against nuclear power in Lithuania in general.

Poland

As far as publicly known, Poland has not signed any contracts for the construction of a new nuclear power plant after the construction of the Soviet designed Zarnowiec project was halted in 1989.

803 - Geert De Clercq, "Exclusive: Qatar asks IAEA to intervene over 'threat' posed by UAE nuclear plant", *Reuters*, 20 March 2019, see https://www.reuters.com/article/us-qatar-emirates-nuclearpower-exclusive/exclusive-qatar-asks-iaea-to-intervene-over-threat-posed-by-uae-nuclear-plant-idUSKCN1R120L, accessed 12 August 2019.

804 - Christian Lowe, "Lithuanians send nuclear plant back to drawing board", *Reuters*, 15 October 2012, see http://www.reuters.com/article/us-lithuania-nuclear-idUSBRE89E0BW20121015, accessed 22 April 2018.

805 - *NIW*, "Lithuania—Prospective PM Wants to Scrape Visaginas", 9 November 2012.

806 - *The Baltic Course*, "Masiulis: Visaginas NPP project has been shelved for now", 20 January 2016, see http://www.baltic-course.com/eng/energy/?doc=115564, accessed 22 April 2018.

Poland planned the development of a series of nuclear power stations in the 1980s and started construction of two VVER1000/320 reactors in Żarnowiec on the Baltic coast, but both construction and further plans were halted following the Chernobyl accident. In 2008, however, Poland announced that it was going to re-enter the nuclear arena and in November 2010, the Ministry of Economy put forward a Nuclear Energy Program. On 28 January 2014, the Polish Government adopted a document with the title "Polish Nuclear Power Programme" outlining the framework of the strategy. The plan included proposals to build 6 GW of nuclear power capacity with the first reactor starting up by 2024.[807] The reactor types then under consideration included AREVA's EPR, Westinghouse's AP-1000, and Hitachi-GE's Advanced Boiling Water Reactor (ABWR).

In January 2013, the Polish utility PGE (Polska Grupa Energetyczna) had selected WorleyParsons to conduct a five-year, US$81.5 million study, on the siting and development of a nuclear power plant with a capacity of up to 3 GW.[808] At that time, the project was estimated to cost US$13–19 billion, site selection was to have been completed by 2016, and construction was to begin in 2019.[809] A number of vendors, including AREVA, Westinghouse, and GE-Hitachi, all lobbied Warsaw aggressively.[810] PGE formed a project company PGE EJ1, which also had a ten percent participation of each of the other large Polish utilities, Tauron Polska Energia and Enea, as well as the State Mining and Metallurgical Combine (KGHM). In January 2014, PGE EJ1 received four bids from companies looking to become the company's "Owner's Engineer" to help in the tendering and development of the project, which was eventually awarded to Amec Nuclear U.K. in July 2014. The timetable demanded that PGE make a final investment decision on the two plants by early 2017.[811] That did not happen.

In December 2017, the rating agency Fitch warned that "if the utilities decide to get involved in building the nuclear power plant and put it on their balance sheets then certainly, we will have a close look as this may be negative for the ratings." This is because Polish utilities are already "substantially leveraged" and the massive cost of nuclear investment would be problematic. Furthermore, the agency suggested that offshore wind, with falling technology costs, would be more economic.[812]

The Polish General Directorate for the Environment (GDOS) started, in December 2015, the scoping phase for the Environmental Impact Assessment for the first Polish nuclear power station with a notification to states within 1,000 km from the proposed three sites. Directly after the start of this scoping phase, PGE EJ1 informed GDOS that it was withdrawing one of the three proposed sites, at Choczewo, because of the potential impacts on protected nature

807 - Polish Ministry of Economy, "Polish Nuclear Power Programme", National Atomic Energy Agency, January 2014, see http://www.paa.gov.pl/sites/default/files/PPEJ%20eng.2014.pdf, accessed 17 August 2018.

808 - *NIW*, "Briefs—Poland", 8 February 2013.

809 - *The Economist*, "Polish Energy, Going nuclear", 31 January 2014, see http://www.economist.com/blogs/easternapproaches/2014/01/polish-energy, accessed 24 April 2018.

810 - *NEI*, "Potential and Existing Global Nuclear Newbuild Projects", 25 April 2014.

811 - *Nucnet*, "Amec Wins USD 430 Million Contract To Support Polish New-Build", 9 July 2014, see https://www.nucnet.org/all-the-news/2014/07/21/amec-wins-usd-430-million-contract-to-support-polish-new-build, accessed 24 April 2018.

812 - Agnieszka Barteczko, Anna Koper, "Funding nuclear project could hit Polish utilities' ratings: Fitch", *Reuters*, 8 December 2017, see https://www.reuters.com/article/us-poland-nuclear/funding-nuclear-project-could-hit-polish-utilities-ratings-fitch-idUSKBN1E21YM, accessed 30 June 2018.

areas. In March 2017, PGE EJ1 began, again, environmental assessment and site selection at only two sites, both in the Northern province of Pomerania, due to be completed in 2020.[813]

However, the decisions have not been taken, and in late 2017, the Energy Minister, Krzysztof Tchórzewski, said that he would like to see Poland build three nuclear reactors, at five-yearly intervals, the first to operate in 2029, with each unit costing US$7 billion.[814] The financial model being proposed by the Government is not clear, although it has previously said that it would adopt the strike-price model then favored in the U.K.

In November 2018, the Government published a draft strategic energy development program, which called for the construction of four reactors (providing between 6–10 GW of capacity) by 2040, with the first in operation by 2033[815], a decade later than a plan published just five years earlier. The Ministry of Energy envisages that the selection of location for the first plant would be made in 2020, while the selection of the technology would be in 2021.[816]

Vietnam

A decision by the Prime Minster of Vietnam of July 2011 stated that by 2020 the first nuclear power plant will be in operation, with a further 7 GW of capacity to be in operation by 2025 and total of 10.7 GW in operation by 2030. In October 2010, Vietnam signed an intergovernmental agreement with Russia's Atomstroyexport to build the Ninh Thuan-1 nuclear power plant, using 1200 MW VVER reactors. Construction was slated to begin in 2014, with the turnkey project being owned and operated by the state utility Electricity of Vietnam (EVN). However, numerous delays have occurred and the national electricity development plan, approved by the government in March 2016, envisioned the "first nuclear power plant put into operation in 2028".[817] At the same time, the revised "National Power Master Plan"—likely the same as the "national electricity development plan"—suggested a diminishing role for nuclear power from 10.1 percent to 5.7 percent by 2030.[818]

Vietnam's nuclear power ambitions were severely curtailed in November 2016, when 92 percent of the members of the National Assembly approved a government motion to cancel the proposed nuclear projects with both Russia and Japan, due to slowing electricity demand increases, concerns of safety and rising construction costs.[819] While Vietnam has signed

813 - *NEI*, "Site Studies begin for Poland's first NPP", 12 April 2017, see http://www.neimagazine.com/news/newssite-studies-begin-for-polands-first-npp-5784946/, accessed 24 April 2018.

814 - Wojciech Zurawski, Agnieszka Barteczko "Poland may have first nuclear power plant by 2029", *Reuters*, 6 September 2017, see https://www.reuters.com/article/poland-nuclear/poland-may-have-first-nuclear-power-plant-by-2029-idUSL8N1LN222, accessed 24 April 2018.

815 - Gary Peach, "Power Demand in Poland Bolsters Case for Nuclear", *NIW*, 11 November 2018.

816 - *WNN*, "Poland already preparing for nuclear plant, says energy minister", 16 May 2019, see https://www.world-nuclear-news.org/Articles/Poland-already-preparing-for-nuclear-plant,-says-e, accessed 14 June 2019.

817 - *VietNamNet*, "Vietnam needs US$148 billion to develop national electricity until 2030", 20 March 2016, see http://english.vietnamnet.vn/fms/society/152739/vietnam-needs-us-148-billion-to-develop-national-electricity-until-2030.html, accessed 22 April 2018.

818 - Viet Phuong Nguyen, "The fate of nuclear power in Vietnam", *Bulletin of the Atomic Scientists*, 5 December 2016, see https://thebulletin.org/fate-nuclear-power-vietnam10245, accessed 22 April 2018.

819 - *NIW*, "Briefs - Vietnam", 28 November 2016.

nuclear cooperation agreements with Russia (July 2017)[820], China (November 2017)[821] and India (March 2018)[822], a December 2018 presentation in China by a senior official of Vietnam's electricity company EVN on "Intelligent Clean Energy" does not even mention the term "nuclear".[823]

"COMMITTED PLANS"

The fortunes of the two countries in the World Nuclear Association's (WNA) "committed plans" category differ considerably. In the case of Egypt, once again through concessional financing from Russia, the project seems to be making progress, but in Jordan the prospect of building any of the current generation of designs has all but vanished and a future program would, if it is developed at all, rely on future Gen IV designs.

Egypt

In Egypt, the government's Nuclear Power Plants Authority was established in the mid-1970s, and plans were developed for 10 reactors by the end of the century. Despite discussions with Chinese, French, German, and Russian suppliers, little development occurred for several decades.

In February 2015, Russia's Rosatom and Egypt's Nuclear Power Plant Authority eventually did sign an agreement, followed in November 2015 by an intergovernmental agreement for the construction of four VVER-1200 reactors at Dabaa, 130 km northwest of Cairo. The deal was apparently worth €20–22 billion (US$23–27 billion), with Russia providing up to 90 percent of the finance, to be paid back through the sale of electricity. In May 2016, it was announced that Egypt concluded a US$25 billion loan with Russia for nuclear construction. According to the Egyptian official journal, the loan is to cover 85 percent of the project cost, with the total investment thus estimated at around US$29.4 billion. In March 2017, Ayman Hamza, a spokesman of the Egyptian Ministry for Electricity, said that contracts for construction works and for training of personnel had been signed with Russia and that commercial contracts were expected to be signed later in 2017.[824] In April 2017, the Energy and Environment Committee of the Parliament began discussions about regulating nuclear construction in Egypt.

In December 2017, Rosatom Director General Alexey Likhachov and Mohamed Shaker, Egypt's Energy Minister signed a notice to proceed with construction as well as an agreement that "spans the power plant's entire life cycle, i.e. 70 to 80 years". The total cost of the project was now reported to be US$60 billion including US$30 billion for the reactor construction. Three other deals were signed to cover the supply of nuclear fuel for 60 years, operation and

820 - *WNN*, "Russia signs MOU for Vietnam nuclear research centre", 4 July 2017, see http://www.world-nuclear-news.org/NN-Russia-signs-MOU-for-Vietnam-nuclear-research-centre-0407175.html, accessed 22 April 2018.

821 - *WNN*, "China and Vietnam to cooperate on nuclear safety", 13 November 2017, see http://www.world-nuclear-news.org/RS-China-and-Vietnam-to-cooperate-on-nuclear-safety-1311175.html, accessed 22 April 2018.

822 - *WNN*, "India and Vietnam enhance nuclear cooperation", 5 March 2018, see http://www.world-nuclear-news.org/NP-India-and-Vietnam-enhance-nuclear-cooperation-0503185.html, accessed 22 April 2018.

823 - EVN, "Intelligent Clean Energy—Viet Nam's experience", International Forum for Clean Energy, Macao, December 2018.

824 - *NEI*, "Egypt and Russia agree on two contracts for El Dabaa NPP", 20 March 2017, see https://www.neimagazine.com/news/newsegypt-and-russia-agree-on-two-contracts-for-el-dabaa-npp-5765715/, accessed 14 June 2019.

maintenance for the first 10 years of operation and operating and training of personnel. Russia would supply a loan of US$25 billion, at three percent interest for 85 percent of the construction cost. The Egyptian government agreed to repay over 22 years starting in 2029.

The next two and half years will focus on the site preparation and licensing. According to Anatolos Kovatnov, the head of engineering work at the Dabaa project, Rosatom has submitted all the documents required, and hopes to obtain the permits to start construction at the first unit of the Dabaa plant by 2020. In March 2019, the Egyptian Nuclear Plants Authority granted the site a permit for the reactors, which is the first step in getting the construction permit.[825] With construction expected to take five years, the completion of the project is now expected in 2026/27. However, questions have been raised as to whether the Nuclear and Radiological Regulatory Authority will have the capacity and political independence to effectively oversee the project.

Jordan

Influential policymakers in Jordan have long desired the acquisition of a nuclear power plant. In 2007, the government established the Jordan Atomic Energy Commission (JAEC) and the Jordan Nuclear Regulatory Commission. JAEC started conducting a feasibility study on nuclear power, including a comparative cost/benefit analysis.[826]

In September 2014, JAEC and Rosatom signed a two-year development framework for a project, which was projected to cost under US$10 billion and generate electricity costing US$0.10/kWh.[827]

In March 2018, the nuclear industry and the U.S. Department of Energy's Energy Information Administration continued to project that construction would start in 2019 and that two 1000 MW reactors would be completed by 2024.[828] But in May 2018, an unnamed Jordanian government official revealed to *The Jordan Times* that the plan to build two 1000 MW "is now over", and that "Jordan is now focusing on small modular reactors because the large reactors place financial burden on the Kingdom and in light of the current fiscal conditions we believe it is best to focus on smaller reactors".[829] This was confirmed the following month by JAEC which stated: "Jordan and Russia held a meeting last year to discuss means to move forward with the project and how to secure necessary finance for the plant... The Russians requested obtaining loans from commercial banks, which would have increased the cost of the project and the prices of generated electricity. The Jordanian government rejected the proposal".[830] This suggests not only that Jordan was unable to secure financing for the two 1000 MW proposal, but also that Russia is unable to provide low-interest financing.

825 - *NEI*, "Egypt's El-Dabaa NPP granted site permit", 16 April 2019, see https://www.neimagazine.com/news/newsegypts-el-dabaa-npp-granted-site-permit-7156405/, accessed 14 June 2019.

826 - Mark Hibbs, "Jordan reactor siting study to be done in 2009, JAEC says", *NW*, 27 September 2007.

827 - *NIW*, "Briefs—Jordan", 18 April 2014.

828 - *WNN*, "Middle East nuclear power to quadruple in ten years", 6 March 2018, see http://www.world-nuclear-news.org/NP-Middle-East-nuclear-power-to-quadruple-in-ten-years-06031801.html, accessed 24 April 2018.

829 - Mohammad Ghazal, "Jordan to replace planned nuclear plant with smaller, cheaper facility", *Jordan Times*, 26 May 2018, see http://www.jordantimes.com/news/local/jordan-replace-planned-nuclear-plant-smaller-cheaper-facility, accessed 1 June 2018.

830 - Mohammad Ghazal, "Funding issues behind scrapping nuclear deal with Russia", *Jordan Times*, 12 June 2018, see http://www.jordantimes.com/news/local/funding-issues-behind-scrapping-nuclear-deal-russia-%E2%80%94-jaec, accessed 5 July 2018.

Jordan has been focusing on small modular reactors in the last year after it dropped plans to construct Russian VVERs. The Chairman of JAEC explained this focus at an International Atomic Energy Agency (IAEA) conference in November 2018 by arguing "the proposed project to build a nuclear power plant relying on Small Modular Reactors (SMRs) seems to be the more appropriate in bridging the gap in the Jordanian electricity generation mix".[831] It is reported that the chosen site for the SMR is Aqaba on the Red Sea "due to its proximity to industrial and transportation infrastructure".[832]

JAEC has entered into agreements with King Abdullah City for Atomic and Renewable Energy, Rolls-Royce, and NuScale to carry out feasibility studies to construct SMRs.[833] Of course, since none of these designs are really ready, especially Rolls-Royce, these feasibility studies can only be based on hypothetical numbers.

The Government is updating its National Energy Strategy 2030, where renewables are expected to play a more important role due to the success of solar and wind deployment, rising from 2 percent to 10 percent of national electricity supply since 2014. Energy Minister Hala Zawatim, said in late 2018 that renewable energy should provide more than 20 percent of the country's electricity by 2020[834], doubling the previous target[835].

"WELL DEVELOPED PLANS"

Under the World Nuclear Association's (WNA) definition these countries have plans that are well developed but are still to make a full commitment to nuclear power. In many of these countries, the likelihood of further development is diminishing as political enthusiasm wanes and the economics of alternatives become more advantageous.

Indonesia

Since the mid-1970s, Indonesia has discussed and brought forward plans to develop nuclear power, releasing its first feasibility study, supported by the Italian government, in 1976. The analysis was updated in the mid-1980s with help from the IAEA, the U.S., France and Italy. Numerous discussions took place over the following decade, and by 1997 a Nuclear Energy Law was adopted that gave guidance on construction, operation, and decommissioning. A decade

831 - Khaled Toukan, "Speech of H.E. Dr. Khaled Toukan, Chairman, Jordan Atomic Energy Commission", presented at the Ministerial Conference on Nuclear Science and Technology: Addressing Current and Emerging Development Challenges, 28 November 2018, see https://www.iaea.org/events/ministerial-conference-on-nuclear-science-and-technology-2018/statements, accessed 24 June 2019.

832 - Joy Nasr and Ali Ahmad, "Middle East Nuclear Energy Monitor: Country Perspectives 2018", Energy Policy and Security Program, Issam Fares Institute for Public Policy and International Affairs, American University of Beirut, January 2019.

833 - *WNN*, "Jordan and Saudi Arabia team up on uranium, SMRs", 29 March 2017, see http://www.world-nuclear-news.org/Articles/Jordan-and-Saudi-Arabia-team-up-on-uranium,-SMRs, accessed 24 June 2019; and *WNN*, "NuScale SMR to be considered for use in Jordan", 15 January 2019, see http://www.world-nuclear-news.org/Articles/NuScale-SMR-to-be-considered-for-use-in-Jordan, accessed 24 June 2019; also *WNN*, "Rolls-Royce to conduct SMR study for Jordan", 9 November 2017, see http://www.world-nuclear-news.org/NN-Rolls-Royce-to-conduct-SMR-study-for-Jordan-09111702.html, accessed 24 April 2018.

834 - *The Jordan Times*, "'20% of country's energy mix to be supplied from renewable sources by 2020'", 11 December 2018, see http://www.jordantimes.com/news/local/%E2%80%9820-countrys-energy-mix-be-supplied-renewable-sources-2020%E2%80%99, accessed 23 July 2019.

835 - U.S. Department of Commerce , International Trade Administration, "Jordan - Renewable Energy", Export.gov, 23 February 2017, see https://www.export.gov/article?id=Jordan-Renewable-Energy, accessed 7 May 2018.

later, the 2007 Law on National Long-Term Development Planning for 2005–25 stipulated that between 2015 and 2019, four units should be completed with an installed capacity of 6 GW.[836]

In July 2007, Korea Electric Power Corp. (KEPCO) and Korea Hydro & Nuclear Power Co. (KHNP) signed a memorandum of understanding with Indonesia's PT Medco Energi Internasional to undertake a feasibility study for building two 1000 MW units at a cost of US$3 billion. Then, in December 2015, the Indonesian government pulled the plug on all nuclear plans, even for the longer-term future. Trade journal *Nuclear Engineering International* (*NEI*) cited the Energy and Mineral Resources Minister Sudirman Said: "We have arrived at the conclusion that this is not the time to build up nuclear power capacity. We still have many alternatives and we do not need to raise any controversies."[837]

According to the IAEA, in 2017, the Indonesian government continued to work on a roadmap for nuclear energy development, but that nuclear energy is "a last resort in the national energy policy".[838] The latest revision of the new and renewable energy policy mix mentions that nuclear will be only considered should the renewable energy target not be achieved in 2025. [839]

Despite this, research is ongoing and in March 2018, the National Nuclear Energy Agency launched a roadmap for the development of the design of a domestic Small Modular Reactor, which was due to completed by the end of the year.[840]

Kazakhstan

Kazakhstan is the world's largest producer of uranium, with about 40 percent of the global total. It operated a small fast breeder reactor, the BN 350 at Aktau, during 1972–1999. A number of countries, including Russia, Japan, South Korea, and China have signed co-operation agreements with Kazakhstan for the development of nuclear power.

In 2014, President Nursultan Nazarbayev used his State of the Nation address to highlight the need to develop nuclear power. Since then, negotiations have continued, particularly with Toshiba-Westinghouse of Japan and Rosatom of Russia.[841] In October 2015, the Vice Minister of Energy Bakhytzhan Dzhaksaliyev said that finding a suitable site and strategic partner may

836 - Hanan Nugroho, "Development of Nuclear Power in Indonesia: Stop or Go?", *Jakarta Post*, 5 May 2010, see http://www.thejakartapost.com/news/2010/05/05/development-nuclear-power-indonesia-stop-or-go.html, accessed 26 April 2017.

837 - *NEI*, "Indonesia rules out nuclear as major power source", 14 December 2015, see http://www.neimagazine.com/news/newsindonesia-rules-out-nuclear-as-major-power-source-4752814, accessed 15 December 2015.

838 - IAEA, "Indonesia—Country Nuclear Power Profiles", Update 2017, see https://cnpp.iaea.org/countryprofiles/Indonesia/Indonesia.htm, accessed 24 April 2018.

839 - Asean Centre for Energy, "Pre-feasbility study on the establishment of nuclear power plant in Asea", April 2018, see http://www.aseanenergy.org/resources/pre-feasibility-study-on-the-establishment-of-nuclear-power-plant-in-asean/, accessed 16 June 2019.

840 - *WNN*, "Progress with Indonesian SMR project", 16 March 2018, see http://www.world-nuclear-news.org/NN-Progress-in-Indonesian-SMR-project-1603184.html, accessed 30 June 2018.

841 - *WNN*, "Russia and Kazakhstan to ink nuclear power accord this year", 2 March 2016, see http://www.world-nuclear-news.org/NP-Russia-and-Kazakhstan-to-ink-nuclear-power-accord-this-year-02031601.html, accessed 24 April 2018.

take two to three years.[842] In December 2015, a draft Atomic Energy Law was referred to the Senate, in order to address licensing, security, environmental protection rules and standards.[843]

In the following years, Kazakhstan has had a number of discussions with countries and reactor suppliers. In August 2017, Kazakhstan and the U.S. signed a nuclear cooperation agreement. According to Kazakh Energy Minister Kanat Bozumbayev, the agreement aims to "focus on cooperation in such areas as the peaceful use of nuclear energy, containment of carbon dioxide, sustainability of energy systems, opening and expansion of energy markets, as well as the non-proliferation of nuclear weapons and security".[844]

Then in April 2019, during a meeting between President Putin of Russia and Kazakhstan's president Qasym-Zhomart Toqaev, it was suggested that Russia help in the construction of a nuclear power plant at Ulken in the southeastern Almaty Province. Soon after this, Deputy Kazakh Energy Minister Magzum Mirzagaliev said there was no "concrete decision" to construct a nuclear power plant in Kazakhstan.[845]

Press in the region report that the critically acclaimed HBO series "Chernobyl" is increasing public opposition to the proposals to the Russia nuclear deal, with Kazakhstani filmmaker Zhanna Issabayeva in a Facebook post. "Never, never, never in Kazakhstan should there be a nuclear power plant."[846]

Saudi Arabia

In 2012, the IAEA suggested that by 2013 the Kingdom of Saudi Arabia might start building its first nuclear reactor.[847] The King Abdullah City for Atomic and Renewable Energy (KA-CARE) had earlier been set up in 2010 to advance this agenda, and in June 2011, the coordinator of scientific collaboration at KA-CARE announced plans to construct 16 nuclear power reactors over the next 20 years at a cost of more than 300 billion riyals (US$80 billion). The first two reactors were planned to be online ten years later and then two more per year until 2030.

During 2015, new cooperation agreements were signed with France, Russia, China and South Korea. The latter seemed to be the most advanced and with proposals for the building of two "smart" reactors and ongoing research and collaboration.[848] In March 2017, a cooperation

842 - *Tengri News*, "Kazakhstan to define location and strategic partners for its first nuclear power plant in 2-3 years", 23 October 2015, see https://en.tengrinews.kz/industry_infrastructure/Kazakhstan-to-define-location-and-strategic-partners-for-its-262679/, accessed 24 April 2018.

843 - Government of the Republic of Kazakhstan, "Draft law on use of nuclear energy, as amended, referred to Senate", 21 December 2015, see http://www.government.kz/en/novosti/29961-draft-law-on-use-of-nuclear-energy-as-amended-referred-to-senate.html, accessed 24 April 2018.

844 - Dana Omirgazy, "Kazakhstan, US agree to cooperate on nuclear energy", *The Astana Times*, 30 August 2017, see https://astanatimes.com/2017/08/kazakhstan-us-agree-to-cooperate-on-nuclear-energy/, accessed 4 July 2018.

845 - Bruce Pannier, "Putin Offers Russian Help To Build Kazakh Nuclear Plant", *RadioFreeEurope/RadioLiberty*, 6 April 2019, see https://www.rferl.org/a/kazakhstan-putin-offers-russian-nuclear-plant-help/29865177.html, accessed 19 April 2019.

846 - *Eurasianet*, "HBO's Chernobyl stokes anti-nuclear mood in Kazakhstan", 7 June 2019, see https://eurasianet.org/hbos-chernobyl-stokes-anti-nuclear-mood-in-kazakhstan, accessed 16 June 2019.

847 - Lucas W. Hixson, "IAEA—Vietnam and 4 other countries to incorporate nuclear energy after Fukushima", *Enformable.com*, 24 February 2012, see http://enformable.com/2012/02/iaea-vietnam-and-4-other-countries-to-incorporate-nuclear-energy-after-fukushima/, accessed 26 April 2017.

848 - *NIW*, "Saudi Arabia, Will Water Scarcity Spur Nuclear Growth?", 31 July 2015.

agreement was signed with China Nuclear Engineering Group Corporation (CNEC) on the development of high-temperature gas cooled reactors.[849]

In a reiterated push for the deployment of nuclear power a new domestic target of 17.6 GW by 2021 was put forward. In March 2018, the Government approved a national nuclear program, which is said to include a shortlist of bidders (China, France, Russia, South Korea and United States) with reports suggesting contracts for the construction of two reactors expected by 2018,[850] and planned commissioning in 2027,[851] a target that has not been met. However, Energy Minister Khalid al-Falih said in January 2019 that his government still planned to build two reactors in the next decade and then expand the program once these were in operation.[852]

The five vendors had been requested to supply information on financing frameworks as well as technical information. Amongst the bidders, Korea Electric Power Corporation (KEPCO) is thought to be in a strong position, given its experience in the United Arab Emirates (UAE), although Russia is also in contention due to a track record of offering finance. The French, who are likely to offer the European Pressurized Water Reactor (EPR)—with only two reactors in China newly commissioned—and along with China (Hualong One) are proposing relatively untested designs and so may be viewed less favorably, just as is the U.S. bid, using the AP-1000 technology of bankrupt Westinghouse.[853]

In mid 2018 the IAEA undertook an Integrated Nuclear Infrastructure Review (INIR). Mikhail Chudakov, IAEA Deputy Director General and Head of the Department of Nuclear Energy, stated on the completion of the review that Saudi Arabia had established a legislative framework to support the next stage of nuclear development.[854]

Reuters reported in April 2019 that a full tender would be launched in 2020. "Saudi Arabia is continuing to make very deliberate steps forward although at a slower pace than originally expected"—originally it was proposed to select a vendor in 2018.[855] The murder of Saudi journalist Jamal Khashoggi in October 2018 led a number of countries to reduce their engagement with the Kingdom. Importation of equipment from the United States will require the signing of a Nuclear Co-operation Agreement (123 Agreement). However, there is increasing pressure to go further and include a requirement to forego reprocessing and/or processing, which is counter to previous Saudi insistence on their desire to fabricate their own fuel.[856]

849 - *NEI*, "Saudi Arabia looks to China and Korea for nuclear assistance", 20 March 2017, see http://www.neimagazine.com/news/newssaudi-arabia-looks-to-china-and-korea-for-nuclear-assistance-5767240/, accessed 25 April 2018.

850 - *NEI*, "Saudi Arabia approves national nuclear programme", 19 March 2018, see http://www.neimagazine.com/news/newssaudi-arabia-approves-national-nuclear-programme-6087593/, accessed 25 April 2018.

851 - *NEI*, "Saudi Arabia to prequalify NPP bids by May", 18 January 2018, see http://www.neimagazine.com/news/newssaudi-arabia-to-prequalify-npp-bids-by-may-6029868/, accessed 25 April 2018.

852 - *Saudi Gazette*, "Saudi Arabia to use N-energy for electricity production, asserts Al-Falih", 16 January 2019, see http://saudigazette.com.sa/article/557047/SAUDI-ARABIA/Saudi-Arabia-to-use-N-energy-for-electricity-production-asserts-Al-Falih, accessed 14 April 2019.

853 - Phil Chaffee, "Ka-Care Hopes to Choose from Five Bids by Year's End", *NIW*, 19 January 2018.

854 - IAEA, "IAEA Delivers Report on Nuclear Power Infrastructure Development to Saudi Arabia", 25 January 2019, see https://www.iaea.org/newscenter/news/iaea-delivers-report-on-nuclear-power-infrastructure-development-to-saudi-arabia, accessed 16 June 2019.

855 - Sylvia Westall, "Saudi plans to invite bids for nuclear power project in 2020: sources", *Reuters*, 4 April 2019, see https://uk.reuters.com/article/us-saudi-nuclear/saudi-plans-to-invite-bids-for-nuclear-power-project-in-2020-sources-idUKKCN1RG1LL, accessed 9 April 2019.

856 - Timothy Gardner, "U.S. Senate proposal would block Saudi path to atomic weapon in nuclear deal", *Reuters*, 13 February 2019, see https://www.reuters.com/article/us-usa-nuclear-saudi/u-s-senate-proposal-would-block-saudi-path-to-atomic-weapon-in-nuclear-deal-idUSKCN1Q12UT, accessed 9 April 2019.

Despite this, *Reuters* reported that U.S. Energy Secretary Rick Perry has approved six secret authorizations by companies to sell nuclear power technology. Perry's approvals, known as Part 810 authorizations, allow companies to do preliminary work on nuclear power ahead of any deal.[857]

Concerns have been raised about the connection the Saudi leadership has expressed between the civil nuclear program and the desire to acquire nuclear weapons. In March 2018, Prince Mohammed bin Salman (MbS) told *CBS News*, "Saudi Arabia does not want to acquire any nuclear bomb, but without a doubt if Iran developed a nuclear bomb, we will follow suit as soon as possible."[858] An active civil nuclear program would enable the country to develop a nuclear weapons program much more rapidly.

Thailand

The National Energy Policy Council of Thailand in 2007 proposed that up to 5 GW of capacity be operational between 2020 and 2028. However, this target will not be met for a number of reasons, including significant local opposition at the proposed sites. The latest proposal from the Electricity Generating Authority of Thailand (EGAT) is for two 1 GW units to be operational by 2036, although no location has been named.[859] Thailand's largest private power company has announced that it will invest US$200 million for a 10 percent stake of the China General Nuclear Power Corporation (CGN) and Guangxi Investment Group's Fangchenggang nuclear power plant in China.[860] CGN obviously eyes a role in the potential, although very vague, nuclear project in Thailand.

Meanwhile in 2018, the Government announced plans to double the use of renewable energy, so it would provide 30 percent of capacity by 2030, up from 14.5 percent today.[861]

Uzbekistan

Uzbekistan has announced that it intends to develop nuclear power with the help of Russia. In preparation, President Shavkat Mirziyoyev signed a decree in July 2018 to develop nuclear power in Uzbekistan and created UzAtom, the Uzbek Agency for Nuclear Energy. UzAtom's remit includes developing policy and law; attracting investment and financing; technology and safety; the execution of contracts for designing and building the country's new nuclear facilities; ensuring regulatory best practice in collaboration with the IAEA.[862]

857 - Timothy Gardner, "U.S. approved secret nuclear power work for Saudi Arabia", *Reuters*, 28 March 2019, see https://www.reuters.com/article/us-usa-saudi-nuclear-idUSKCN1R82MG, accessed 4 May 2019.

858 - Aileen Murphy, M.V. Ramana, "The Trump administration is eager to sell nuclear reactors to Saudi Arabia. But why?", *Bulletin of the Atomic Scientists*, 16 April 2019, see https://thebulletin.org/2019/04/the-trump-administration-is-eager-to-sell-nuclear-reactors-to-saudi-arabia-but-why/, accessed 4 May 2019.

859 - WNA, "Emerging Nuclear Energy Countries", July 2018.

860 - *WNN*, "Thai power company buys into Fangchenggang II", 25 January 2018, see http://www.world-nuclear-news.org/NN-Thai-power-company-buys-into-Fangchenggang-II-2501164.html, accessed 25 April 2018.

861 - *Bangkok Post*, "State targets 30% renewable power by 2030", 20 July 2018, see https://www.bangkokpost.com/business/news/1506658/state-targets-30-renewable-power-by-2030, accessed 16 June 2019.

862 - *fDi Intelligence*, "UzAtom chief explains why Uzbekistan is taking the nuclear route", 14 February 2019, see https://www.fdiintelligence.com/Sectors/UzAtom-chief-explains-why-Uzbekistan-is-taking-the-nuclear-route, accessed 16 June 2019.

In an April 2019 interview with *Nuclear Engineering International* (*NEI*), Jurabek Mirzamakhmudov, director general of UzAtom, has said that it intends to carry out site analysis over the next 18 months at three locations. Mirzamakhmudov says UzAtom has chosen a VVER 1200 reactor design, which would be financed via a soft loan from Russia through an engineering, procurement and construction agreement. The reactors would be used for domestic use, but some of the power would also be exported to neighboring countries such as Afghanistan.[863]

Table 16 | Summary of Potential Nuclear Newcomer Countries

Country	Reactor/Site	Proposed Vendor	Proposed/Actual Construction Start	Initial Planned Startup Date	Current Planned Startup Date
Under Construction					
Bangladesh	Rooppur	Rosatom	November 2017	11/ 2017 7/2018	2023 2024
Belarus	Ostrovets / Belarusian	Rosatom	2013	2016	Q4 2019
			2014	2018	7/2020
Turkey	Akkuyu	Rosatom	2018	2015	2024
UAE	Barakah-1	KEPCO	2012	2017	2020
	Barakah-2		2013	2018	2021
	Barakah-3		2014	2019	2022
	Barakah-4		2015	2020	2023
Contract Signed or Advanced Development					
Lithuania	Visegrade	Hitachi	Suspended	-	-
Poland		?	?	-	-
Vietnam	Ninh Thuan	Rosatom	Suspended	-	-
"Committed Plans"					
Egypt		Rosatom	2018	-	-
Jordan		Rosatom	Abandoned	-	-
Turkey	Sinop	Mitsubishi/Areva	Abandoned	-	-
	Ingeada	SNPTC/WH	2019	-	-
"Well Developed Plans"					
Indonesia		Rosatom	Indefinitely Postponed	-	-
Kazakhstan		Rosatom	?	-	-
Saudi Arabia		?	?	-	-
Thailand		?	?	-	-
Uzbekistan		Rosatom	?	-	-

Sources: Various, compiled by WNISR, 2019

863 - *NEI*, "Uzbekistan's nuclear aspirations", 9 April 2019, see https://www.neimagazine.com/features/featureuzbekistans-nuclear-aspirations-7145738/, accessed 19 April 2019.

CONCLUSION ON POTENTIAL NEWCOMER COUNTRIES

2018 has been a mixed year for the development of new nuclear power programs. In the UAE, which for over a decade has been held up as a role model for potential newcomer countries, increasing construction and personnel issues are coming to light, leading to even more delays and even higher costs. Operation of Barakah-1 in the UAE is now expected in 2020, some three years late. In Belarus, no startup rescheduling has been made public over the past few years, and the present year will show whether the current timetables for commissioning in late 2019 are accurate. Construction is ongoing in Bangladesh, where work on a second reactor started in 2018, and in Turkey, although at such an early stage that monitoring of progress is difficult.

Of all the other countries, Egypt has the most concrete plans. Delays and abandonments have been experienced in all the other countries that the WNA surprisingly categorizes as in a stage of advanced development or with committed plans. The stop/start developments in Saudi Arabia seem to have taken a step forward in the past year, although wider geopolitical developments may hinder co-operation with a number of countries and thus further progress. (See **Table 16** for overview).

What is clear is that Russia remains the dominant proposed exporter, actively promoting its technology with concessional financial packages and fuel services that appear attractive to a small number of countries, if Russia—with its state finances in serious difficulties—can afford to deliver.

SMALL MODULAR REACTORS

Small Modular Reactors (SMRs) continue to attract inordinate attention. SMRs as well as other "advanced reactor" designs are often positioned as a solution to one or more of the problems confronting nuclear power.[864] Although talked about as physical reactors, most SMRs are only theoretical designs, and all too often at a very initial stage of development. At the same time, there has been a long history of promotion of SMRs premised on rapid commercialization and expansion, none of which has come true. Based on such expectations, several countries, especially the United States, Canada, and the United Kingdom, are putting in place processes and policies to promote these designs.[865] What follows is an update of earlier analysis (in particular WNISR2015 and WNISR2017) on SMR programs in selected countries (in alphabetical order).

ARGENTINA

The CAREM-25 reactor has been under construction in Argentina since February 2014.[866] When construction started, Argentina's Comision Nacional de Energia Atómica (CNEA) announced that CAREM-25 would begin cold testing in 2016 and receive its first fuel load in the second half of 2017.[867] By 2018, this date had been pushed back to 2020.[868] As of mid-2019, the unit is expected to start up in late 2021 or 2022.

CANADA

In the past two years, Canada has emerged as the site of an aggressive push to develop SMRs, led by the chief institutional promoters of nuclear energy in the country, including the Canadian Nuclear Association and Natural Resources Canada (NRCan). In November 2018, NRCan published the Canadian Small Modular Reactor (SMR) Roadmap.[869] Unlike in other countries, SMRs are being promoted in Canada as potentially aimed at meeting the electricity

864 - The acronym SMR is also used to mean "small and medium-sized reactor" by the International Atomic Energy Agency (IAEA). For the IAEA, a "small" reactor is one having electrical output less than 300 MWe and a "medium" reactor is one having a power output between 300 MWe and 700 MWe.

865 - The exact number of SMR designs under development is unclear because many designs are dormant. In one 2018 document, the International Atomic Energy Agency (IAEA) states that currently "there are around 20 primary SMR designs under development in 10 countries (Argentina, China, France, India, Italy, Japan, the Republic of Korea, the Russian Federation, South Africa, and the United States of America) for domestic energy production and, in the case of some designs, for commercial export"; see IAEA, "Deployment indicators for small modular reactors", 2018. But another IAEA document from 2018 lists 56 SMR designs; see IAEA, "Advances in Small Modular Reactor Technology Developments—A Supplement to: IAEA Advanced Reactors Information System (ARIS)—2018 Edition", September 2018, see https://aris.iaea.org/Publications/SMR-Book_2018.pdf, accessed 30 August 2019.

866 - *WNN*, "Construction of CAREM underway", 10 February 2014, see http://www.world-nuclear-news.org/NN-Construction-of-CAREM-underway-1002144.html, accessed 24 May 2019.

867 - Ibidem.

868 - *NEI*, "Progress for Argentina's CAREM SMR", 9 May 2018, see http://www.neimagazine.com/news/newsprogress-for-argentinas-carem-smr-6144828, accessed 19 May 2018.

869 - CNS, "SMR Roadmap Launch", Canadian Nuclear Society, 30 September 2018, see https://www.cns-snc.ca/events/g4sr1/, accessed 30 September 2018.

needs of remote communities and mines (in the northern part of the country),[870] and to process tar sands.[871] However, these markets are insufficient to develop the facilities needed to manufacture those SMRs, and the costs of the electricity from any reactors small enough to power a remote mine or community would be prohibitively high.[872]

The Canadian Nuclear Safety Commission (CNSC) has also for many years expressed its readiness to license SMRs, touting its "appropriate regulatory framework and internal processes in place for the timely and efficient licensing of all types of reactor, regardless of size" and offers what it calls "a technology neutral approach" and offers "a pre-licensing vendor design review", an optional service for SMR vendors.[873] However, pre-licensing vendor design review does not lead to any regulatory decision.

The CNSC's pre-licensing vendor design review takes place in three phases. The first phase involves "an overall assessment of the vendor's nuclear power plant design against the most recent CNSC design requirements for new nuclear power plants in Canada" as well as "all other related CNSC regulatory documents and Canadian codes & standards". The second phase focuses on "identifying any potential fundamental barriers to licensing the vendor's nuclear power plant design in Canada". The third phase "allows the vendor to follow-up on certain aspects of Phase 2 findings by:

- seeking more information from the CNSC about a Phase 2 topic; and/or
- asking the CNSC to review activities taken by the vendor towards the reactor's design readiness, following the completion of Phase 2".[874]

As of May 2019, there are 11 designs at various stages of this process, according to CNSC.[875] Those agreements in force are listed in **Table 17**. Agreements under development are listed in **Table 18**.

870 - HATCH, "SMR Deployment Feasibility Study—Feasibility of the Potential Deployment of Small Modular Reactors (SMRs) in Ontario", Ontario Ministry of Energy, June 2016, see http://ontarioenergyreport.ca/pdfs/MOE%20-%20Feasibility%20Study_SMRs%20-%20June%202016.pdf, accessed 10 May 2018; and CNL, "Perspectives on Canada's SMR Opportunity", Canadian Nuclear Laboratories, October 2017, see http://www.cnl.ca/site/media/Parent/CNL_SmModularReactor_Report.pdf, accessed 27 June 2018.

871 - Sarah Rieger, "Small nuclear reactors could make Alberta's oilsands cleaner, industry experts suggest", *CBC*, 21 May 2019, see https://www.cbc.ca/news/canada/calgary/nuclear-power-oilsands-1.5142864, accessed 30 May 2019.

872 - Sarah Froese, Nadja C. Kunz and M.V. Ramana, "Too Small to be Viable? The Potential Market for Small Modular Reactors in Mining and Remote Communities in Canada", *Energy Policy*, submitted as of July 2019.

873 - S. Herstead, M. de Vos and S. Cook, "Canadian Nuclear Safety Commission: Readiness to Regulate SMRs in Canada", American Society of Mechanical Engineers (ASME), ASME 2011 Small Modular Reactors Symposium, 28 September 2011, see http://dx.doi.org/10.1115/SMR2011-6561, accessed 8 October 2018.

874 - CNSC, "Pre-Licensing Vendor Design Review", Canadian Nuclear Safety Commission, 26 March 2019, see http://nuclearsafety.gc.ca/eng/reactors/power-plants/pre-licensing-vendor-design-review/index.cfm, accessed 28 May 2019.

875 - Ibidem.

Table 17 | Vendor design review service agreements in force between vendors and the CNSC

Vendor	Name of design and cooling type	Approximate electrical capacity (MW electrical)	Applied for	Review start date	Status
Terrestrial Energy Inc.	IMSR Integral Molten Salt Reactor	200	Phase 1	April 2016	Complete
			Phase 2	December 2018	Assessment in progress
Ultra Safe Nuclear Corporation	MMR-5 and MMR-10 High-temperature gas	5-10	Phase 1	December 2016	Complete
			Phase 2	Pending	Project start pending
LeadCold Nuclear Inc.	SEALER Molten Lead	3	Phase 1	January 2017	On hold at vendor's request
Advanced Reactor Concepts Ltd.	ARC-100 Liquid Sodium	100	Phase 1	September 2017	Assessment in progress
Moltex Energy	Moltex Energy Stable Salt Reactor Molten Salt	300	Series Phase 1 and 2	December 2017	Phase 1 assessment in progress
SMR, LLC. (A Holtec International Company)	SMR-160 Pressurized Light Water	160	Phase 1	July 2018	Assessment in progress
NuScale Power, LLC	NuScale Integral pressurized water reactor	60	Phase 2*	Pending 2019	Project start pending

Source: CNSC, 2019

Notes

*Phase 1 objectives will be addressed within the Phase 2 scope of work

Table 18 | Vendor design review service agreement between vendors and the CNSC under development

Vendor	Name of design and cooling type	Approximate electrical capacity (MW electrical)	Application received	Applied for
StarCore Nuclear	StarCore Module High-temperature gas	10	October 2016	Series Phase 1 and 2
URENCO	U-Battery High-temperature gas	4	February 2017	Phase 1
Westinghouse Electric Company, LLC	eVinci Micro Reactor solid core and heat pipes	Various outputs up to 25 MWe	February 2018	Phase 2*
GE-Hitachi Nuclear Energy	BWRX-300 boiling water reactor	300	March 2019	Phase 2*

Source: CNSC, 2019

Notes

*Phase 1 objectives will be addressed within the Phase 2 scope of work

CHINA

China has pursued multiple SMR designs, but the only one currently under construction is the High Temperature Gas-Cooled Reactor (HTR) developed since the 1970s. Called the HTR-PM, the power plant being constructed at Shidaowan (Shidao Bay) in China's eastern Shandong province has a net capacity of 200 MW, with two 100 MW modules in one reactor building driving one 200 MW turbine.

The HTR-PM received final approval from China's cabinet and its national energy bureau in 2011.[876] But due to the changes in Chinese policy following the Fukushima accidents,[877] it was only on 9 December 2012 that construction of HTR-PM commenced.[878] According to the official schedule, construction was to take 59 months,[879] so the reactor should have started operating in 2017. The current estimate is sometime "in the first half of 2020".[880]

The main reason reported for the delay is that the design was incomplete and not ready for construction. A 2017 report by the project company's marketing department technology had reportedly described a situation where "research, design, engineering and construction" were "sometimes taking place simultaneously". More specifically, there were "prolonged delays in manufacturing two key pieces of equipment—the helium circulator and the steam generator. While a prototype of the main helium circulator—referred to as the "heart" of the HTGR and similar to the reactor coolant pumps in pressurized water reactors—was completed in 2014, the final product was only recently shipped to the site" [reported in April 2019].[881]

These problems seem to have convinced decisionmakers to call off earlier plans that envisioned constructing a further nine units (18 modules) of the same type at the same site.[882] That no longer seems to be the case.[883] Part of the reason might be the cost of generating electricity at the plant, which is reported to be 60 fen[884] (US8.4¢) per kilowatt-hour, significantly higher than the reported average 43 fen/kWh for Generation III reactors, and this has been listed as one of the "key challenges" confronting HTGRs in China.[885]

In recent years, mainstream Chinese nuclear institutions have been promoting other SMR designs: the ACPR-50 and ACPR-100 from China General Nuclear (CGN) and the ACP100 from China National Nuclear Corporation (CNNC). All these designs have been in the news, as a result of an announcement that China was going to build maritime nuclear power platforms in the South China Sea.[886] CNNC and CGN have been working on these designs since around 2010, but development and plans for deployment have clearly accelerated in the last couple of years, perhaps as a result of conflicts over islands in the South China Sea.

876 - Keith Bradsher, "China Building Nuclear Reactors With Radically Different Design", *The New York Times*, 24 March 2011, see http://www.nytimes.com/2011/03/25/business/energy-environment/25chinanuke.html, accessed 24 April 2012.

877 - Amy King, M.V. Ramana, "The China Syndrome? Nuclear Power Growth and Safety After Fukushima", *Asian Perspective*, 2015.

878 - Zuoyi Zhang et al., "The Shandong Shidao Bay 200 MWe High-Temperature Gas-Cooled Reactor Pebble-Bed Module (HTR-PM) Demonstration Power Plant: An Engineering and Technological Innovation", *Engineering*, March 2016.

879 - Ibidem., p.112.

880 - C. F. Yu, "Progress on HTGR", *NIW*, 26 April 2019.

881 - Ibidem.

882 - David Dalton, "China Begins Construction Of First Generation IV HTR-PM Unit", *NucNet*, 7 January 2013, see http://www.nucnet.org/all-the-news/2013/01/07/china-begins-construction-of-first-generation-iv-htr-pm-unit, accessed 9 January 2013.

883 - *WNN*, "First vessel installed in China's HTR-PM unit", 21 March 2016, see http://www.world-nuclear-news.org/nn-first-vessel-installed-in-chinas-htr-pm-unit-2103164.html, accessed 25 February 2017.

884 - 100 fen = 1 yuan

885 - C. F. Yu, "CNEC-CFHI Deal—Boosting the HTGR Or Chinese Manufacturing?", *NIW*, 9 September 2016.

886 - *NEI*, "China gets onboard", 16 August 2016, see http://www.neimagazine.com/features/featurechina-gets-onboard-4980507/, accessed 5 March 2017.

INDIA

India's SMR offering is the Advanced Heavy Water Reactor (AHWR) design that has been under development since the 1990s.[887] There are two versions, one utilizing plutonium as fuel and the other using low-enriched uranium advertised as possessing "intrinsic proliferation resistant features".[888]

The AHWR continues to be delayed. In the early 2000s, construction of the first unit of this design was projected to start in 2005.[889] But even the 2017–18 "Annual Report" of India's Department of Atomic Energy stated that only a test station has been set up at the Bhabha Atomic Research Centre in Mumbai "for validation of AHWR" Control & Instrumentation "system architecture, system application, development and integrated system testing of functional, performance and safety requirements".[890] In other words, the AHWR design is not yet complete and it is unlikely that construction of the AHWR will start anytime soon.

RUSSIA

Russia has a number of SMR designs under development but only one of them has advanced to construction. The first two reactors of the KLT-40S design are placed on a ship called the Akademik Lomonosov and together they constitute the small nuclear plant that Russia hopes to sell to remote coastal communities. However, the Akademik Lomonosov itself is intended to "supply electricity to settlements and companies extracting hydrocarbons and precious stones in the Chukotka region" and the residents of these areas "are key for Russian plans to tap into the hidden Arctic riches of oil and gas as Siberian reserves diminish".[891] Thus, nuclear power, if and when it is produced by these KLT-40S reactors, will contribute to carbon dioxide emissions.

In November 2018, the first of the two reactors attained criticality.[892] So far, there have been no reports of the second reactor's criticality. Akademik Lomonosov was reported to be towed to the port of Pevek on the Chukotka Peninsula in the east Arctic[893], starting in August 2019. The ship's construction has taken at least four times as long as originally projected; a little before construction of the ship began in 2007, Rosatom announced that the plant would begin

887 - R. K. Sinha, Anil Kakodkar, "Advanced Heavy Water Reactor", Nu-Power, 1999, xiii, 22–27.

888 - K. L. Ramkumar, "Th-LEU Fuel in AHWR to enhance proliferation resistance characteristics", presented at the IAEA 3rd Technical Meeting on Options to incorporate intrinsic proliferation resistance features to Nuclear Power Plants with innovative Small Modular Reactors, 15 August 2011.

889 - B. Bhattacharjee, "An Overview of R&D in Fuel Cycle Activities of AHWR", in Nuclear fuel cycle technologies: closing the fuel cycle, 14th Indian Nuclear Society Annual Conference, 2003.

890 - DAE, "Annual Report 2017-2018", Department of Atomic Energy, Government of India, 2018, see https://dae.nic.in/?q=node/855.

891 - Mary Ilyushina, "Russia plans to tow a nuclear power station to the Arctic. Critics dub it a 'floating Chernobyl'", *CNN*, 30 June 2019, see https://www.cnn.com/2019/06/28/europe/russia-arctic-floating-nuclear-power-station-intl/index.html, accessed 3 July 2019.

892 - Thomas Nilsen, "First reactor started at floating nuclear plant", *The Barents Observer*, 2 November 2018, see https://thebarentsobserver.com/en/industry-and-energy/2018/11/first-reactor-started-floating-nuclear-plant, accessed 4 November 2018.

893 - Gary Peach, "Rosatom Pursues SMRs Across Multiple Platforms", *NIW*, 17 May 2019.

to operate in October 2010.[894] In July 2019, Rosatom announced "that it has completed and transferred… the 70 MW Akademik Lomonosov floating nuclear power plant…to its subsidiary Rosenergoatom Concern, which recently received a license from the nuclear regulator Rostekhnadzor to operate the nuclear unit until 2029".[895]

The projected cost rose too, from an initial estimate of around six billion rubles (US$_2007$232 million),[896] to 37 billion rubles as of 2015 (US$_2015$740 million).[897] The delays and high cost may have led Rosatom to conclude that there wouldn't be a market for this configuration, and it is reported that the agency is now examining if a modified version of the RIT-M200, currently installed on Russian atomic icebreakers, could be modified and marketed.[898]

Two other SMR designs Russian developers have long been promoting are the SVBR-100 and the BREST-300. Both are fast reactor designs; the BREST-300 is lead-cooled whereas the SVBR-100 is cooled by a lead-bismuth mixture. Both are now delayed. According to the official Federal Target Program (FTP) titled "Nuclear power technologies of the new generation", the construction of a prototype unit of the lead-cooled fast reactor BREST-300 was to have started in 2016.[899] That has not happened so far. In October 2018, Rosatom announced that the reactor will not begin operation before 2026.[900]

The FTP also called for the SVBR-100 lead-bismuth cooled fast reactor to be built before 2020. But according to a government resolution adopted on 11 November 2017 on amending the FTP, the construction of the SVBR-100 was postponed beyond the horizon of 2020.[901] According to a July 2019 update of the World Nuclear Association (WNA), "in 2018 the project [was] dropped".[902] One reason for the delay and probable cancellation is that the reactor is reported to have cost much more than initial estimates—36 billion rubles (US$632 million) as compared to 15 billion rubles (US$262 million).[903]

894 - Rosatom, "The first offshore nuclear heat and electrical power plant of small capacity is planned to operate in October 2010 in Severodvinsk (Arkhangelsk district)", Press Release, 15 December 2006; and IPFM, "Global Fissile Material Report 2007 – Developing the technical basis for policy initiatives to secure and irreversibly reduce stocks of nuclear weapons and fissile materials", Second Report of the International Panel on Fissile Materials, Program on Science and Global Security, Princeton University, October 2007.

895 - *NIW*, "Briefs - Russia", Nuclear Intelligence Weekly, 5 July 2019.

896 - *WNN*, "Russian floating reactor construction starts", 17 April 2007, see http://www.world-nuclear-news.org/newsarticle.aspx?id=13250, accessed 30 April 2017.

897 - Charles Digges, "New documents show cost of Russian floating nuclear power plant skyrockets", Bellona, 25 May 2015, see http://bellona.org/news/nuclear-issues/2015-05-new-documents-show-cost-russian-nuclear-power-plant-skyrockets, accessed 28 December 2015.

898 - Gary Peach, "Rosatom Pursues SMRs Across Multiple Platforms", *NIW*, 17 May 2019.

899 - L. Andreeva-Andrievskaya, "Nuclear R&D Activities in Russia", Rosatom, Presented at the Nuclear Innovation Roadmap (NI2050) Workshop of the Nuclear Energy Agency, July 2015, see https://www.oecd-nea.org/ndd/workshops/ni2050/presentations/docs/2_20_Russia_Nuclear%20R_D%20Activities%20in%20Russia_L_Andreeva_Andrievskaya,%20ROSATOM.pdf, accessed 29 July 2019.

900 - *NEI*, "Russia's Brest reactor now scheduled for 2026", 16 October 2018, see https://www.neimagazine.com/news/newsrussias-brest-reactor-now-scheduled-for-2026-6803677, accessed 29 July 2019.

901 - Government of the Russian Federation, "О внесении изменений в федеральную целевую программу 'Ядерные энерготехнологии нового поколения на период 2010-2015 годов и на перспективу до 2020 года'—Утратило силу с 1 января 2019 года на основании постановления Правительства Российской Федерации от 30 ноября 2018 года N 1451", Resolution, 11 November 2017, see http://docs.cntd.ru/document/555631831, accessed 29 July 2019. Thanks to Anatoli Diakov for this reference and information.

902 - WNA, "Nuclear Power in Russia", July 2019, see https://www.world-nuclear.org/information-library/country-profiles/countries-o-s/russia-nuclear-power.aspx, accessed 29 July 2019.

903 - *NEI*, "Russia seeks partners for its SVBR project", 15 November 2016, see http://www.neimagazine.com/news/newsrussia-seeks-partners-for-its-svbr-project-5669556, accessed 30 April 2017.

SOUTH KOREA

South Korea's System-Integrated Modular Advanced Reactor (SMART), a 100 MW Pressurized Water Reactor, has been under development by the Korea Atomic Energy Research Institute (KAERI) since 1997 and is the first land-based SMR of Light Water Reactor or LWR design (not including the designs from the 1950s and 1960s) to be licensed for construction. In July 2012, SMART received Standard Design Approval from Korea's Nuclear Safety and Security Commission.[904] But there are no plans to construct a SMART in South Korea, because it is not cost-competitive. As the World Nuclear Association pointed out: "KAERI planned to build a 90 MWe demonstration plant to operate from 2017, but this is not practical or economic in South Korea".[905]

KAERI has therefore been pursuing export orders. The main potential clients are Jordan and Saudi Arabia. In 2015, KAERI signed a Memorandum of Understanding (MoU) with the King Abdullah City for Atomic and Renewable Energy (KA-CARE), to "conduct a three-year preliminary study to review the feasibility of constructing SMART reactors in Saudi Arabia".[906] Two years later, KA-CARE and the Jordan Atomic Energy Commission signed an MoU that called for conducting a feasibility study on the construction of two small modular reactors in Jordan.[907] The MoU did not specify any design but because it mentions both the production of electricity and desalinated water, the likely design that would be considered for the feasibility study is the SMART reactor. According to some KA-CARE officials, the company has joint ownership of intellectual property rights with KAERI and Saudi engineers have been trained in Korea.[908] More generally, KA-CARE has also advanced ambitious if unrealistic plans of localizing some of the reactor manufacture in Saudi Arabia.[909]

UNITED KINGDOM

The United Kingdom's SMR interests date back at least to 2014, when the U.K. government commissioned a feasibility study[910] co-funded by seven nuclear industry organisations, including Rolls-Royce, and carried out by the National Nuclear Laboratory. The following year, in November 2015, the government announced that "at least £250 million" (US$$_{2015}$380 million) will be spent by 2020 on an "ambitious" programme to "position the UK as a global leader in

904 - Kwon Dong-joon, "Korean All-in-one SMR Won World's First Standard Design Approval", *etnews*, 5 July 2012, see http://english.etnews.com/20120705200008, accessed 30 April 2017.

905 - WNA, "Nuclear Power in South Korea", February 2017, see http://www.world-nuclear.org/information-library/country-profiles/countries-o-s/south-korea.aspx, accessed 30 April 2017.

906 - *WNN*, "Saudi Arabia teams up with Korea on SMART", 4 March 2015, see http://world-nuclear-news.org/NN-Saudi-Arabia-teams-up-with-Korea-on-SMART-0403154.html, accessed 30 August 2019.

907 - *WNN*, "Jordan and Saudi Arabia team up on uranium, SMRs", 29 March 2017, see http://www.world-nuclear-news.org/Articles/Jordan-and-Saudi-Arabia-team-up-on-uranium,-SMRs, accessed 24 June 2019.

908 - Rashad Abuaish, "Saudi National Atomic Energy Project", K.A.CARE, Presented at the Small Modular Reactor Safety and Licensing IAEA Workshop, 12–15 December 2017, 12 December 2017, see https://gnssn.iaea.org/NSNI/SMRP/SitePages/Home.aspx, accessed 28 June 2019.

909 - Ali Ahmad, Reem Salameh and M. V. Ramana, "Localizing Nuclear Capacity? Small Modular Reactors and Saudi Arabia", Issam Fares Institute for Public Policy and International Affairs, American University of Beirut, July 2019, see www.aub.edu.lb/ifi, accessed 30 August 2019.

910 - *WNN*, "National Nuclear Laboratory urges UK investment in SMRs", 4 December 2014, see https://www.world-nuclear-news.org/NN-National-Nuclear-Laboratory-urges-UK-investment-in-SMRs-4121401.html, accessed 6 July 2019.

innovative nuclear technologies" and that there would "be a competition" to identify the best SMR and aim to build "one of the world's first SMRs in the U.K. in the 2020s".[911]

The only U.K. company to come up with a new reactor design is Rolls-Royce. At 450 MW, the power output of the Rolls-Royce design cannot be considered small by definition, but the company insists on terming it the "U.K. SMR".[912] In a September 2017 report, Rolls-Royce termed its development a "national endeavour" and "a once in a lifetime opportunity for UK nuclear companies to design, manufacture, build and operate next generation reactors to meet our energy challenge" and promised "to invest in this programme, if matched by Government support".[913]

Although the government was willing to fund the SMR program, the level of funding and other commitments that Rolls-Royce demanded was clearly too high. In January 2019, it was reported that Rolls-Royce wanted—and would match—more than £200 million (US$250 million) from the U.K. Government to develop the design to the point where it could receive approval from the U.K. safety regulator.[914]

The U.K. Government, though, seems to be walking away from such support. In December 2017, it released a report that, as *The Times* stated, "found that the first SMR was likely to be more expensive, with lifetime electricity costs of about £101 [US$127] per megawatt-hour. It said this was much higher than estimates submitted by leading small nuclear developers, which were likely to be subject to 'overly optimistic' outlooks".[915] And in June 2018, the Business and Energy Secretary told the U.K. Parliament when discussing the proposed Wylfa Newydd nuclear power plant that "no technology will be pursued at any price: new nuclear must provide value for money for consumers and taxpayers".[916] Should that requirement be implemented fully, there might be no case for Rolls-Royce's SMR plans.

UNITED STATES

The U.S. Department of Energy (DOE) has been an important and persistent advocate for SMRs. Over the past decade alone, it has invested hundreds of millions of dollars into promoting research and development work on SMRs. The most substantial DOE investment was in the form of a "cost-shared partnership" to provide support "first-of-a-kind engineering, design certification and licensing" that chose two SMR designs, the mPower design in 2012 and the NuScale design in 2013, for awards of up to US$226 million each.

911 - Damian Carrington, "George Osborne puts UK at the heart of global race for mini-nuclear reactors", *The Guardian*, 24 November 2015, see https://www.theguardian.com/environment/2015/nov/24/mini-nuclear-reactors-answer-to-climate-change-crisis, accessed 6 July 2019.

912 - Rolls-Royce, "UK Small Modular Reactors: A National Endeavour", September 2017, see https://www.uknuclearsmr.org/uk-smr-a-national-endeavour-report/, accessed 6 July 2019.

913 - Ibidem., p.4.

914 - Sylvia Pfeifer, David Sheppard, "Rolls-Royce leads drive for small nuclear sites: Energy", *Financial Times*, 28 January 2019.

915 - Emily Gosden, "Double setback casts big shadow over mini reactors", *The Times*, 8 December 2017.

916 - Greg Clark, "Statement to Parliament on Horizon project at Wylfa Newydd", Business and Energy Secretary, Department for Business, Energy & Industrial Strategy, Oral Statement to Parliament, 4 June 2018, see https://www.gov.uk/government/speeches/statement-to-parliament-on-horizon-project-at-wylfa-newydd, accessed 6 July 2019. In July 2019, it was reported that the UK Government would commit GBP18.0 million (USD22.4 million) of initial funds to support the development of the Rolls Royce project as part of the Industrial Strategy Challenge Fund, subject to final confirmation in the early autumn.

The **mPower** design was proposed by Babcock & Wilcox (B&W) and was promoted by the company as "creating the future of nuclear power" and was targeting to obtain "Design Certification" from the U.S. Nuclear Regulatory Commission in 2017 according to an official presentation as late as December 2012.[917] By 2014, B&W had slashed its spending on the SMR project from about US$80 million/year to less than US$15 million/year.[918] What happened? B&W had not found any companies willing to invest in mPower nor customers willing to enter into a contract for the reactor.[919] Despite a further attempt at resuscitation, mPower is essentially dead.

The other beneficiary of DOE funding, **NuScale**, has continued with the development of its reactor design. It has submitted its design for review by the Nuclear Regulatory Commission (NRC) and in March 2017, the NRC accepted NuScale's application for full review and has commenced the design certification process that, according to officials, is "expected to take 40 months".[920] The following year, in April 2018, NRC completed its first phase of the review, but the next stages are expected to take longer. The same month DOE provided another grant of US$40 million to NuScale.[921] As of 2019, NuScale had reportedly invested approximately US$850 million into SMR development, with the majority of it coming from the Fluor Corp., and a little more than a third coming from the federal government.[922]

NuScale is trying to sell its reactor design to Utah Associated Municipal Power Systems (UAMPS), which is "a political subdivision of the State of Utah that provides comprehensive wholesale electric-energy, transmission, and other energy services, on a nonprofit basis, to community-owned power systems… [in] Utah, California, Idaho, Nevada, New Mexico and Wyoming".[923] However, many members of UAMPS have still not agreed to this project and there are not enough subscribers to absorb all the electrical output of a NuScale power plant consisting of 12 units with gross outputs of 60 MW each. As of March 2019, there was not enough commitment for even 150 MW, the trigger for the project moving to the next phase.[924] Once again, the DOE has tried to rescue NuScale by expressing the "intent to use the output from the first two modules, one for research and development, and the other to supply power" to the DOE's Idaho National Laboratory. The DOE had earlier agreed to have the reactors sited within the Idaho National Laboratory.[925]

917 - John Ferrara, "B&W mPower Small Modular Reactor: Creating the future of nuclear power", presented at the Energy Facility Contractors Group Executive Council Semi-Annual Meeting, Energy Facility Contractors Group Executive Council Semi-Annual Meeting, 5 December 2012, see http://www.efcog.org/library/council_meeting/12SAECMtg/2012SAMindex.htm.

918 - *WNN*, "Funding for mPower Reduced", 14 April 2014, see http://www.world-nuclear-news.org/C-Funding-for-mPower-reduced-1404141.html, accessed 24 May 2015.

919 - Jason Ruiter, "Babcock & Wilcox Cuts Investment in mPower", *NewsAdvance.com*, 14 April 2014, see http://www.newsadvance.com/news/local/babcock-wilcox-cuts-investment-in-mpower/article_d7998d52-c3d3-11e3-8fbb-0017a43b2370.html, accessed 25 May 2015.

920 - NEI, "NuScale SMR Design Ready for Full Review, NRC Says", 16 March 2017, see https://www.nei.org/News-Media/News/News-Archives/NuScale-SMR-Design-Ready-for-Full-Review,-NRC-Says, accessed 29 April 2017.

921 - Pete Danko, "Oregon's small-nuke company wins US$40M federal grant", *Portland Business Journal*, 27 April 2018, see https://www.bizjournals.com/portland/news/2018/04/27/oregon-small-nuke-company-nuscale-wins-40m-federal.html, accessed 28 June 2019.

922 - Emily Green, "Could nuclear power return to Oregon?", *Street Roots News*, 7 June 2019, see https://news.streetroots.org/2019/06/07/could-nuclear-power-return-oregon, accessed 13 June 2019.

923 - UAMPS, "About UAMPS", Utah Associated Municipal Power Systems, 29 April 2017, see http://www.uamps.com/, accessed 29 April 2017.

924 - Stephanie Cooke, "NuScale Prepares for SMR Development Phase", *NIW*, 29 March 2019.

925 - *Modern Power Systems*, "Preferred site identified for first NuScale SMR plant", 31 October 2016, see http://www.modernpowersystems.com/features/featurepreferred-site-identified-for-first-nuscale-smr-plant-5653358/, accessed 29 April 2017.

NuScale's estimated total cost is currently US$4.2 billion, although that is likely to increase.[926] More relevant to potential purchasers of the NuScale design, it claims that the levelized cost of energy from the UAMPS project would be around US$65/MWh, much lower than other nuclear projects. The secret to this bold prediction is that being a municipal utility, UAMPS has access to low-interest financing. Unlike market projects that typically use a weighted average cost of capital of 8–9 percent, UAMPS can access debt at interest rates around 4 percent or lower. As a NuScale official told *Nuclear Intelligence Weekly* (*NIW*) "The financing UAMPS has available to it clearly makes a difference".[927]

Other financial advantages that NuScale is hoping for are future federal production tax credits, the current DOE cost-sharing, an anticipated DOE loan guarantee, plus limits Idaho provides on property taxes at INL.[928] Even after all these advantages, there are many other alternatives at lower cost.[929]

CONCLUSION ON SMRs

Although policymakers in many countries continue to be interested in SMRs, it has become evident that they will be even less capable of competing economically than large nuclear plants, which have themselves been increasingly uncompetitive. Thus, even if a few SMR projects get built over the next decade or beyond, typically as a result of massive support from one or more governments, it is unlikely that SMRs could play any significant role in the future electricity sector.

926 - Wendy Wilson, "Tough Economics for UAMPS Small Modular Reactors", Snake River Alliance, 11 April 2018, see http://snakeriveralliance.org/tough-economics-for-uamps-small-modular-reactors/, accessed 16 May 2019.

927 - Stephanie Cooke, "NuScale Prepares for SMR Development Phase", *NIW*, 29 March 2019.

928 - Ibidem.

929 - Energy Strategies, "Analyzing the Cost of Small Modular Nuclear Reactors and Alternate Power Portfolios", Prepared for Healthy Environment Alliance of Utah, May 2019, see https://www.healutah.org/smnr/, accessed 28 June 2019.

NUCLEAR POWER VS. RENEWABLE ENERGY DEPLOYMENT

INTRODUCTION

The next 18 months will be a crucial period for the development of a more ambitious international climate regime. In September 2019, the United Nations is hosting the Climate Action Summit, to galvanize support for more determined action, including through the revision of the country-specific carbon abatement plans or Nationally Determined Contributions (NDCs) required under the Paris Agreement. As was analyzed in WNISR2016, within the INDCs—at the time the pledges were only Indicative Nationally Determined Contributions—just eleven countries mentioned they were operating or considering to operate nuclear power as part of their mitigation strategy and even fewer (five) actually stated that they were proposing to expand its use (Belarus, India, Japan, Turkey and United Arab Emirates). This compares with 144 that mention the use of renewable energy, and 111 that explicitly mention targets or plans for expanding its use. It is therefore highly unlikely that the revision of the carbon abatement plans will lead to stronger statements of support for nuclear power because, as is outlined in this chapter, it is renewable energy technologies that are the preferred non-fossil fuel option.

The Intergovernmental Panel on Climate Change (IPCC) is the United Nations body established for assessing the science related to climate change. Periodically, the IPCC publishes Assessment Reports that review developments and changing understanding in both climate adaptation and mitigation. The most recent, the 5th report (AR5), was published in 2015; the next will be in 2022. In addition, the IPCC undertakes special reports, such as on Renewable Energy Sources in 2011. The 2015 Paris Agreement states that its "central aim is to strengthen the global response to the threat of climate change by keeping a global temperature rise this century well below 2 degrees Celsius above pre-industrial levels and to pursue efforts to limit the temperature increase even further to 1.5 degrees Celsius"; consequently, the IPCC undertook a 2018 special report on the impacts of 1.5 degrees of global warming.

In the chapter on mitigation, the IPCC review the role of different energy technologies and are clear that in order to have a high degree of confidence in meeting a 1.5 degree target, the share of primary energy from renewables (including bioenergy, hydro, wind, and solar) needs to increase by 2050, so that they supply 52–67 percent of primary energy. Solar and wind together are expected to provide 28–343 EJ[930] (with a median of 121 EJ) by 2050, while the role for nuclear power is much less certain, with the suggestion that by 2050 primary energy supplied by nuclear would range from 3 to 66 EJ/year (median of 24 EJ).[931] Furthermore, the IPCC states that "some 1.5°C pathways with no or limited overshoot no longer see a role for nuclear fission

930 - EJ = exajoule = 10^{18} joules = 23.884 MTOE = 277.8 TWh

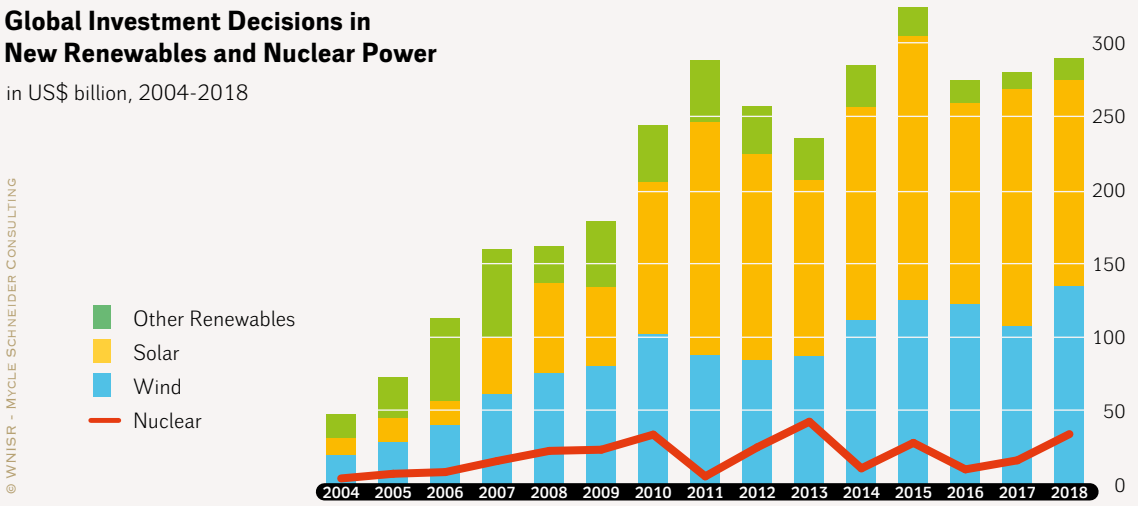
931 - IPCC et al., "Global Warming of 1.5 °C—Chapter 2: Mitigation Pathways Compatible with 1.5°C in the Context of Sustainable Development", Special Report, 2018, see https://www.ipcc.ch/sr15/, accessed 23 June 2019.

by the end of the century".[932] While there is no agreement on the extent, if any, of the role nuclear power will have in the future, even in a rapidly decarbonizing world, what is clear is that renewable energy will now dominate a future energy system and as its deployment rates accelerate its advantages over nuclear will become more obvious. Furthermore, there is every indication, as outlined below, that nuclear power will be at best a marginal contributor in a selective set of countries and markets, and most likely will continue to fade for basic economic reasons.

INVESTMENT

Investment decisions are not only an important indicator of the future power mix, but they also highlight the confidence that the technology-neutral financial sector has in different power generation options. Consequently, they can be seen as an important barometer of the current state of policy certainty and costs of technologies on the global and regional levels.

Figure 38 | Global Investment Decisions in Renewables and Nuclear Power 2004–2018



Sources: FS-UNEP/BNEF, 2018 and REN21, 2019 and WNISR Original Research

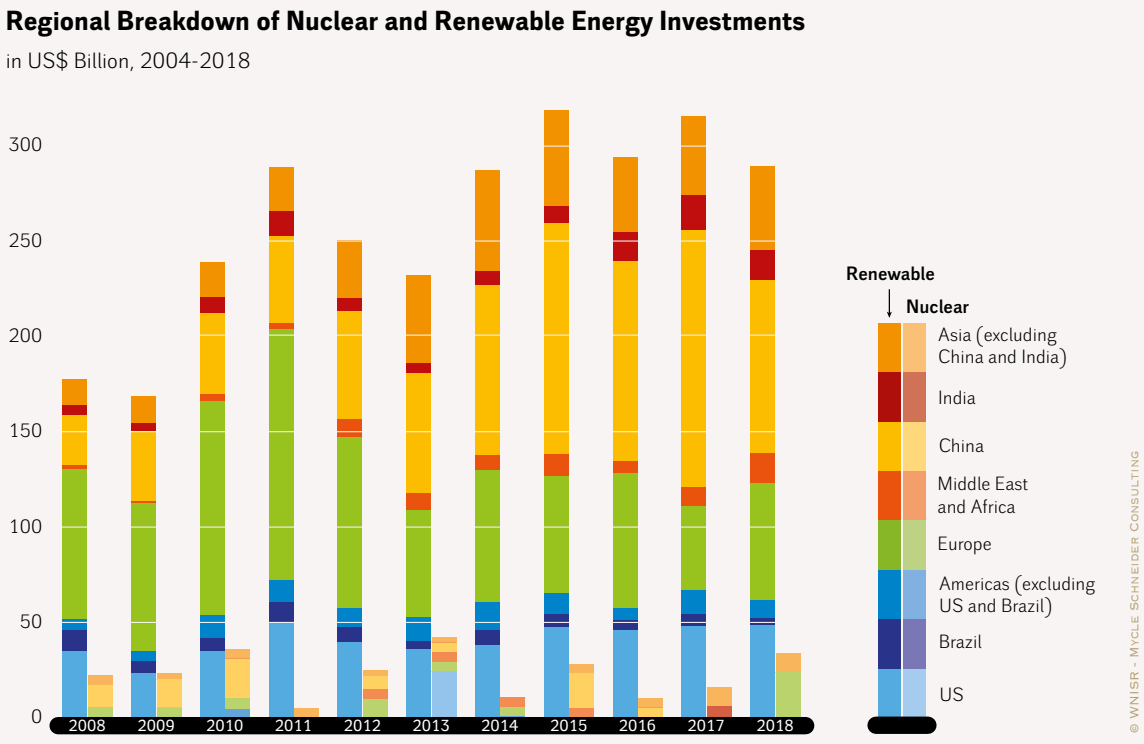
Figure 38 compares the annual investment decisions for the construction of new nuclear plants with those for renewable energy since 2004. Construction began on five nuclear reactors in 2018, in Bangladesh, Russia, South Korea, Turkey and the U.K., compared to four new reactors in 2017, three in 2016 and eight in 2015. The total reported investment for the construction of the 2018 projects is around US$33 billion for 6.2 GW. (That is considerably higher per MW than the US$16 billion for 4.25 GW in 2017, due to the declared 2018-start of construction of Unit 1 at Hinkley Point C in the U.K.) However, this is still less than a quarter of the investment in wind *or* solar, with over US$134 billion and US$139 billion of 2018 investment, respectively.

932 - Jeff McMahon, "New Solar + Battery Price Crushes Fossil Fuels, Buries Nuclear", *Forbes*, see https://www.forbes.com/sites/jeffmcmahon/2019/07/01/new-solar--battery-price-crushes-fossil-fuels-buries-nuclear/, accessed 2 July 2019.

In the absence of comprehensive, publicly available investment estimates for nuclear power by year, and in order to simplify the approach, WNISR includes the total projected investment costs in the year in which construction was started, rather than spreading them out over the entire construction period. Furthermore, the nuclear investment figures do not include revised budgets if cost overruns occur. The WNISR nuclear investment assessment in 2018 is similar to that proposed by the Renewable Energy Policy Network for the 21st Century (REN21)[933], which suggests US$33 billion in new investment (although the methodology is unclear). REN21 concludes that new renewable energy investment in 2018, excluding large-scale hydro, made up 65 percent of all new electricity generating capacity and totaled US$273 billion.[934]

Globally, the relative importance of Europe and North America for renewable energy investments is diminishing, with the rise of Asia, especially China, India and Japan (see **Figure 39**). Chinese nominal-dollar renewable investment rose from US$26 billion in 2008 to US$146 billion in 2017 before a steep cut to US$91 billion in 2018. Total *cumulated* investment in nuclear in China over the same period was about US$82 billion.

Figure 39 | Regional Breakdown of Nuclear and Renewable Energy Investment Decisions 2008–2018



Sources: REN21, 2019, WNISR Original Analysis

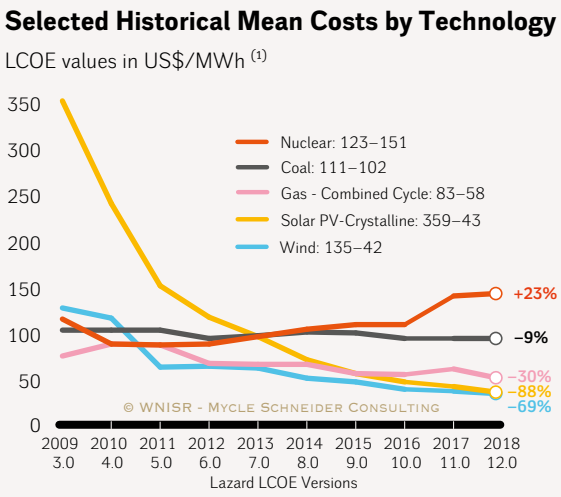
933 - International policy network dedicated to the development of renewable energies that publishes the annual Global Status Report on renewables.

934 - REN21, "Renewables 2019 – Global Status Report", June 2019, see https://www.ren21.net/wp-content/uploads/2019/05/gsr_2019_full_report_en.pdf, accessed 30 August 2019.

TECHNOLOGY COSTS

Levelized Cost of Energy (LCOE) analysis for the U.S. undertaken by Lazard at the end of 2018 (see Figure 40) suggests that the cost of solar photovoltaics (PV, thin film) ranges from US$36 to US$44/MWh, compared to US$43–48/MWh in 2017; onshore wind is US$29–56/MWh (US$30–60/MWh in 2017); and nuclear is US$112–189 (US$112–143/MWh in 2017). This continues an existing trend of rapidly falling costs of renewables, vs. static or rising costs of nuclear. The costs of renewable electricity are now also below those of coal (US$60–143/MWh) and combined-cycle gas (US$41–74/MWh). Between 2009 and 2018, utility-scale solar costs came down 88 percent and wind 69 percent, while nuclear increased by 23 percent, according to Lazard.[935] Other authoritative market-based analyses, notably the subscriber database of Bloomberg New Energy Finance, give similar results.

Figure 40 | The Declining Costs of Renewables vs. Traditional Power Sources



Notes

(1) Reflects the average of the high and low LCOE for each respective technology in each respective year. Percentages represent the total decrease in the average LCOE since Lazard's LCOE—Version 3.0.

LCOE = Levelized Cost of Energy Reflects average of unsubsidized high and low LCOE range for given version of LCOE study. Primarily relates to North American alternative energy landscape but reflects broader/global cost declines.

Source: Lazard Estimates, 2018[936]

According to the International Renewable Energy Agency (IRENA), both the installation and the power production costs of solar and wind have fallen significantly over the past decade. Utility-scale photovoltaics (PV) plants' construction costs have fallen by 74 percent between 2010 and 2018, from a US$3,300–7,900/kW range in 2010 to US$800–2,700/kW in 2018, while plants commissioned in 2018 had a global weighted-average LCOE of US$0.085/kWh, which was around 13 percent lower than the equivalent for 2017. For onshore wind the global weighted average installed costs fell between 2010 and 2018, from US$1,913/kW to US$1,497/kW, while new capacity was commissioned at a global weighted average LCOE of US$0.056/kWh, which was also 13 percent lower than the value for 2017.[937] As a consequence, onshore wind and solar

935 - Lazard, "Lazard's Levelized Cost of Energy Analysis—Version 12.0", November 2018, see https://www.lazard.com/media/450784/lazards-levelized-cost-of-energy-version-120-vfinal.pdf, accessed 30 August 2019.

936 - Ibidem.

937 - IRENA, "Renewable Power Generation Costs in 2018", International Renewable Energy Agency, May 2019, see https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2019/May/IRENA_2018_Power_Costs_2019.pdf?la=en&hash=1C7553C3BFD997DEA36D07149D60005258C9C8A8, accessed 29 May 2019.

PV power are now often less expensive than any fossil-fueled option, without subsidy or other financial assistance.

Furthermore, new solar and wind installations increasingly undercut even the operating-only costs of existing coal-fired plants. *Forbes* recently reported under the headline "New Solar + Battery Price Crushes Fossil Fuels, Buries Nuclear" that, within weeks, the LA Board of Water and Power Commission was expected to approve "a 25-year contract that will serve 7 percent of the city's electricity demand at 1.997¢/kWh for solar energy and 1.3¢ for power from batteries". That means a price guarantee of less than US$20/MWh for solar and US$13 for storage, which matches the average operation and maintenance (O&M) costs of operating nuclear plants in the U.S., that is, undercuts the O&M costs of many operating plants. As *Forbes* comments, these prices "leave fossil fuels in the dust and may relegate nuclear power to the dustbin".[938]

The declining costs of renewables globally contrast with nuclear costs that are at best constant and more often, when numbers are available, are rising, often significantly. As a consequence, it is now widely recognized that the costs of renewables are now significantly below those of either nuclear power or gas. The International Energy Agency (IEA) stated, in its recent assessment of nuclear power, that:

> Today, the high capital cost of nuclear makes it significantly more costly on a levelized costs basis than wind power or gas fired generation in both the European Union and United States. By 2040, in the United States, the LCOE for nuclear power is projected to be around USD100 per MWh, double that of solar PV and wind. In the European Union, the gap is smaller as nuclear's LCOE averages around USD110 per MWh compared to wind and solar PV in [a] range of USD 85–90 per MWh.[939]

Given the anticipated operational lifetimes of modern reactors, their relative economic performance will only deteriorate compared to the next generations of renewables, locking utilities into operating uneconomic assets.

INSTALLED CAPACITY AND ELECTRICITY GENERATION

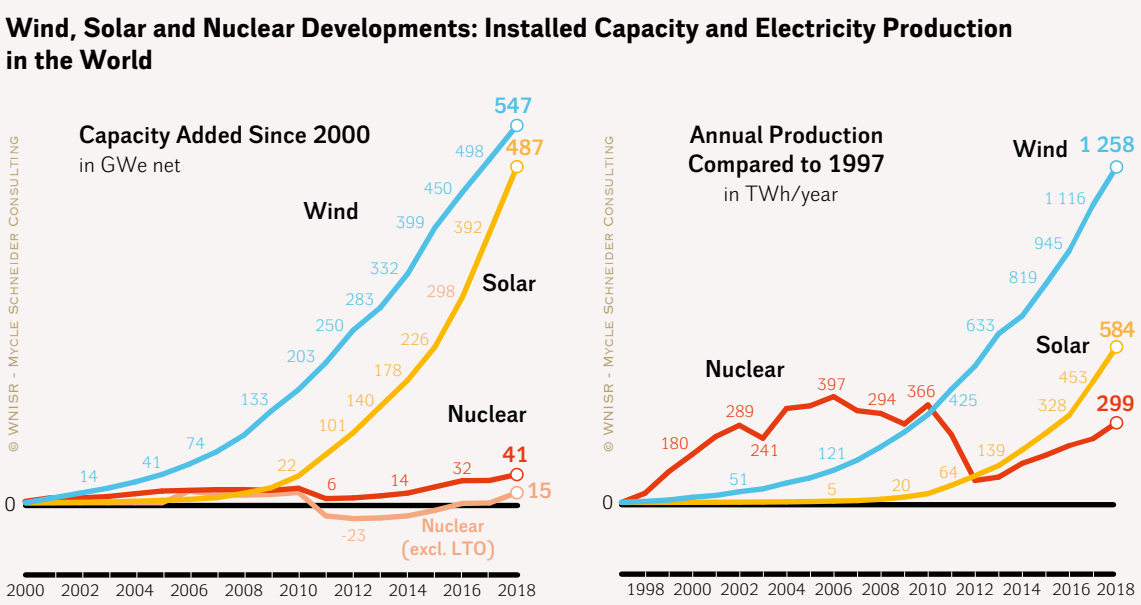
While there has been a slowdown in the rate of increase of investment in renewables, this reflects changes in policies in some countries and regions, and importantly, a rapid reduction in investment costs per MW, so renewables' net installed capacity increases (and often accelerates) despite lower total investment. In total, 165 GW of new renewable generating capacity (excluding hydro) was installed in 2018 according to REN21,[940] compared with 157 GW in 2017.

938 - Jeff McMahon, "New Solar + Battery Price Crushes Fossil Fuels, Buries Nuclear", *Forbes*, see https://www.forbes.com/sites/jeffmcmahon/2019/07/01/new-solar--battery-price-crushes-fossil-fuels-buries-nuclear/, accessed 2 July 2019.

939 - IEA, "Nuclear Power in a Clean Energy System", International Energy Agency, May 2019, see https://webstore.iea.org/download/direct/2779?fileName=Nuclear_Power_in_a_Clean_Energy_System.pdf, accessed 23 June 2019.

940 - REN21, "Renewable 2019—Global Status Report", June 2019.

Figure 41 | Variation of Wind, Solar and Nuclear Capacity and Electricity Production in the World



Sources: WNISR, IAEA-PRIS, BP Statistical Review, 2019

The net capacity additions of wind power slowed down for the third year with 49.2 GW of new capacity compared to 52 GW in 2017, 55 GW in 2016 and 64 GW in 2015. Solar PV remained almost stable with 96 GW of added capacity, down from 97 GW installed in 2017, up from 75 GW in 2016 and 51 GW in 2015. As China has been the main driver of increased deployment of solar, a decline in China (by around 10 GW), due largely to 2018 policy shifts, has had global impacts.

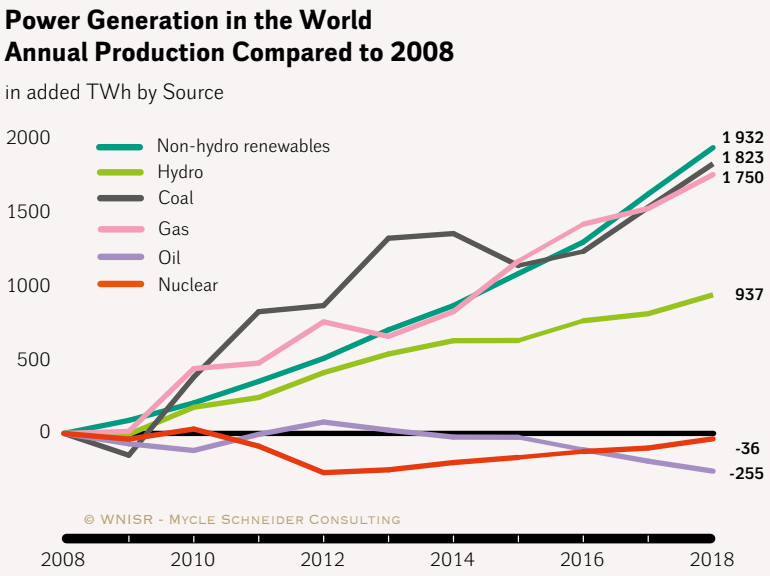
Figure 41 illustrates how quickly the extent to which renewables have been deployed at scale since the start of the millennium, with capacity increasing by 547 GW for wind and of 487 GW for solar, compared to the relative stagnation of nuclear power capacity, which meanwhile rose by around 41 GW, including all reactors currently in Long-Term Outage (LTO). Considering that almost 26 GW of nuclear power were in LTO at the end of 2018, and thus not operating, the nuclear balance is an addition of 15 GW since 2000, or less than 1/40th of the increase in wind and solar capacity alone.

Of course, the characteristics of electricity generating technologies vary due to different load factors. In general, over the year, operating nuclear power plants produce more electricity per MW of installed capacity than renewables. However, as can be seen in Figure 41, since 1997, an additional 1,259 TWh of wind power was generated in 2018 and 584 TWh from solar PV, totaling six times the additional 299 TWh of generation by nuclear energy. In 2018, annual growth rates for the generation from wind power were 12.6 percent (compared to 17.8 percent in 2017) globally, 28.9 percent (38 percent in 2017) for solar PV, and 2.4 percent (1 percent in 2017) for nuclear power.

The growth of renewable electricity—mainly but not exclusively from wind and solar power—is now not only outcompeting nuclear power but is rapidly overtaking fossil fuels, and is the

source of choice for new generation. Figure 42 below shows the extent to which, over the last decade, different energy sources have increased their electricity production. The energy source that has provided the greatest amount of additional electricity over the last decade is non-hydro renewables, generating an additional 1,932 TWh of power. The sector with the second largest growth was coal, followed by gas and hydro, with nuclear power and oil's net production both below their respective 2008 levels.

Figure 42 | Net Added Electricity Generation by Power Source 2008–2018



Source: BP Statistical Review, 2019

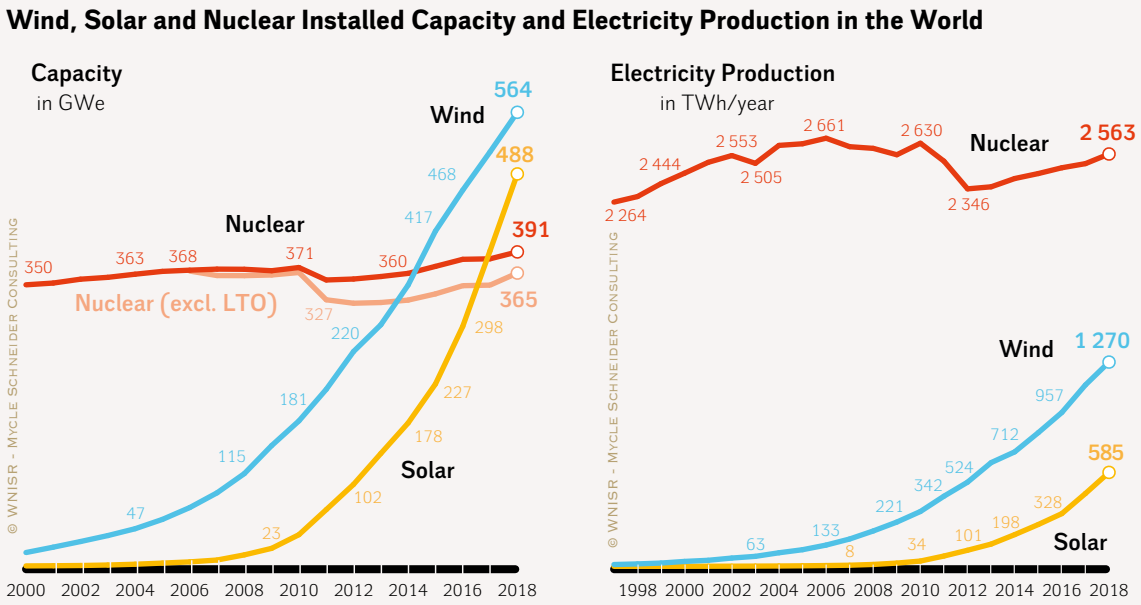
Note

A clerical error distorted this graph and its interpretation in WNISR2018. Solar and wind were mistakenly included twice in the "Non-hydro renewables" category. Our apologies.

The stagnation of nuclear power development allowed wind and solar to outpace nuclear energy in total installed generating capacity. And while in 2018 nuclear still generated more electricity (2,563 TWh), wind (1,270 TWh) and solar (585 TWh) are catching up fast and together represent almost three quarters of nuclear power production. By 2018, other sources excluding big hydro—biomass-fueled generators, geothermal, small hydro, etc.—had brought modern renewables' generating total beyond nuclear power's. In addition, data from the Organisation for Economic Co-operation and Development's (OECD) International Energy Agency and REN21 show that modern renewable sources of direct *heat* (biomass, solar, and geothermal) now approximate global production of wind-plus-solar *electricity*[941], but are missing from BP's "Statistical Review" (the basis for Figure 42).

941 - A.B. Lovins et al., "Recalibrating Climate Prospects," 2019, in peer review as of August 2019.

Figure 43 | Wind, Solar and Nuclear Capacity and Electricity Production in the World



Sources: WNISR, IAEA-PRIS, BP Statistical Review, 2019

STATUS AND TRENDS IN CHINA, THE EU, INDIA, AND THE UNITED STATES

China

China remains a dominant force in the global renewable business and has once again topped the Ernst & Young Country Attractiveness Index in 2018 for renewable investments.[942] Growth in electricity generation picked up in 2018, following a slowdown in recent years, although it is still high compared to the global average. In 2018, the increase was 7.7 percent, above the decadal average of 7.2 percent.

The solar sector had a record year in 2017 with the deployment of 53 GW. However, reductions in financial support from central government led to a slowdown of deployment with an additional 44.3 GW of installed capacity in 2018. As of the end of the year, China had a total installed solar capacity of 175 GW according to BP.

On the other hand, in 2018, the annual deployment of wind capacity increased by 17.3 percent or 23 GW, including 21.2 GW onshore and 1.8 GW offshore. Wind power capacity in China now totals 206 GW, according to the Global Wind Energy Council[943], but BP "Statistical Review" (WNISR's reference) using IRENA's data suggests the total is 184 GW. According to the National Energy Administration, by the end of 2018 China's renewable energy power generation capacity reached 728 GW, a year-on-year increase of 12 percent; of which hydropower installed

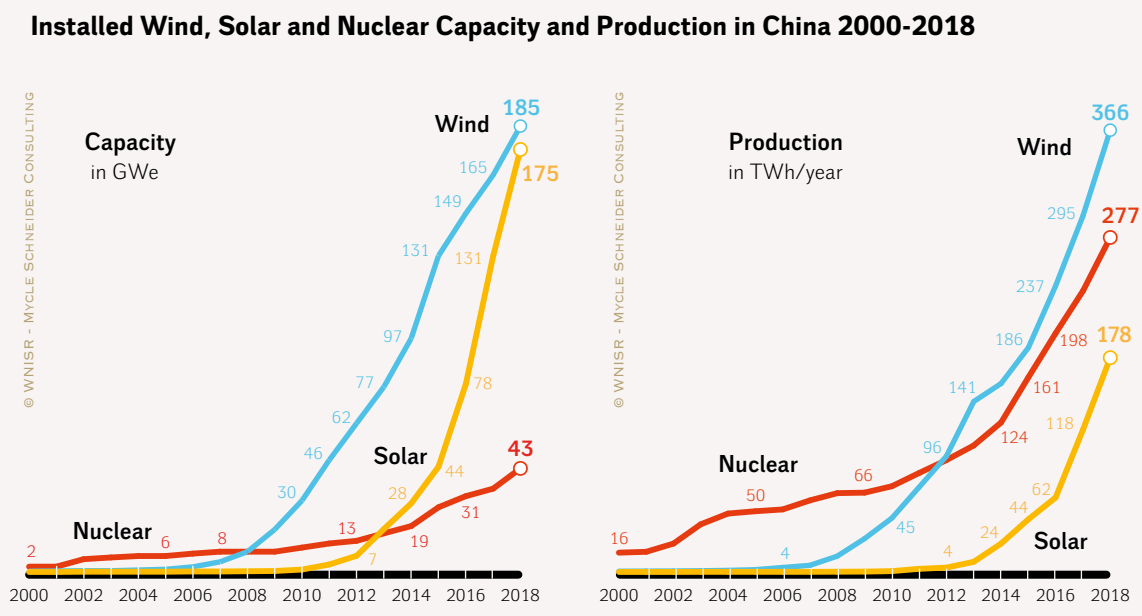
942 - EY, "Renewable Energy Country Attractiveness Index – Issue 52", 18 November 2018, see https://www.ey.com/uk/en/industries/power---utilities/ey-renewable-energy-country-attractiveness-index, accessed 14 May 2019.

943 - GWEC, "Global Wind Energy Report 2018", April 2019, see https://gwec.net/wp-content/uploads/2019/04/GWEC-Global-Wind-Report-2018.pdf, accessed 23 June 2019.

capacity was 352 GW, wind 184 GW, solar PV 174 GW, biomass power 17.81 GW, with respective year-on-year growth rates of 2.5 percent, 12.4 percent, 34 percent and 20.7 percent. Renewable energy power generation accounted for 38.3 percent of all China's installed generating capacity. In contrast, nuclear power increased its capacity by about 8 GW, with the completion of seven reactors, up from three the previous year (see **Figure 44**). The new reactors started up in China in 2018 represent over three quarters of global grid connections, with only two other reactors starting up, both in Russia.

In 2018, renewable energy generation in China reached 1,870 TWh, an increase of about 170 TWh over the previous year; renewable energy, including hydropower, accounted for 26.7 percent of total power generation. Hydropower produced 1,200 TWh; wind power 366 TWh; solar PV 177.5 TWh (a year-on-year increase of 50 percent, and a multiplication by a factor of 21 since 2013); biomass power generation 90.6 TWh.[944] China produced 277 TWh of nuclear electricity in 2018 (see **Figure 44**).

Figure 44 | Installed Wind, Solar and Nuclear Capacity and Electricity Production in China 2000–2018



Sources: BP, IAEA-PRIS, WNISR 2019

Large-scale production and greater operating experience continues to drive down the costs of renewable energy. An assessment by Swiss bank UBS has suggested that a 500-MW solar farm was connected to the grid in northwest China's Qinghai province, supplying electricity at 0.316 yuan per kWh (US$4.5¢/kWh), cheaper than the 0.325 yuan per kWh (US$4.6¢/kWh) benchmark for coal.[945] According to Bloomberg New Energy Finance (BNEF), the cost of new

944 - National Energy Administration, "NEA Press conference: 2018 operational statistics of grid-connected renewable power generation", China Energy Portal, 28 January 2019, see https://chinaenergyportal.org/nea-press-conference-2018-operational-statistics-of-grid-connected-renewable-power-generation/, accessed 14 May 2019.

945 - David Kirton and Caixin, "China Is Wasting Less Solar and Wind Power", *Sixth Tone*, 2 May 2019, see https://www.sixthtone.com/news/1003939/china-is-wasting-less-solar-and-wind-power, accessed 21 June 2019.

bulk and dispatchable electricity in China is now for nuclear US$68-81/MWh, for coal US$54–74/MWh, onshore wind US$49–72/MWh and PV US$44–84/MWh.[946]

China "is now the world's largest producer, exporter and installer of solar panels, wind turbines, batteries and electric vehicles" with "over 150,000 renewable energy patents as of 2016, 29 percent of the global total". The next closest country in the patent category is the U.S. with a little over 100,000 patents, with Japan and the EU nearer to 75,000 patents each.[947]

A particular focus area in China appears to be storage technology. In June 2019, the World Bank approved a US$300 million loan for the China Renewable Energy and Battery Storage Promotion Project, with the aim of reducing "curtailment of renewable energy" and encouraging "further investments into changing China's energy mix".[948] Another major area of focus is offshore wind. Currently the installed capacity of offshore wind in China is only 4.6 GW.[949] However, this is dwarfed by the roughly 55 GW of offshore wind projects that would be soon under "construction or in the pipeline, representing more than 1 trillion yuan (US$145 billion) at stake".[950] Because these projects are all, naturally, adjacent to coastal provinces in Eastern China, where all existing and currently planned nuclear reactor projects are, these pose "a threat" to the potential growth of nuclear power in China.[951]

The 13th Five Year Plan (2016–2020) proposes new targets for energy efficiency and the reduction of carbon intensity as well as diversification away from fossil fuels, whereby non-fossil fuels are to provide 15 percent of primary energy consumption by 2020, up from 7.4 percent in 2005.[952] However, in 2016, a total of 34.5 GW of solar PV were installed, almost double the forecasted 15 to 20 GW per year indicated by the National Energy Administration (NEA).[953] In November 2016, NEA announced an update of the 13th Five Year Plan for the power sector (2016–2020). The target for wind power (210 GW) is higher than the previous announcement (200 GW), while the target for solar (110 GW) is considerably lower than previous announcements (up to 150 GW). Given the deployment levels at the end of 2018 of 184 GW of wind and 174 GW of solar, these targets are now easy to meet in wind and have already been exceeded in solar. Consequently, there are calls for the targets to be increased again. Liu Hanyuan, who is chairman of one of China's largest solar firms, the TonWei Group and a member of the National People's Congress,

946 - Becky Beetz, "Solar, wind cheapest source of new generation in major economies", *PV Magazine*, 19 November 2018, see https://www.pv-magazine.com/2018/11/19/solar-wind-cheapest-source-of-new-generation-in-major-economies-report/, accessed 29 June 2019.

947 - Dominic Dudley, "China Is Set To Become The World's Renewable Energy Superpower, According To New Report", *Forbes*, 11 January 2019, see https://www.forbes.com/sites/dominicdudley/2019/01/11/china-renewable-energy-superpower/, accessed 15 June 2019.

948 - *Modern Diplomacy*, "World Bank to Help China Develop Renewable Energy with Battery Storage", 13 June 2019, see https://moderndiplomacy.eu/2019/06/13/world-bank-to-help-china-develop-renewable-energy-with-battery-storage/, accessed 15 June 2019.

949 - IRENA, "Renewable Capacity Statistics 2019", May 2019, op. cit.

950 - C. F. Yu, "Offshore Wind Poses Threat to Nuclear", *NIW*, 14 June 2019.

951 - Ibidem.

952 - *China Dialogue*, "Climate, energy and China's 13th Five-Year Plan in graphics", 18 March 2017, see https://www.chinadialogue.net/article/show/single/en/8734-Climate-energy-and-China-s-13th-Five-Year-Plan-%20in-graphics, accessed 22 June 2017.

953 - Richard Martin, "China is on an epic solar power binge", *MIT Technology Review*, 22 March 2016, see https://www.technologyreview.com/s/601093/china-is-on-an-epic-solar-power-binge/, accessed 22 June 2017.

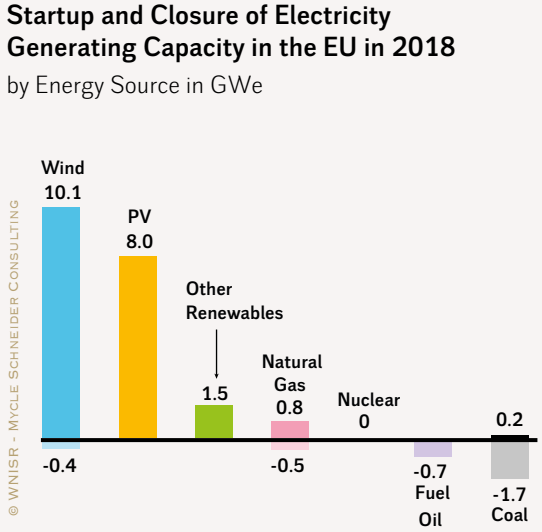
has called for the targets for the non-fossil fuel share of the energy mix to rise to 20 percent by 2020, then 30 percent by 2030 and over 50 percent by 2050.[954]

The 13th Five Year Plan is also proposing to increase nuclear capacities to a total of 58 GW by 2020. However, only 44.5 GW are operating as of 1 July 2019, with another 8.8 GW under construction. Therefore, it will be impossible to meet this target.

European Union

In the European Union, renewables are now providing nearly all new capacity, in 2018, 95 percent coming from wind (10.1 GW or 49 percent), solar PV (8.0 GW or 39 percent) and biomass (1.1 GW or 5 percent).[955] (See **Figure 45**).

Figure 45 | Startup and Closure of Electricity Generating Capacity in the EU in 2018



Sources: WindEurope, WNISR, 2019

Note
Other Renewables here include large hydro.

In 2018, Europe invested €27 billion (US$31 billion) in wind farms alone.[956] Between 2000 and 2018, the net changes in installed generating capacities highlight the shift towards renewables and gas power plants, with respectively 168 GW, 115 GW and 97 GW of wind, solar and gas power plants. On the other end, nuclear capacities *decreased* by 18.8 GW over the same period, coal by 42.9 GW and fuel oil plants by 41.1 GW (see **Figure 46**).[957] As of 2018, the installed solar capacity had almost caught up with nuclear at 116 GW vs. 118 GW (see **Figure 47**).

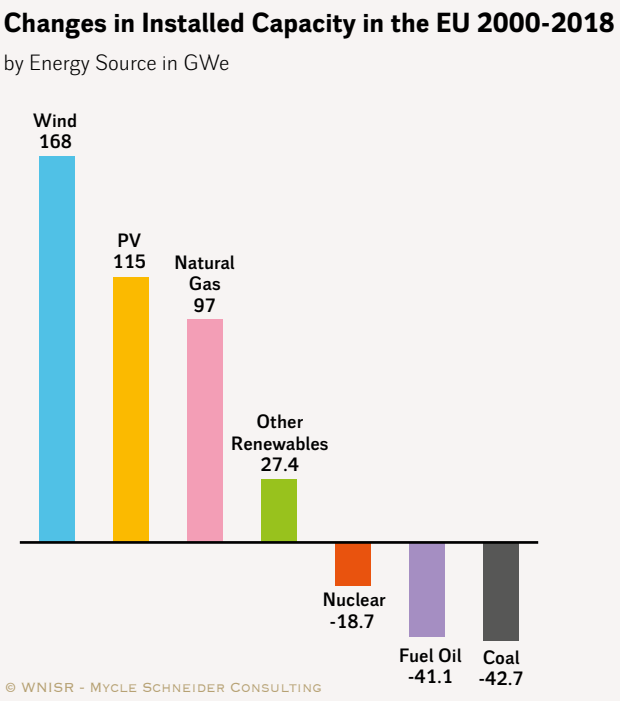
954 - *China Energy Portal*, "Renewable energy goals nearly achieved—NPC representative suggests higher long-term targets: 20% by 2020, 30% by 2030", 14 March 2019, see https://chinaenergyportal.org/renewable-energy-goals-nearly-achieved-npc-representative-suggests-higher-long-term-targets-20-by-2020-30-by-2030/, accessed 14 May 2019.

955 - WindEurope, "Wind energy in Europe in 2018", 21 February 2019, see https://windeurope.org/about-wind/statistics/european/wind-energy-in-europe-in-2018/, accessed 14 May 2019.

956 - WindEurope, "Europe invests €27bn in new wind farms in 2018", Press Release, 18 April 2019, see https://windeurope.org/newsroom/press-releases/europe-invests-27bn-in-new-wind-farms-in-2018/, accessed 25 May 2019.

957 - Ibidem.

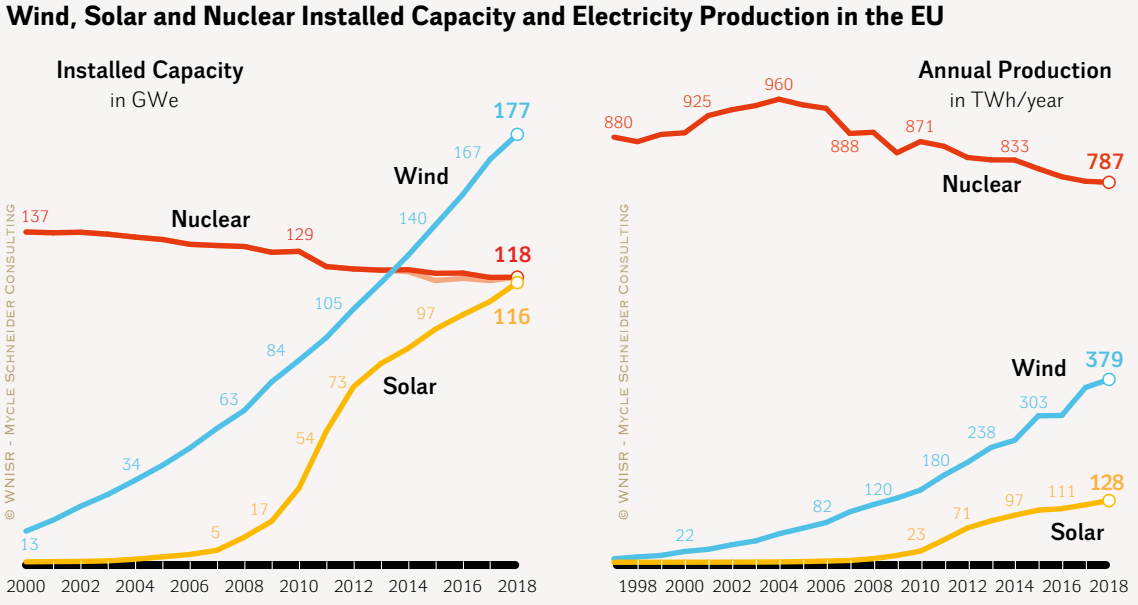
Figure 46 | Changes in Electricity Generating Capacity in the EU in 2000–2018



Sources: WindEurope, WNISR, 2018–19

Note
Other Renewables here include large hydro.

Figure 47 | Wind, Solar and Nuclear Capacity and Electricity Production in the EU (Absolute Numbers)



Sources: BP, IAEA-PRIS, WNISR 2019

In 2018, in the EU renewables provided 32.3 percent of the electricity production (wind was 11.8 percent[958], 3.9 percent from solar PV, biomass 6.1 percent and hydro 10.6 percent).[959] The nuclear share for 2018 is not available from the same sources, but BP indicates a share in gross power production of 25 percent.[960]

Production of renewable electricity exceeded 1,000 TWh for the first time (1,051 TWh) up from 679 TWh in 2010. Other highlights in terms of renewable generation in Europe in 2018 include:

- Since 2000, wind added 164 GW, solar 116 GW, while nuclear declined by 19 GW. Since the signature of the Kyoto Protocol in 1997, aawind and solar increased annual production by 372 TWh and 128 TWh, while nuclear generated 94 TWh less power than two decades earlier. (See **Figure 48**).
- In 2018, wind supplied 11.6 percent of the EU's power, led by Denmark at a remarkable 41 percent, Portugal and Ireland at 28 percent, and Germany at 21 percent and Spain and the U.K. 19 percent (up from 13.5 percent in 2017).[961] Wind generation rose by 6 percent, compared to 0.2 percent rise in power consumption in general. While solar generation rose by 7 percent (8 TWh).[962]
- Solar provided around 4 percent of the EU's electricity in 2018, but with significant variations. In Italy and Germany, solar provided 8 percent or more, and in Greece, 7 percent.[963]
- In Germany, in 2018, renewables provided almost 40 percent of the country's electricity consumption, up from 38 percent in 2017. This includes 20 percent coming from wind, 8.4 percent from solar and 8.2 percent from biomass. Nuclear provided 13.2 percent. Wind has the largest installed capacity, with 53 GW onshore and 6.4 GW offshore and solar 46 GW.[964]

This growth in renewable electricity production is set to continue beyond the current 2020 targets, as in preparation of the UN climate meeting in Paris in December 2015, the EU initially agreed a binding target of at least 27 percent renewables in the primary energy mix by 2030, which is likely to have meant 40–50 percent of power coming from renewables. However, in June 2018, it was agreed to increase ambition, with a new target of 32 percent of renewables in primary energy by 2030, with an opportunity to further increase this in 2023.[965] By 2050, the EU aims for a completely low-carbon electricity system. This will require speeding up the current rate of renewable electricity deployment. There is no EU-wide nuclear deployment target and the nuclear share has been shrinking for decades.

958 - There is a slight difference from the Wind Europe figures quoted below.

959 - Dave Jones, Alice Sakhel, et al., "The European Power Sector in 2018 – Up-to-date analysis on the electricity transition", Agora Energiewende, Sandbag, January 2019, see https://sandbag.org.uk/project/power-2018/, accessed 14 May 2019.

960 - BP, "Statistical Review of World Energy–Workbook", Statistics Work Book, June 2019, op. cit.

961 - WindEurope, "Wind Energy in Europe in 2018", 18 April 2019. Op. cit.

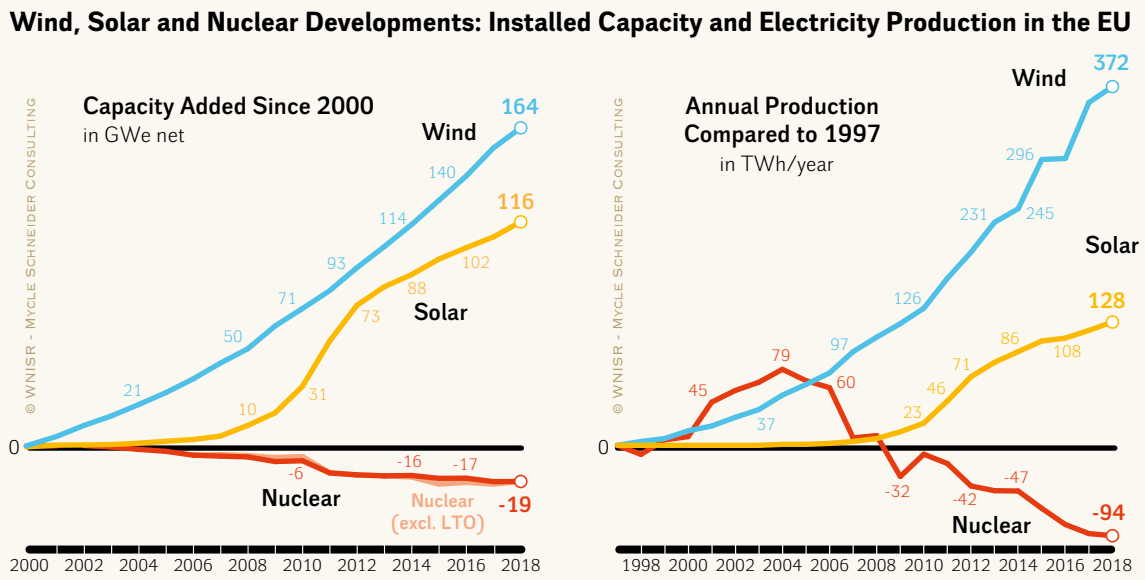
962 - Dave Jones, Alice Sakhel, et al., "The European Power Sector in 2018—Up-to-Date Analysis on the Electricity Transition", January 2019.

963 - Ibidem.

964 - Fraunhofer Institute for Solar Energy Systems ISE, "Energy Charts—Electricity Generation", see https://www.energy-charts.de/energy_pie.htm?year=2018, accessed 14 May 2019.

965 - European Commission, "Europe leads the global clean energy transition: Commission welcomes ambitious agreement on further renewable energy development in the EU", 14 June 2018, see http://europa.eu/rapid/press-release_STATEMENT-18-4155_en.htm, accessed 18 June 2018.

Figure 48 | Wind, Solar and Nuclear Capacity and Electricity Production in the EU (Developments)



Sources: BP, IAEA-PRIS, WNISR 2019

India

India has one of the oldest nuclear programs, starting electricity generation from fission in 1969. It is also one of the most troubled nuclear sectors in the world and has encountered many setbacks (see **India section**). This is in stark contrast to India's extremely rapid increase in the use of renewable energy.

Figure 49 shows, how, since the turn of the century, the wind sector has grown rapidly, from 1.5 TWh to 60.3 TWh in 2018, and since 2016 has overtaken nuclear generation, which now stands at 35 TWh. Solar is also growing rapidly, rising from 7 MWh in 2000 to 30 TWh in the 2018 calendar year. In the fiscal year to March 2019, for the first time, solar energy fed more electricity to the grid (39.3 TWh) than nuclear energy (37.7 TWh), while wind energy contributed 62 TWh. The gap between renewables and nuclear will widen in the coming years, as solar and wind grow while the nuclear sector stagnates.

According to BP, since 2010, India's solar capacity has increased by a factor of 69 from 39.4 MW to 27 GW at the end of 2018, while wind increased from 13 GW to 35 GW. These increases were despite 2018 being criticized for bad government policies that slowed renewable growth. The Government further states that it will reach its target of 175 GW of renewable energy capacity well ahead of a 2022 deadline, as bids to build new capacity for the entire amount will be completed by 2020.[966]

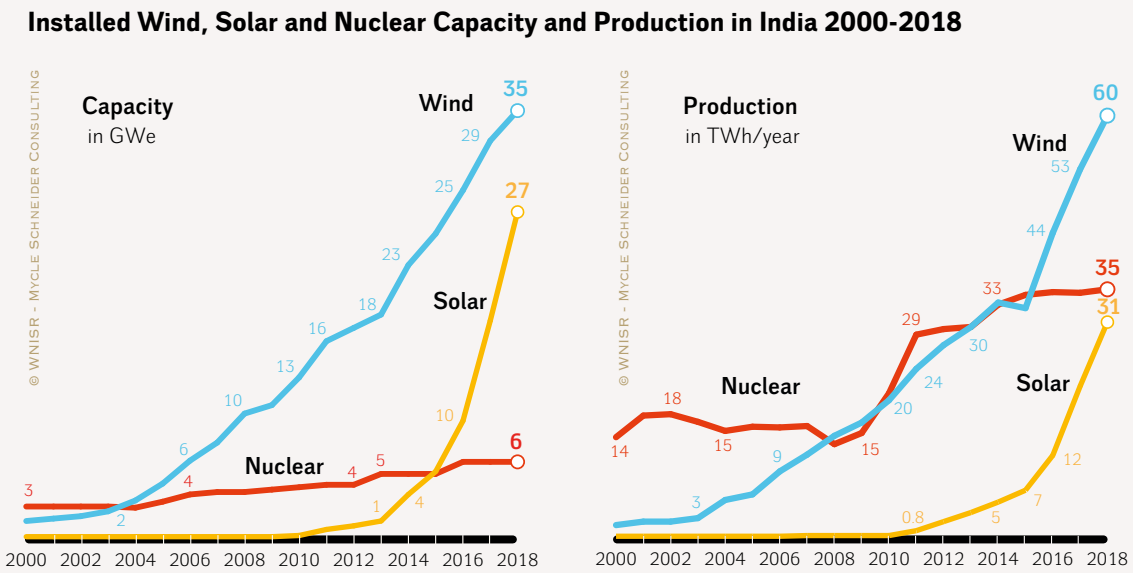
The International Renewable Energy Agency (IRENA) reported that India had the world's lowest cost of installation for solar PV power plants in 2018. The agency compared installation costs for 19 countries including heavyweights like China, United States, Japan, Italy, and Germany. The agency compared costs across multiple components like modules and inverters,

966 - *The Hindu*, "'Will achieve 175 GW renewable energy target well before 2022'", 6 June 2018, see http://www.thehindu.com/todays-paper/tp-business/will-achieve-175-gw-renewable-energy-target-well-before-2022/article24091514.ece, accessed 7 June 2018.

balance-of-system hardware, installation costs and soft costs. The total cost of installation per kilowatt in India in 2018 was US$793 while the average cost of installation among the 19 countries was US$1,427/kW.[967]

The installation costs of wind power have fallen more in India than in any other country studied by IRENA, having dropped by 66 percent between 1991 and 2018 and are now around US$1,000/kW with an LCOE around US$0.06/kWh.[968] It is notable that the auctions for both solar and wind power create maximum price disclosure, in contrast to the rather opaque nuclear sector. However, one independent analysis of proposed light water reactor (AP-1000 and ESBWR) projects calculated levelized costs that ranged from US$0.13–0.38/kWh depending on assumptions about the capital costs.[969]

Figure 49 | Wind, Solar and Nuclear Installed Capacity and Electricity Production in India



Source: BP, IRENA, IAEA-PRIS, WNISR 2019

United States

In the United States, during his election campaign Donald Trump pledged to support the coal and nuclear sectors. Nevertheless, in 2018, the use of coal for electricity generation fell to its lowest level since 1982—with coal plants retiring at twice the pace seen under the previous Administration—and petroleum consumption in the power sector was the lowest on record. The production of power from nuclear plants increased in 2018, to 808.3 TWh—slightly higher (+0.1 TWh) than the previous record in 2010—as a result of shorter outages and increased capacity from the remaining units (see **Figure 50**).[970]

967 - IRENA, "Renewable Power Generation Costs in 2018", May 2019.

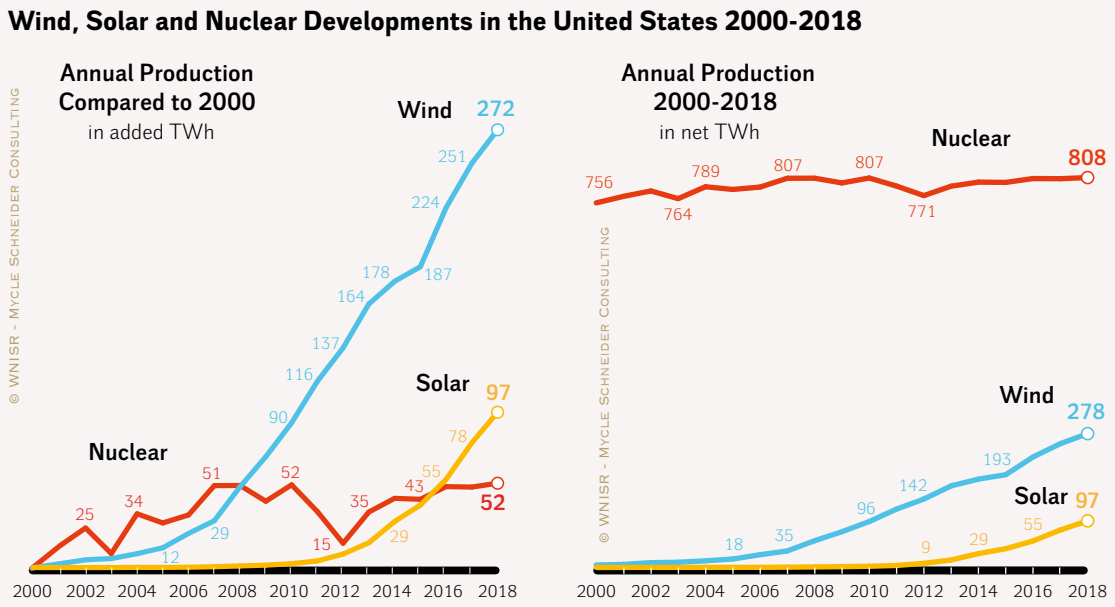
968 - Ibidem.

969 - David A. Schlissel, "Bad Choice: The Risks, Costs and Viability of Proposed U.S. Nuclear Reactors in India", Institute for Energy Economics and Financial Analysis, March 2016.

970 - Michael Scott, Owen Comstock, "Despite closures, U.S. nuclear electricity generation in 2018 surpassed its previous peak", *Today in Energy*, U.S.EIA, 21 March 2019, see https://www.eia.gov/todayinenergy/detail.php?id=38792, accessed 16 June 2019.

Across the power sector as a whole, in 2018, 31.3 GW of generating capacity were added and 18.7 GW of capacity were retired. The 2018 annual capacity additions were the largest since 48.8 GW were added in 2003. The majority of the new capacity of 19.3 GW is fueled by gas, with an additional 6.6 GW of wind and 4.9 GW of utility-scale solar.[971] The figures published by the U.S. Department of Energy's (DOE) Energy Information Administration (EIA) for deployment in 2018 are significantly lower than those released by other organizations. BNEF-BCSE estimate utility-scale solar additions in 2018 were 8.1 GW, and wind 7.5 GW.[972] In 2019, it is expected that new wind power commissions will be around 12.7 GW, the second highest annual deployment, due to projects rushing to be completed to meet changes to tax incentives.[973] In 2018, 12.9 GW of coal was retired, along with 4.7 GW of gas and 0.6 GW of nuclear (Oyster Creek in New Jersey).[974]

Figure 50 | Increases in Electricity Production from Nuclear, Solar and Wind Since 2000 in the United States



Sources: BP, IAEA-PRIS, 2019

As solar and wind continue to be deployed at scale their installation costs continue to fall and therefore so does the cost of electricity that they produce. As a consequence, the combined fuel, maintenance, and other going-forward costs of coal-fired power from many existing coal plants is now more expensive than the all-in costs of new wind or solar projects. Energy Innovation and Vibrant Clean Energy (VCE) research finds that in 2018, 211 GW of existing (end of 2017) U.S. coal capacity, or 74 percent of the national fleet, was at competitive risk from local wind or solar that could provide the same amount of electricity more cheaply. By

971 - Kenneth Dubin, "More than 60% of electric generating capacity installed in 2018 was fueled by natural gas", *Today in Energy*, U.S.EIA, 11 March 2019, see https://www.eia.gov/todayinenergy/detail.php?id=38632, accessed 16 June 2019.

972 - BCSE, "Sustainable Energy in America—Factbook", Business Council for Sustainable Energy, 2019.

973 - Richard Bowers, "Tax credit phaseout encourages more wind power plants to be added by end of year", *Today in Energy*, U.S.EIA, Republished 15 May 2019 to clarify the timing of the production tax credit phase-out, see https://www.eia.gov/todayinenergy/detail.php?id=39472&src=email, accessed 16 June 2019.

974 - Kenneth Dubin, "More than 60% of Electric Generating Capacity Installed in 2018 Was Fueled by natural gas", U.S.EIA, op. cit.

2025, at-risk coal increases to 246 GW, nearly the entire U.S. fleet.[975] In April 2019, for the first time ever, the renewable energy sector (hydro, biomass, wind, solar and geothermal) generated more electricity than coal-fired plants across the U.S.[976] According to data from the Electric Reliability Council of Texas (ERCOT)—the transmission operator running the system that supplies 90 percent of the state's electric load—wind and solar generation topped coal's output in Texas in the first quarter of 2019, the first time that this has happened on a quarterly basis.[977]

CONCLUSION ON NUCLEAR POWER VS. RENEWABLE ENERGY

The increasing public and political attention to the climate crisis and the need for rapid action to reduce emissions favor economic and replicable mitigation options. Within the power sector—notwithstanding the crucial role that energy efficiency has to play—it is becoming increasingly clear that this logic supports renewable energy, currently primarily solar and wind, and not nuclear power. That is why some noted scenarios, including those from the IPCC, envisage rapid and ambitious emissions reductions without an expansion or even a role for nuclear power in the longer term.

The dominance of renewables in the future vision of the power sector is not surprising given current trends. In 2018, the total reported global investment decisions for the construction of nuclear power totaled around US$33 billion for 6.2 GW, which is less than a quarter of the investment in wind and solar individually, with over US$134 billion investment in wind power and US$139 billion in solar, and that year's investment was skewed by the start of construction of the extremely expensive Hinkley Point C in the U.K. The gulf between the investments in renewables and nuclear is expected to widen, as the cost of renewables continue to fall, while nuclear's construction costs show the opposite trend. Between 2009 and 2018, utility-scale solar costs came down 88 percent and wind 69 percent, while nuclear increased by 23 percent, according to Lazard.

The falling costs of renewables have been in part driven by higher deployment rates, creating economies of scale, which in turn leads to higher deployment numbers. As a consequence, since the start of the millennium, there has been an increase in capacity of 547 GW for wind and of 487 GW for solar, compared to the relative stagnation of nuclear power capacity, which over this period increased by around 41 GW, including all reactors currently in Long-Term Outage (LTO). Considering that almost 26 GW of nuclear power were in LTO as of the end of 2018, and thus not operating, the balance is an addition of just 15 GW operational capacity compared to 2000—about 2.4 percent of the added wind-plus-solar capacity.

As a consequence, the energy source that has provided the greatest amount of additional electricity over the last decade is non-hydro renewables, generating an additional 1,932 TWh

975 - Eric Gimon, Christopher T. M. Clack and Sarah Mckee, "The coal cost crossover: economic viability of existing coal compared to new local wind and solar resources", *Energy Innovation and Vibrant Clean Energy*, March 2019.

976 - U.S. EIA, "U.S. electricity generation from renewables surpassed coal in April", 26 June 2019, see https://www.eia.gov/todayinenergy/detail.php?id=39992, accessed 29 June 2019.

977 - IEEFA, "IEEFA U.S.: April is shaping up to be momentous in transition from coal to renewables", Institute for Energy Economics & Financial Analysis, 25 April 2019, see http://ieefa.org/ieefa-u-s-april-is-shaping-up-to-be-momentous-in-transition-from-coal-to-renewables/, accessed 1 May 2019.

of power. The sector with the second largest growth was coal, followed by gas and hydro, with nuclear power and oil's net production below their respective 2008 level.

However, what has become increasingly clear is that renewable energy is no longer just cheaper than new-build nuclear, but it is now competitive with new coal—and increasingly with just the running cost of operating, amortized nuclear and coal plants. Coal is the largest source of electricity globally, at about 38 percent, almost four times that of nuclear power. Therefore, outcompeting coal will open up new opportunities for renewable energy, which will further drive down their production costs and increasing the system integration experience, further speeding up their deployment.

A power sector dominated by renewables is fundamentally different from many grids today. It is a system that values and prioritizes flexibility and therefore encourages generators, storage options and demand-side a Maanshan ctors that can rapidly respond to the availability of the renewable resource and shifting demand. Consequently, the age of the large, centralized, inflexible generators dominating supply is drawing to an end, hastening the demise of both coal and nuclear power.

CLIMATE CHANGE AND NUCLEAR POWER

THE STAKES

The threats to the biosphere and human prospect from Climate Change[978], increasingly termed Climate Emergency[979], demand six unprecedentedly rapid changes in the global economy:

- replace energy use with "passive" ways to deliver the same services[980];
- use energy[981] and energy-intensive materials[982] with dramatically greater efficiency to serve human needs by providing desired services in buildings, mobility, and industry;
- convert devices that provide heat and mobility from burning fossil fuels to using low-carbon energy carriers that can be made cleanly (electricity, hydrogen, renewable direct heat, etc.);
- drastically decarbonize energy supplies;
- remove excess carbon from the air, most readily by natural systems (forests, grasslands, croplands, wetlands, oceans, etc.), though engineered systems are being tried too; and
- reduce non-CO2 greenhouse gas emissions—particularly methane by drastically limiting flaring, leakage and venting in the oil and gas industries.

Of these, decarbonization is progressing fastest in generating electricity—formerly by replacing fossil-fueled with nuclear power plants, whose share then declined since 1996 (see **Figure 3**), and lately with even larger and faster-growing renewable generation. Experiments underway[983] may add the option of burning fossil fuels and capturing and storing their carbon (as waste or useful products) rather than emitting it.

Electricity is only about 20 percent of delivered energy[984], but that share is slowly rising. Making electricity emits 38 percent (2016)[985] of fossil carbon dioxide (CO_2), the most important greenhouse gas, so if existing nuclear generation (a tenth of global commercial electricity)

978 - IPCC, "Global Warming of 1.5°C", Intergovernmental Panel on Climate Change, Special Report, 2018, see https://www.ipcc.ch/sr15/.

979 - See The Climate Mobilization, "Climate Emergency Campaign", see https://www.theclimatemobilization.org/climate-emergency-campaign, accessed 3 August 2019.

980 - E.g. daylighting to provide light, insulation to provide thermal comfort, densifying local services to avoid transport and/or increase mobility options (walking, biking), etc.

981 - Amory B. Lovins, "How big is the energy efficiency resource?", *Environmental Research Letters*, 13:090401, 18 September 2018, see https://iopscience.iop.org/article/10.1088/1748-9326/aad965/pdf, 4-min video here https://iopscience.iop.org/article/10.1088/1748-9326/aad965, both accessed on 5 August 2019.

982 - Energy Transitions Commission, "Mission Possible", 19 November 2019, see www.energy-transitions.org/mission-possible, finds that industrial CO_2 emissions can be abated by mid-century at reasonable cost, two-fifths by "circular economy" measures that wring more work from fewer tons of cement, steel, aluminum, etc. Complementary further savings are being explored.

983 - Those mainly discussed chemically separate CO_2 from flue gas right after burning fuels. So far they appear costly and not available in the short term, except arguably the Allam cycle for oxygen-and-natural-gas generation by using hot CO_2 rather than steam as the working fluid: Sonal Patel, "Inside NET Power: Gas Power Goes Supercritical", 1 April 2019, *POWER Magazine*, see https://www.powermag.com/inside-net-power-gas-power-goes-supercritical/, accessed 30 August 2019.

984 - IEA, "Key World Energy Statistics—2016 simplified world energy balances, Mtoe", see https://www.iea.org/statistics/kwes/balances/, excluding feedstock uses.

985 - IEA, "Global Energy & CO2 Status Report", March 2019, p 21, see www.iea.org/geco/.

displaced an average mix of fossil-fueled power generation and nothing else, it would offset the equivalent of 4 percent of total global CO_2 emissions. Expanding nuclear power could displace other generators—fossil-fueled or renewable. Nuclear power is frequently promoted as a nearly carbon-free[986] substitute for electricity made from coal and natural gas (oil-fired electricity is negligible). Nuclear power is thus often presented as an essential part of the climate solution, deserving greater subsidy and policy support (called "not forcing nuclear out of the market" or "not taking nuclear off the table" or "keeping the nuclear option open")—either because climate protection is so hard and urgent that all options would be needed, or to protect existing jobs and infrastructures, or because other solutions would be too small, slow, costly, or impractical.

> *"we must pay attention to carbon, cost, and time, not to carbon alone"*

Any claim that not expanding or sustaining nuclear power makes climate solutions "drastically harder and more costly"[987] must depend on comparing the nuclear option with other options. What criteria should such comparisons use? Past criteria have been incomplete. The coal-fired power plants that make 38 percent of the world's electricity and emit 30 percent of the world's total energy-related CO_2 were built by paying attention to cost but not carbon. The nuclear plants, which make just over one-fourth as much electricity but directly burn no fossil fuel, are defended by paying attention to carbon but not cost. Yet to protect the climate, we must abate the most carbon at the least cost—and in the least time—*so we must pay attention to carbon, cost, and time, not to carbon alone.* This chapter explores that logic. An analytic framework and metric to compare all options' "climate-effectiveness," including those with intermediate carbon emissions such as gas-fired generation or cogeneration (of electricity plus useful heat), is available elsewhere[988].

The more urgent climate protection becomes, the more vital it is to achieve *the greatest greenhouse gas reductions per dollar and per year.* Being virtually carbon-free is not sufficient; limited money and time also require "climate-effectiveness." Any solution that saves less greenhouse gas emission per dollar, or does so slower, than it could have will stabilize the Earth's climate less and later than it should have. That is, costly and slow options avoid less carbon per dollar and per year than cheaper and faster options could have, and thus make climate change worse than it should have been: even though they are low-carbon, they still reduce and retard achievable climate protection compared to what was achievable. Yet such common-sense comparisons are rarely discussed—leading to results akin to arguing that since people are hungry, hunger is urgent, and filet mignon and rice are both food, both are essential

986 - A complex literature points out that nuclear power is not strictly carbon-free, not only because of fossil-fuel energy embodied in its construction but also because of complex fuel-chain requirements: Benjamin K. Sovacool, "Valuing the greenhouse gas emissions from nuclear power: A critical survey", *Energy Policy*, August 2008, see https//:doi.org/10.1016/j.enpol.2008.04.017; and for comparison with other energy technologies, see Fig. 7.6, p. 539, in T. Bruckner et al., "Energy Systems," in O. Edenhofer et al., eds., "Climate Change 2014: Mitigation of Climate Change", Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, *Cambridge University Press*, 2014, see www.ipcc.ch. These indirect emissions linked to the nuclear system are far smaller than the direct CO_2 releases from burning fossil fuel, and will not be considered further here. We also do not assess here such other debated climate effects as krypton-85's causing atmospheric ionization, nuclear heat release, nuclear power's effect on water resources and atmospheric humidity, or other indirect effects.

987 - IEA, "Nuclear power in a clean energy system", 28 May 2019, see https://www.iea.org/publications/nuclear/.

988 - Amory B. Lovins, T. Palazzi, "Effectively decarbonizing the electricity system", 2019, see https://www.rmi.org/decarb.

to combatting hunger. Our priorities in feeding people or providing energy services must be informed by relative cost and speed.

NUCLEAR POWER DISPLACES OTHER CLIMATE SOLUTIONS

Nuclear power is obviously not the only way to displace fossil-fueled electricity generation. The past decade's electricity transformation has morphed what were once considered distinctive nuclear advantages—billion-watt scale, steady operation (most of the time), low operating cost—into the handicaps of gigantism and complexity, inflexibility, and greater dispatch cost than nearly free-to-run renewables and demand-side resources (using electricity more efficiently or more timely). Since each of these competing options can succeed only at the expense of the others, nuclear advocates increasingly seek to ensure that their favored technology replaces not only fossil fuels but also renewable power.

This might be rational if nuclear power were far more effective. For example, it might seem obvious that nuclear power has avoided huge CO_2 emissions from fossil-fueled power plants—63 $GTCO_2$ during 1971–2018 according to a new nuclear report by the OECD's International Energy Agency (IEA), which says

> Without nuclear power, emissions from electricity generation would have been almost 20% higher, and total energy-related emissions 6% higher, over that period.[989]

But that depends on what would have been bought in its place. IEA assumes mostly fossil-fueled power plants.[990] But if a portfolio of end-use efficiency or renewables or both had been backed, matured, and bought instead (as U.S. President Truman's Paley Commission recommended in 1953), they could have avoided as much or significantly more carbon emissions.[991]

Similarly, IEA states that

> For countries lacking their own domestic energy resources, reliance on nuclear power can reduce import dependence and enhance supply security. For example, in Japan, which must import all its fuels for nonrenewable power generation, it is estimated that fuel imports over the period 1965–2010 were reduced by at least 14.5 trillion yen (US$132 billion) due to the development of nuclear power.[992]

989 - IEA, "Nuclear power in a clean energy system", 28 May 2019, op. cit.

990 - IEA, "Nuclear power in a clean energy system", op. cit., p.9, Fig.4, Pp.53–4 show the assumed mix was about 44 percent gas, 12 percent coal, 44 percent renewable, and zero efficiency.

991 - What delayed the renewable revolution until the 2010s was not lack of technology or market opportunity but sparse attention, even outright opposition, by the same governments that instead lavished more than a trillion dollars of support on nuclear power. Indeed, an early spurt of efficiency and renewables adoption in the U.S. in the mid-1980s—until its success crashed energy prices—demonstrated their early ripeness.

992 - IEA, "Nuclear power in a clean energy system", 28 May 2019, op. cit.

However, fossil fuel saved by Japan's nuclear program came at a very high economic cost.[993] Building renewables instead, or providing more energy services by saving electricity, would have cost less (at international prices), fuel costs would be zero and other operating costs negligible, and accident costs practically zero, so those alternatives would have saved even more yen and no less carbon. Renewables and efficiency can thus "bolster energy security" at least as well as nuclear power. Actually, Japan is poor in domestic *fuels* but rich in a scarcely tapped renewable *energy* potential. Though energy trade and exchange are often advantageous, renewable resources are so abundant, diverse, and widespread that probably no nation lacks sufficient renewable potential to meet its people's needs efficiently.[994]

> *"Renewables and efficiency can thus "bolster energy security" at least as well as nuclear power"*

This tension between nuclear power and other low-carbon resources is not just theoretical. They compete for the same markets, where efficiency and renewables, and often natural gas, outcompete new and even existing nuclear plants. The nuclear industry's unrivaled political power has therefore been applied, initially in six of the United States, to adding new operating subsidies for distressed nuclear plants (see **United States Focus**). These novel schemes generally substitute political deals for market choices, carve out long-term mandatory nuclear supply allotments not contestable by renewables, and in exchange offer renewable allotments arguably smaller than continued market competition would have yielded. At the same time, both nuclear and fossil-fuel industries and lobbyists press strongly at all policy levels to inhibit, disparage, and suppress renewables, both directly and more subtly. For example, every kWh of uncompetitive generation forced into the market by new subsidies or guaranteed to nuclear operators by preferential dispatch (like Japan's nuclear must-run rule) is a kWh for which renewables cannot compete; and by letting utilities block renewable energy from their grids at any time, for any reason or no reason, Japan makes renewable developers' revenues unpredictable and their projects very hard and costly to finance.

Such rivalry occurs in many countries. Globally, an important subset of the technical literature criticizing renewable energy is prepared and publicized by nuclear advocates to support campaigning by the industry and its allies. For understandable commercial reasons, the nuclear industry has become one of the +most potent obstacles to renewables' further progress, seeking to strangle a competitor to defend its own prospects by diverting demand and capital to itself. The nuclear industry may complain of a reciprocal effort by practitioners and advocates of renewable energy. This chapter examines that tangled competition of technologies, investments, and ideas.

993 - Building Japan's nuclear plants (at historic average costs around ¥$_{2014}$286/We, plus ~10 percent for construction financing) cost about as much as those fuel savings—plus their non-fuel operating costs and decommissioning, plus fuel-chain infrastructure (just the Rokkasho reprocessing plant has already cost ¥2.9 trillion (US$26.8 billion), not counting earlier reprocessing, enrichment and fuel fabrication facilities), plus the officially estimated cost of the Fukushima Daiichi accidents—¥22 trillion (US$203 billion) estimated by the government or ¥35–81 trillion (US$323–748 billion) estimated by Japan Center for Economic Research. Thus, it appears that so far, cumulative cost is several times cumulative benefit, leaving little prospect of covering total costs over the fleet's lifetime. As in the previous example, this raises the question whether fuel and carbon could have been saved more cost-effectively.

994 - See e.g. IRENA, "Global Atlas for Renewable Energy: Overview of Solar and Wind Maps", International Renewable Energy Agency, 2014, see www.irena.org/publications/2014/Jan/Global-Atlas-for-Renewable-Energy-Overview-of-Solar-and-Wind-Maps; IPCC, "Fifth Assessment Report", 2014, pp. 525–526.

NON-NUCLEAR OPTIONS SAVE MORE CARBON *PER DOLLAR*

New-build Costs

New nuclear plants, lacking a business case[995] (see **Nuclear Power vs. Renewable Energy Deployment**), have never been bid into competitive wholesale power markets as competing resources routinely are. Nearly all the nuclear plants under construction are transactions between governments or state-owned enterprises not subject to market discipline and generally unable to engage capital markets without sovereign guarantees. As the International Energy Agency (IEA) states:

> Because of the sheer scale of the investment required, all but 7 of the 54 nuclear power plants under construction globally [see Overview of Current New-Build] are owned by state-owned companies and all but one of the projects in private hands (all of which are in advanced economies) are subject to price regulation, which reduces risks to investors....This is unlikely to change soon. In the current policy and market environment, it is difficult to see any privately-owned utility embarking on a Generation III project in Europe or in North America without strong government support to minimize financial risks to investors. In developing countries, state-owned companies are responsible for all new nuclear investment.[996]

Table 19 | New-build Costs for Nuclear, Renewables and Efficiency

	Lazard Ltd. (2018)[a] (in US$$_{2018}$/MWh)	BNEF[b] (in US$$_{2019}$/MWh)	Market Actuals (in US$$_{2018–2019}$/MWh)
Nuclear new-build	151	195–344 (US)	see country sections
Utility-scale solar	36–44	30–35	19 (Mexico)
Onshore wind power	29–56	27–32	22–26 (India), 17 (Mexico)
Electric end-use efficiency bought by utility programs	0–50	—	U.S. average 23–31[c] (2009–12)

Source: Lazard, BNEF, Market Actuals

Notes

a - Lazard, "Levelized Cost of Energy Analysis–Version 12.0", 8 November 2018, see www.lazard.com/media/450784/lazards-levelized-cost-of-energy-version-120-vfinal.pdf.

b - E. Giannakopoulou, T. Brandily, 1H 2019 LCOE Update, 26 March 2019, Bloomberg New Energy Finance subscriber database, see www.bnef.com, accessed 9 July 2019.

c - Megan A. Billingsley, Ian M. Hoffman, et al., "The program administrator Cost of Saved Energy for utility customer-funded energy efficiency programs", Lawrence Berkeley National Laboratory (LBNL), March 2014, see https://emp.lbl.gov/sites/all/files/lbnl-6595e.pdf; and Maggie Molina, "The best value for America's energy dollar: a national review of the cost of utility energy efficiency programs", American Council for an Energy-Efficient Economy, Research Report U1402, 25 March 2014, see http://aceee.org/research-report/u1402; also M. Wemple, "DSM Achievements and Expenditures 2013", see http://www.esource.com/members/DSM-INDBMK-Achievements-2013/DSM-Achievements-and-Expenditures-Study.

Even before the latest unhappy chapters such as Olkiluoto-3 (see **Finland Focus**) and Flamanville-3 (see **France Focus**), nuclear new-build's real levelized electricity costs were officially assessed as rising 130 percent in France during 2005–15, 29 percent in Japan, and

995 - Ben Wealer et al., "High-priced and dangerous: nuclear power is not an option for the climate-friendly energy mix", German Institute for Economic Research, July 2019, see www.diw.de/documents/publikationen/73/diw_01.c.670581.de/dwr-19-30-1.pdf.

996 - IEA, "Nuclear power in a clean energy system," 2019, op. cit., p. 19. P 5 recommends for new-build support "long-term contracts, price guarantees and direct state investments."

75 percent in the U.S.[997] Conversely, just in the past five years, U.S. solar and wind prices fell by two-thirds, putting new nuclear power out of the money by about 5–10-fold (see **Nuclear Power vs. Renewable Energy Deployment** for additional details):

Nuclear new-build thus costs many times more per kWh, so it buys many times less climate solution per dollar, than these major low-carbon competitors. That reality could usefully guide policy and investment decisions if the objective is to save money or the climate or both.

This gap is widening as nuclear costs keep rising and renewable costs falling. IEA agrees that

> Solar PV costs fell by 65 percent between 2012 and 2017, and are projected to fall by a further 50% by 2040; onshore wind costs fell by 15% over the same period and are projected to fall by another 10–20% to 2040.[998]

The National Renewable Energy Laboratory (NREL) expected in 2018[999] that onshore wind power would get 27 percent cheaper during 2016–50 and photovoltaics 60 percent, so by 2050 they should cost respectively around US$27/MWh and US$18/MWh in good sites. Yet those projections exceed Mexico's respective unsubsidized low prices of US$19 and US$17 bid *in the previous year*—33 years before 2050. The main outlier in acknowledging this pattern, the IEA, is struggling to improve its renewables forecasting: since 2002, it has raised wind power forecasts sixfold and solar forecasts 23-fold without ever catching up with reality, so installed solar capacity is now over 50 times the 2002 forecast. That's because IEA's renewable cost projections lag the market, and because its forecasting model, like other conventional economic models, is structurally unable to handle increasing returns—as Thomas Friedman says, "The more you buy, the cheaper it gets, so you buy more, so it gets cheaper."

> *"installed solar capacity is now over 50 times the 2002 forecast"*

IEA publishes many excellent studies on diverse topics, but its May 2019 nuclear report, the first in nearly two decades, is only partly consistent with evidence offered here, so we highlight some points that are not. IEA shows a 2040 levelized new-nuclear cost of just US$$_{2018}$100/MWh (34–71 percent below the market prices in **Table 19**), yet agrees it exceeds solar and onshore wind power costs.[1000] However, IEA projects those renewables to exceed US$50/MWh through 2040 for Europe and North America "under the same financing conditions" as its nuclear analysis (8 percent weighted-average cost of capital, 10–20-year financing duration). Capital markets evidently do not consider the risks equivalent, so U.S. wind power, for example, currently pays <4.5 percent for its capital, and unsubsidized renewables from Mexico to India are bid at around US$17–26/MWh. By inappropriately applying short-term nuclear-upgrade financial assumptions to long-range renewable investments, IEA calculates renewable prices for 2040 that are about twice today's competitive renewable prices and exceed those observed in all major markets (except Japan) according to BNEF's authoritative assessment.

997 - IEA/NEA, "Projected Costs of Generating Electricity 2015", Nuclear Energy Agency, September 2015, see www.oecd-nea.org/ndd/pubs/2015/7057-proj-costs-electricity-2015.pdf.

998 - IEA, "Nuclear power in a clean energy system", 28 May 2019, op. cit.

999 - National Renewable Energy Laboratory, "Annual Technology Baseline: 2018 ATB Cost and Performance Summary", 2018, see https://atb.nrel.gov/electricity/2018/summary.html.

1000 - IEA, "Nuclear power in a clean energy system", 28 May 2019, op. cit.

The business case for modern renewables is so convincing to investors that the latest official U.S. forecast[1001] foresees 45 GW of renewable additions from mid-2019 to mid-2022, *vs.* 7 GW of net retirements for nuclear and 17 for coal. With modern renewables now supplying nearly two-thirds of the world's 2017–18 net additions to global generating capacity, the marketplace rout is nearly complete: non-hydro renewables in 2018 got eight times as much investment as nuclear power, nearly three times that of fossil-fueled generation.[1002] The nuclear industry's spectacular failures to deliver on its promises of a nuclear renaissance are "scaring off investors".[1003] But might they be drawn back by the latest round of claims that imminent new technologies will turn decades of rising nuclear costs into sharp declines?

> *"even free steam from any kind of fuel, fission, or fusion is not good enough, because the rest of the plant costs too much"*

A current fashion in nuclear advocacy is to admit today's reactors are uneconomic, then use the novel candor thus displayed to bolster the claim that new reactor types or fuel systems will make nuclear new-build competitive, so their development merits major public funding. That hope, however, is tempered by an awkward fact: of the prohibitive capital cost of Gen-III+ reactors, on the order of US$5,000–8,000+/ kW, ~78–87 percent is for *non*-nuclear costs.[1004] Thus, if the other ~13–22 percent—the "nuclear island" (Nuclear Steam Supply System)—were *free*, the rest of the plant would still be grossly uncompetitive with renewables or efficiency. That is, even *free* steam from any kind of fuel, fission, or fusion is not good enough, because the rest of the plant costs too much.

Equally simple logic clouds the economies of mass production hoped for from Small Modular Reactors (SMRs). As a matter of physics, reactors do not scale down well, so the more-careful analysts acknowledge SMRs—including in China—would initially cost significantly (often about twofold) more per kWh than today's gigawatt-scale reactors (see Small Modular Reactors). But, as shown above, today's new-build reactors already have ~5–10 times the levelized cost of modern renewables (let alone efficiency) per kWh. On durable observed learning curves (which nuclear power has never displayed), renewables will become another twofold cheaper by the time SMRs could be built, tested, and scaled. Two times 5–10 times two is a factor of 20–40—far beyond any plausible saving from mass production. No nuclear miracle is waiting to emerge. Small Modular Renewables, which do scale down well and whose economies of mass production have several decades' head start, have decisively won on cost.[1005]

1001 - Federal Energy Regulatory Commission, "Electricity Infrastructure Update for May 2019", see https://www.ferc.gov/legal/staff-reports/2019/may-energy-infrastructure.pdf.

1002 - REN21, "Global Status Report", Fig. 50, 2019, see https://www.ren21.net/gsr-2019/.

1003 - IEA, "Nuclear power in a clean energy system", 28 May 2019, op. cit., p. 22.

1004 - MIT Energy Initiative, "The Future of Nuclear Energy in a Carbon-Constrained World", 2018, see https://energy.mit.edu/wp-content/uploads/2018/09/The-Future-of-Nuclear-Energy-in-a-Carbon-Constrained-World.pdf, Table 2.2, p. 39, which also presents 10 percent typical and 16 percent best U.S. Light Water Reactor (LWR) cost fractions for the Nuclear Steam Supply System.

1005 - Or, as David Freeman said in his Foreword to WNISR2017: "The report makes clear, in telling detail, that the debate is over." See Mycle Schneider, Antony Froggatt, et al., "WNISR2017", 12 September 2017, see https://www.worldnuclearreport.org/The-World-Nuclear-Industry-Status-Report-2017-HTML.html#linko, accessed 22 July 2019.

Non-Economic Arguments for Nuclear Need

Objections to renewables other than cost-effectiveness are therefore often raised, whether expressed as technical issues or as hidden costs. These become ever less convincing as experience gives grid operators comfort with new ways of operating power systems, and as major heavy-electricals firms like General Electric, Siemens, Schneider and Asea Brown Boveri (ABB) refocus their skills from nuclear power to distributed and renewable energy systems. There are six main arguments:

- *Baseload:* The venerable "baseload" concept—that grid stability needs gigawatt-scale, steadily operating thermal (steam-raising) power plants—reflects the valid and vital economic practice of dispatching power at least operating cost, so resources with lowest operating costs are run most. This traditional role of giant thermal plants led many people to suppose that such plants are always needed. But now that renewables with no fuel cost are taking over the "baseload" role of being dispatched whenever available, those big thermal plants are relegated to fewer operating hours, making the term "baseload" an obsolete honorific. Thermal plants must now adapt to follow the net load left after cost-effective efficiency, demand response, and real-time "base-cost" renewable supply have been dispatched. Nuclear power's limited flexibility, and its technical and economic challenges when cycled, have thus become a handicap, complicating least-cost and stable grid operation with a rising share of zero-carbon, least-cost variable renewables.[1006] That is why Pacific Gas and Electric Company (PG&E) found that early closure of its well running Diablo Canyon reactors would save customers money and, by making the grid more flexible, raise renewables' share. Those reactors had become cheaper to close than to run: the power systems' shift to renewables had turned them from an asset to a liability[1007], so they'll be replaced by competitively procured low-carbon resources, saving both money and carbon.

- *Storage:* Keeping the grid reliable as solar photovoltaics and wind power (both with accurately forecastable but large variations in output) come to dominate electric generation requires changes in markets, institutions, operations, habits, and mental models. This has proven feasible in both theory and practice, as illustrated by national statistics' reports of 75 percent renewable coverage of annual electricity consumption in Scotland (2018), 72 percent in Denmark (2017, domestic production only), 67 percent in Portugal (2018), 40 percent in peninsular Spain (2018), and 38 percent in Germany (2018). Most such grids sometimes achieve over 100 percent renewable supply, just as Japan's southern island of Kyushu reported 76 percent peak solar coverage on 23 April 2017[1008], and Shikoku 102 percent on 3 May 2018[1009], despite Japanese utilities' insistence that far smaller renewable fractions will crash the grid. No "storage miracle" is needed, though some seem to be emerging. Whether solar, fossil-fueled, or nuclear, no generator needs 100 percent

1006 - Amory B. Lovins, "Do coal and nuclear generation deserve above-market prices?", *The Electricity Journal*, Vol.30, Issue 6, July 2017, see https://doi.org/10.1016/j.tej.2017.06.002, notes 58–68; and C. Morris, "Backing up Wind and Nuclear Power", 2015, see www.renewablesinternational.net/backing-up-wind-and-nuclear-power/150/537/86412/.

1007 - Amory B. Lovins, "Closing Diablo Canyon Nuclear Plant Will Save Money and Carbon", *Forbes*, 22 June 2016, see www.forbes.com/sites/amorylovins/2016/06/22/close-a-nuclear-plant-save-money-and-carbon-improve-the-grid-says-pge/, accessed 22 July 2019.

1008 - However, planned nuclear restarts would require such strong solar production to be curtailed under Japan's "uneconomic dispatch" rule.

1009 - Kazuhiko Miko, "Status and Challenges on the Power System in Japan", Smart Community Department, New Energy and Industrial Technology Development Organization, NEDO, IRED 2018 Session 1, 17 October 2018, see www.ired2018.at/Sessions/181017_IRED2018%20Session1_NEDOver.5.pdf, accessed 22 July 2019.

backup, because one generator does not serve one load; rather, all generators serve the grid, which in turn serves all loads. The grid is designed to back up failed plants with working plants, so varying solar and wind power output are backed up by a diversified portfolio of other variable renewables, dispatchable renewables, or other resources. Solar and wind power don't need massive batteries so they can produce power steadily like big thermal plants; rather, at least eight classes of grid flexibility resources[1010] besides bulk electrical storage and fossil-fueled backup are proven, available, cost-effective, and sufficient.[1011] We don't and needn't yet know all details of their ultimate mix as renewables rise toward 100 percent of generation; for now, we need only know that ample and affordable integration options exist.[1012] As climatologist Prof. Ken Caldeira says, "Controversies about how to handle the [electricity] endgame should not overly influence our opening moves."

- *Saturation*: The claim that high fractions of variable renewables suffer inevitable "value deflation" making them uncompetitive with thermal plants has turned out to be an artifact of models that exclude many available forms of effective mitigation.[1013] For example, in the ERCOT (Texas) power pool, thorough installation by 2050 of eight kinds of demand response can more than eliminate the supposedly problematic "duck curve" of steeply ramping net load as solar output declines and home loads rise late on hot summer days. Such a demand response strategy can also halve the summer daily load range, save one-fourth of nonrenewable capacity, make renewable energy one-third *more* valuable, and pay back in about five months.[1014]

> *"renewables generally have lower backup needs and costs than nuclear plants"*

- *Backup*: A related argument often claims that more renewables mean steeply rising grid integration costs. But such effects would be worse for nuclear-dominated grids because nuclear plants are bigger, more transmission-dependent, and more prone to sudden, lengthy, unpredictable failures (see **Belgium Focus** and **France Focus**). No kind of generator is 24/7/365—they all break—but failure is more consequential in big units. Variable renewables' "firming costs"—the cost of diversification (which may include network expansions), backup, storage, or other ways to ensure reliability standards are met even when sun and wind falter—remain low (generally under US$5/MWh, nearly always

1010 - 1. Efficient use; 2. unobtrusively flexible demand; 3. modern forecasting of variable renewables' output (often more accurately than demand); 4. diversifying those variable renewables—wind and solar PV—by type and location; 5. dispatchability—integrating wind and solar PV portfolios with the other renewables (not counting big hydropower, which could also be integrated more effectively than now and with cogeneration that must run anyhow to satisfy its thermal loads; 6. distributed thermal storage worth buying anyway, or managed thermal storage in buildings' existing thermal mass; 7. distributed electrical storage worth buying anyway (e.g. smart charging and discharging of electric vehicles bought to provide mobility); 8. hydrogen, now most likely from renewable electricity.

1011 - Amory B. Lovins, "Reliably integrating variable renewables: Moving grid flexibility resources from models to results", *The Electricity Journal*, Volume 30, Issue 10, December 2017, see https://doi.org/10.1016/j.tej.2017./11.006.

1012 - Tom W. Brown et al., "Response to 'Burden of proof: A comprehensive review of the feasibility of 100% renewable-electricity systems", *Renewable and Sustainable Energy Reviews*, Volume 92, 11 May 2018, see https://doi.org/10.1016/j.rser.2018.04.113.

1013 - Amory B. Lovins, "Do coal and nuclear generation deserve above-market prices?", *The Electricity Journa*l, Volume 30, July 2017, see https://doi.org/10.1016/j.tej.2017.06.002, and its note 81. An instructive four-part debate with two economists commissioned by nuclear owner Exelon, which objected to the article's §2 on climate-effective solutions, is in the October 2017 and December 2017 issues.

1014 - Cara Goldenberg et al., "Demand Flexibility", Insight Brief, Rocky Mountain Institute, February 2018, see www.rmi.org/wp-content/uploads/2018/02/Insight_Brief_Demand_Flexibility_2018.pdf.

under US$10[1015]) even at high renewable fractions.[1016] Indeed, evidence is emerging[1017] that the long-socialized but -unanalyzed corresponding firming costs to guard against the intermittence (forced outages) of large thermal plants are severalfold larger than for (say) wind farms but are not charged to those thermal projects as they are to variable renewables. Such costs can be major, as unbundled prices in ERCOT reveal[1018], because lumpy gigawatt-scale units require large reserve margin and spinning reserve, incurring corresponding part-load penalties and cycling costs. Thus balancing a soundly diversified portfolio of granular renewables may need severalfold fewer and cheaper resources than utilities have already bought to manage their big thermal plants' intermittence. If firming costs are ascribed to specific technologies or projects, then symmetrical comparison favors modern renewables; if firming costs are instead treated as inevitable system costs, as they always were for thermal plants, then they don't affect the choice of technologies. Either way, renewables generally have *lower* backup needs and costs than nuclear plants, despite solar and wind power's much lower capacity factors.

- *Ancillary services*: Large thermal plants provide vital "ancillary services" to the grid, such as frequency stability, voltage stability, short-circuit current, and fault management. However, the same services have turned out to be available at lower cost and higher quality from modern renewables' smart inverters and their virtual inertia, and from repurposing retired thermal plants' synchronous generators, without their prime movers, as synchronous condensers (also called synchronous compensators): these can provide the same services as a standard generator except active power, which can instead come from renewables or storage.[1019]

- *Resilience*: Nuclear power's claimed resilience benefits are compromised by many unpleasant attributes documented elsewhere.[1020] They also exhibit a high historical "dry-hole" risk of yielding no power or far less than expected. Of the 259 U.S. power reactors ordered during 1955–2016, just 28 (as of mid-2017), some slated for closure, remained competitive in their wholesale markets and had not yet suffered a year-plus safety-related outage.[1021] And in an

1015 - Ryan Wiser, Mark Bolinger, et al., "2017 Wind Technologies Market Report", Lawrence Berkeley National Laboratory (LBNL), published by the Office of Energy Efficiency, U.S.DOE, August 2018, p.70, see https://energy.gov/eere/wind.

1016 - Phil Heptonstall, Rob Gross, et al., "The costs and impacts of intermittency – 2016 update", UK Energy Research Centre, 21 February 2017, see http://www.ukerc.ac.uk/publications/the-costs-and-impacts-of-intermittency-2016-update.html, accessed 21 July 2019.

1017 - Amory B. Lovins, "Do coal and nuclear generation deserve above-market prices?", *The Electricity Journal*, July 2017, op. cit., notes 72–75.

1018 - American Wind Energy Association, "Wind energy helps build a more reliable and balanced electricity portfolio", 2015, see http://awea.files.cms-plus.com/AWEA%20Reliability%20White%20Paper%20-202-12-15.pdf.

1019 - Tom W. Brown, et al., "Response to 'Burden of proof: A comprehensive review of the feasibility of 100% renewable-electricity systems", *Renewable and Sustainable Energy Reviews*, Volume 92, September 2018, §3.5, see https://doi.org/10.1016/j.rser.2018.04.113; and Michael Milligan, "Sources of grid reliability services", Milligan Grid Solutions, *The Electricity Journal*, Volume 31, Issue 9, November 2018, see https://doi.org/10.1016/j.tej.2018.10.002.

1020 - Amory B. Lovins, "Do coal and nuclear generation deserve above-market prices?", *The Electricity Journal*, July 2017, §9 ("Fuel on hand"), elaborated in Amory B. Lovins, "Comments by Amory B. Lovins, Cofounder and Chief Scientist, Rocky Mountain Institute", FERC, Notice of Proposed Rulemaking, Grid Resiliency Pricing Rule, Submission 813728, Docket RM18-1-000, 23 October 2017, see https://elibrary.ferc.gov/idmws/file_list.asp?accession_num=20171023-5099; and Amory B. Lovins, "Errata—Correcting 23 October 2017 Comments (Submission 813728 by Amory B. Lovins", FERC, Submission 813743, see https://elibrary.ferc.gov/idmws/file_list.asp?accession_num=20171023-5109; both accessed 30 August 2019.

1021 - Amory B. Lovins, FERC comments, op. cit.

emergent risk, at least 100 reactors are reportedly in low-lying coastal sites vulnerable to sea-level rise that may occur during their lifetimes.[1022]

Costs of Lifetime-Extended Nuclear Plants

IEA's previously mentioned 2019 report admits new reactors can't compete in the market, but strongly encourages decades of lifetime extension for existing reactors to save both money and carbon. IEA says that will cost US$_{2017}$40–55/MWh and will undercut US$50+/MWh renewables (calculated, as noted above, at about twice observed levels, let alone forecast levels, by assuming nuclear rather than actual renewable financing conditions). On its face, this comparison invites skepticism. If lifetime extension and continued operation can beat renewables through 2040, why will it need subsidies, and why won't all operators make that bet with their own money? In fact, many reactors, in particular in the U.S., cannot beat new renewables in day-to-day market competition, and are shutting down one or more decades before their licenses expire unless bailed out by new subsidies (see **United States Focus**). Wouldn't any reactors not yet upgraded become even less competitive after each is burdened by roughly US$0.5–1.1+ billion of backfitting/upgrade costs? And wouldn't their viability then erode further as renewables get cheaper, nuclear plants age, economic dispatch against growing renewable fleets reduces their run hours (spreading their fixed operating costs over smaller sales), and safety standards continue to ratchet?

Since new solar and wind power at market prices, though nearly pure capital costs, empirically undercut the upgrade cost plus operating cost of nuclear lifetime extensions, how does IEA conclude that foregoing those extensions would need a third of a trillion dollars more capital investment (over a third of it for grid expansions to reach "less accessible sites")? And why is IEA so concerned about the Nuclear Fade Case's raising wind and solar output[1023] in advanced economies by only one-fifth above the Sustainable Development Scenario—growing three rather than two times as fast as occurred during 2000–17, both well *below* respected market forecasts? IEA's excellent analysts may have answers, but their untransparent analysis raises doubts. We therefore explore next the most basic and intractable, yet often least noticed, cause of existing reactors' uncompetitiveness: the routine operating costs that according to IEA (p.4) put "most nuclear plants in advanced economies…at risk of closing prematurely."

Operating Costs of Existing Nuclear Plants

Even reactors that already implemented their lifetime-extension and safety-upgrade investments, or are excused by compliant regulators from making them, and whose original

1022 - J. Vidal, "What are coastal nuclear power plants doing to address climate threats?", 8 August 2018, see www.ensia.com/features/coastal-nuclear. Of 51 US nuclear sites, 55 were already found subject to beyond-design-basis flood hazards, but in January 2019, the U.S. Nuclear Regulatory Commission voted 3–2 not to require upgrades to address those identified hazards; see S.Q. Stranahan, "Why don't U.S. nuclear regulators acknowledge the dangers of climate change?", *The Washington Post*, 14 March 2019. In July 2019, NRC staff also proposed fewer safety inspections, fuzzier descriptions of problems, and other weakening of safety oversight. See S. Cooke, "Safety: NRC Proposes Reduced Inspection Effort", *NIW*, 19 July 2019.

1023 - IEA, "Nuclear power in a clean energy system", 28 May 2019, op. cit., p.63 uses implicit capacity factors of 25 percent for wind-plus-solar production. For comparison, the actual 2018 US averages were 37.4 percent for wind power, 26.1 percent for PVs, and 23.6 percent for solar thermal, compared with 73.3 percent for landfill gas and municipal solid waste, 49.3 percent for other biomass including wood, and 77.3 percent for geothermal; see U.S.EIA, "Electric Power Monthly—Table 6.7.B. Capacity Factors for Utility Scale Generators Not Primarily Using Fossil Fuels, January 2013–May 2019", 24 July 2019, see www.eia.gov/electricity/monthly/epm_table_grapher.php?t=epmt_6_07_b.

construction costs were already fully amortized, face normal operating costs. Once assumed too small to discuss, these have become a major obstacle to many plants' continued profitable operation, especially as their age increases the frequency and cost of major repairs. The US$2.9 billion annual losses *Bloomberg* reported in June 2017[1024], spread among 54 GW (over half of the U.S. nuclear installed capacity), probably remain unsustainable for units not yet retired or rescued for a few years by direct subsidies (see **United States Focus**). Their operating-cost data are often commercial secrets, but aggregated data reveal fundamental uncompetitiveness against most electric-efficiency investments and many modern renewables.

The "total generating cost" assessed here excludes initial construction and financing cost, and applies only to subsequent operations. It comprises three terms: fuel (including waste-management and decommissioning provisions), operation and maintenance ("O&M," including normal business costs like taxes and insurance), and Net Capital Additions (post-construction investments for repairs, upratings, or safety upgrades that are large enough that they are capitalized rather than expensed; they are poorly reported and often omitted, their boundary with fixed O&M is rather vague, and those two costs' sum rises nonlinearly with age). Closed plants do not continue to incur these operating costs.

United States

The Nuclear Energy Institute (NEI), the leading industry trade group in the U.S., has summarized in three-year averages the Electric Utility Cost Group's (EUCG) proprietary annual compilation of total generating cost. No list is available of exactly which units are included, hence whether any operating units are excluded, and at what stage a troubled or retired unit is removed from the database, but the broad pattern is clear, as illustrated in **Table 20**. Each quartile includes roughly 25 reactors.

Table 20 | Average Nuclear Generating Costs in the United States (by Quartile)

US$$_{2017}$$ per busbar MWh	2012–14	2013–15	2014–16
Quartile 1	30.26	29.78	28.81
Quartile 2	35.50	34.97	34.40
Quartile 3	43.51	41.72	40.69
Quartile 4	62.17	55.42	51.57

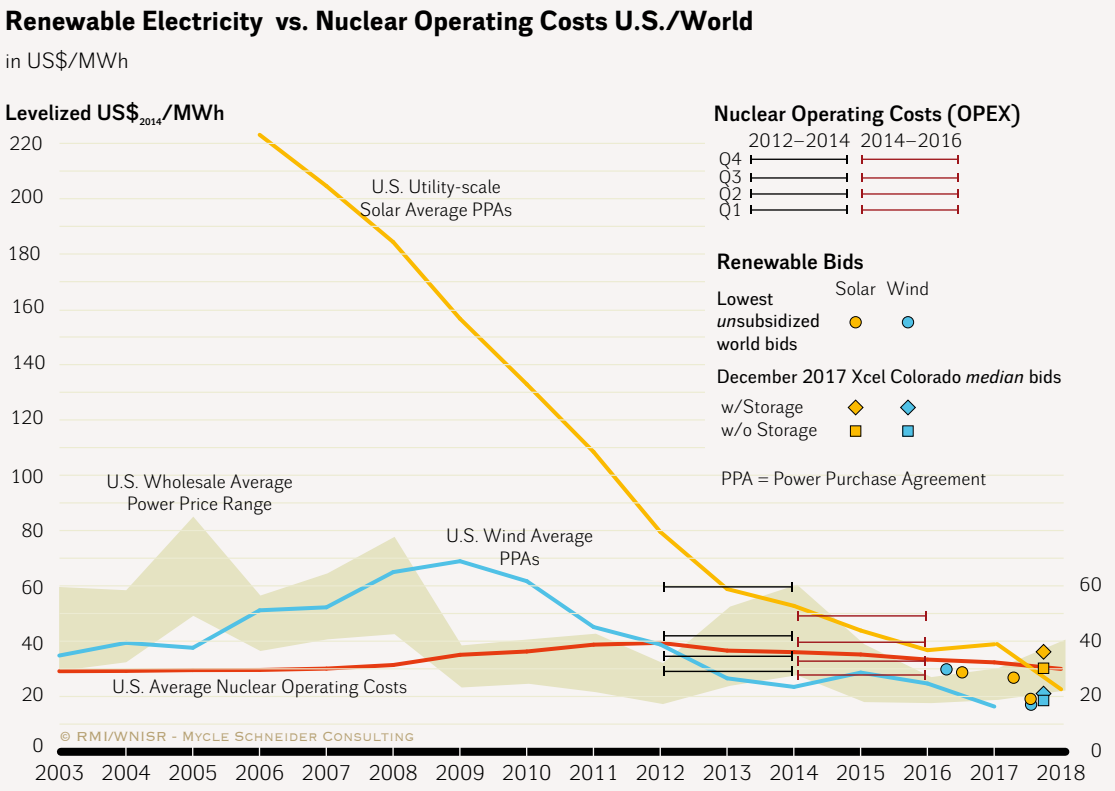
Source: Nuclear Energy Institute, private communication to Amory B. Lovins, 26 July 2018

How are these nuclear operating costs evolving? **Table 21** represents the same EUCG analysts' average generating costs by category and year (US$$_{2017}$$/busbar MWh).[1025]

1024 - Jim Polson, "More Than Half of America's Nuclear Reactors Are Losing Money", *Bloomberg*, 14 June 2017, see www.bloomberg.com/news/articles/2017-06-14/half-of-america-s-nuclear-power-plants-seen-as-money-losers.

1025 - NEI, "Nuclear by the numbers", March 2019, see https://nei.org/CorporateSite/media/filefolder/resources/fact-sheets/nuclear-by-the-numbers.pdf, 2018 data from April 2019 edition converted to 2017 US$ using GDP Implicit Price Deflator, previous data from April 2018 edition. IEA, "Nuclear power in a clean energy system", 28 May 2019, op. cit., p. 34, confusingly equates variable cost with fuel cost, overlooking variable O&M cost.

Figure 51 | Cost Evolution of New Renewables vs. Operating Nuclear



Sources: various compiled by Amory Lovins, Rocky Mountain Institute, 2019[1026]

Notes

Wind and Solar PPAs: US generation-weighted-average Power Purchase Agreements prices, by year of signing.
Nuclear operating cost: fuel, operation and maintenance, and Net Capital Additions average and quartiles. See Table 20 and Table 21.

Figure 51 represents nuclear plants' total generating costs *vs.* competing costs during 2003–18. This reveals that although average U.S. nuclear operating costs have declined since 2012—especially in the costliest quartile, where the most distressed units have begun to retire—the *average* wholesale long-term Power Purchase Agreement (PPA) prices for both new wind power (blue curve) and new utility-scale solar power (gold curve) have declined even faster. This leaves most operating reactors and the 2018 average U.S. nuclear operating costs (red curve) uncompetitive by ~US$10+/MWh with those renewable sources (including wind power plus storage, the blue diamond), or even with the best *un*subsidized international renewable prices (blue and gold round dots), let alone with often-cheaper energy efficiency. Nuclear operating costs for the four-decade-old U.S. fleet probably have limited scope to fall further, but renewables have far more; they're a rapidly moving target that nuclear operating costs are unlikely ever to hit.

1026 - Updated through June 2018; August 2019 Lawrence Berkeley National Laboratory (LBNL) data show wind power PPAs below $20 and continuing their downward trend.
Solar world bids: Chile (US$29.1/MWh, August 2016) and Mexico (US$27 /MWh, February 2017; US$19.2/MWh, November 2017)
Wind world bids: Morocco (January 2016), Mexico (US$17/MWh, November 2017)
Xcel Energy December 2017 median levelized solar bids: US$36/MWh and US$30/MWh with and without storage—wind bids US$21/MWh and US$18/MWh with and without storage
U.S. Wind and Solar PPAs: LBNL
Wholesale price range: RMI Analysis of BNEF Prices, Tariffs and Auctions, US Power & Fuels from subscribers database.
Nuclear operating costs: NEI, "Nuclear by the Numbers", April 2018, plus April 2019 (for 2018 datum) using Electric Utility Cost Group data, converted to 2014 US$ using GDP Implicit Price Deflator.

Table 21 | Average Nuclear Generating Costs in the United States (by Category)

US$$_{2017}$$ per busbar MWh	Fuel	Operation & Maintenance	Net Capital Additions	Total
2012	7.77	11.21	22.37	41.35
2013	8.01	8.49	21.67	38.17
2014	7.47	8.47	21.67	37.60
2015	7.10	8.24	21.56	36.91
2016	6.90	6.89	20.87	34.65
2017	6.45	6.66	20.50	33.61
2018	5.86	6.01	19.30	31.17

Source: Nuclear Energy Institute, "Nuclear by the Numbers," 2018 and 2019

France

In the world's second-largest nuclear fleet, the world's largest nuclear operator Électricité de France's (EDF's) standard price for up to 100 TWh/y of electricity from fully amortized nuclear plants, equivalent to about a quarter of historic fleet production (ARENH[1027]), has been set since 2012 at €42/MWh[1028] (US$$_{2012}$$55.5/MWh). The public Court of Accounts (Cour des Comptes) assessed average nuclear generating costs[1029] at €$_{2019}$54/MWh (US$$_{2019}$$60.6/MWh) for 2010[1030], €$_{2019}$63/MWh (US$70.7/MWh) for 2013[1031], and €$_{2019}$66/MWh (US$74/MWh) for the second half of 2014[1032]; this 22-percent rise was due to higher maintenance costs, including Net Capital Additions for stricter post-Fukushima safety standards. However, the Court of Accounts stressed in its 2016 annual public report[1033] that the costs are even more sensitive to a potential drop in production. This is exactly what happened as generation dropped by 9 percent, from 417 TWh in 2015 to 379 in 2017, with a slight recovery to 393 TWh in 2018.

Romain Zissler, senior researcher at the Renewable Energy Institute in Tokyo, estimated 2017 French operating costs at €$_{2019}$81/MWh (US$91/MWh), based on lower generation[1034]. Published European Power Exchange (EPEX) baseload prices suggest many French reactors are losing money. These nuclear operating costs are less than half realistic new-build costs, yet are several times competitive new-renewables costs. In the second half of 2018, BNEF priced unsubsidized onshore wind power in France at US$67/MWh and solar at US$59/MWh[1035], putting unamortized nuclear plants under severe pressure now and even amortized units soon. No wonder the French Environment & Energy Management Agency concluded

1027 - ARENH = accès régulé à l'énergie nucléaire historique, or Regulated Access to Historic Nuclear Energy.

1028 - Commission de Régulation de l'Énergie, "ARENH", Undated (in French), see https://www.cre.fr/Pages-annexes/Glossaire/ARENH, accessed 18 July 2019.

1029 - Converted to €/US$$_{2019}$$ by WNISR.

1030 - Cour des Comptes, "The costs of the nuclear power sector", Press Release, 8 February 2012, see https://www.ccomptes.fr/sites/default/files/EzPublish/Costs_nuclear_power_sector_press_release.pdf, accessed 18 July 2019.

1031 - Cour des Comptes, "Le coût de production de l'électricité nucléaire—Actualisation 2014", Communication à la Commission d›Enquête de l›Assemblée Nationale, May 2014 (in French), see https://www.ccomptes.fr/sites/default/files/EzPublish/20140527_rapport_cout_production_electricite_nucleaire.pdf, accessed 18 July 2019.

1032 - Cour des Comptes, "Le Rapport Public Annuel 2016–Tome I: Les Observations", February 2016 (in French), see https://www.ccomptes.fr/sites/default/files/EzPublish/RPA2016-Tome-1-integral.pdf, accessed 18 July 2019.

1033 - Ibidem.

1034 - Romain Zissler et.al., "The Rise of Renewable Energy and Fall of Nuclear Power–Competition of Low Carbon Technologies", Renewable Energy Institute, 6 February 2019, see www.renewable-ei.org/en/activities/reports/20190206.php.

1035 - Ibidem.

in October 2018[1036]: "From an economic point of view, the development of a new generation nuclear technology would not be competitive for the French electricity system"—even at an assumed production cost of "a hypothetical €70/MWh" (US$79.5/MWh).

Germany

Detailed operating costs for German reactors appear not to be readily available, but applying 2018 European Commission generic assumptions[1037] to the seven operating reactors implies a 2020 snapshot value (probably below the levelized value) of $€_{2013}$22.5/MWh ($US\$_{2013}$31/MWh) for O&M alone, plus fuel, probably plus Net Capital Additions. The implied total does not look durably competitive with modern renewables.

Sweden

Swedish nuclear operating costs were estimated in 2016 by Vattenfall's head of generation at SEK250/MWh ($US\$_{2016}$29/MWh) excluding the SEK70/MWh ($US\$_{2016}$8/MWh) nuclear operating tax then in force)—above the SEK220/MWh ($US\$_{2016}$26/MWh) typical wholesale electricity price[1038], which was not expected to rise over the next 5–10 years[1039]. As operating costs were expected to durably exceed income, the Vattenfall manager concluded: "Nuclear is in trouble. Profitability needs to improve." Ringhals-1 and -2 are therefore being closed; Oskarshamn-1 and -2 and Barsebäck-1 and -2 already were.

Japan

Japan once had the world's third-largest nuclear fleet, but after the 2011 Fukushima Daiichi disaster started to unfold, all 54 reactors were shut down by 2014, and every year since, they've been outgenerated by solar power. By 2018, restarts left nine operating units generating about 50 TWh–243 TWh less than in 2010. Of that gap, ~75 percent was covered by energy savings plus renewable growth, or 82 percent when adjusted for economic growth so that efficiency gains are not understated.[1040] This is despite Japanese policy's comprehensive efforts to control solar expansion and suppress wind power growth—a regime aptly summarized as "a combination of barriers to access the grid, unfavorable treatment once connected, difficult technical requirements and tedious rather than effective environmental regulations"[1041] raising renewable costs to multiples of international levels. Thus more than four-fifths of the market

1036 - French original: "D'un point de vue économique, le développement d'une filière nucléaire de nouvelle génération ne serait pas compétitif pour le système électrique français", see ADEME, "Trajectoires d'évolution du mix électrique 2020–2060", October 2018.

1037 - P. Capros, E. Dimopoulou et al., "Technology pathways in decarbonisation scenarios", ASSET, Commissioned by the EU Commission, Directorate-General for Energy, July 2018, kindly compiled by Leonard Göke, TU-Berlin, pp. 45–47, see https://ec.europa.eu/energy/sites/ener/files/documents/2018_06_27/technology_pathways_-_finalreportmain2.pdf. The report does not specify what year's Euros it uses, but it solicited data on forms (pp 54–55) stating EUR_{2013}, as used in the EC's previous (2016) forecast.

1038 - Torbjörn Wahlborg, "Swedish nuclear power–Present status and outlook", Vattenfall, 3 March 2016, see https://wecfinland.fi/wp-content/uploads/2016/01/2016-03-03-Vattenfall-and-Fingrid-Final.pdf.

1039 - *WNN*, "Vattenfall seeks to return reactors to profitability", 8 January 2016, see www.world-nuclear-news.org/Articles/Vattenfall-seeks-to-return-reactors-to-profitabili. Actually, prices did then rise.

1040 - Prof. Kenichi Oshima, Personal Communications to Amory B. Lovins, 20 July 2019 and 1 , 3 and 7 August 2019; also 2018 update from REI's senior researcher Romain Zissler, Personal Communication to Amory B. Lovins, 4 July 2019.

1041 - Tomas Kåberger, Romain Zissler, "Solar PV cheaper than LNG-power in Japan makes massive deployment possible", Renewable Energy Institute, 26 May 2017, see www.renewable-ei.org/en/activities/column/20170526.html. REI's 2017 Expert Meeting dissected these policies.

previously served by nuclear power is already gone. If Japan didn't make nuclear units must-run, and began dispatching renewables in merit order, fossil-fueled generation would be largely squeezed out between efficiency and renewables. But are nuclear restarts even worthwhile? Only the owners know, but skepticism seems warranted.

A 2015 government study[1042] estimated average 2014 nuclear operating costs at ¥1,500/MWh (US$$_{2015}$12.6/MWh) for fuel including reprocessing, ¥3,500/MWh (US$$_{2015}$29.4/MWh) for O&M, and ¥400/MWh (US$$_{2015}$3.4/MWh) for additional safety measures (upgrades classifiable as Net Capital Additions). This total of ¥5,400/MWh (US$$_{2015}$45.4/MWh) excludes a further ¥1,300/MWh (US$$_{2015}$10.9/MWh) for policy measures (such as location grant and Monju surcharge) and ¥300/MWh (US$$_{2015}$2.5/MWh) for "costs for nuclear accident risk measures" (assuming an early Fukushima accident cost that was roughly half current estimates).

An 82-line-item compilation of the nuclear operating costs reported in the financial accounts of Japan's nine nuclear utilities for 2001–18[1043] is in reasonable agreement, averaging ¥6,350/MWh (in mixed nominal JPY)[1044] during 2001–10; whether that includes all net Capital Additions is unclear, but the total, more than US$$_{2015}$52/MWh, is similar to the operating costs for the costliest quartile of United States reactors documented in **Table 21**. After the Fukushima Daiichi accident began in 2011, Japanese operating costs soared to astronomical values due to low or zero output, then declined to a still-huge ¥25,000/MWh (US$$_{2018}$225/MWh) in 2018. In theory, that could scale back to roughly the pre-Fukushima ¥6,000/MWh (US$56/MWh) if Japan's nuclear share of total generation rebounded from 2018's 6 percent to the pre-Fukushima ~30 percent, but it can't, because about half of the units have been abandoned (see **Japan Focus** for details) and many durable new costs have been loaded onto the rest. The more units retire, the fewer will be left to share that burden—though the government will probably find ways to charge all electricity customers and taxpayers anyhow.

Leading Japanese experts also consider these cost estimates conservative, and note that Japanese utilities chose to close 12 reactors totaling almost 7 GW during 2015–19 (through April) as they faced safety-upgrade costs officially estimated to total just ¥60 billion (US$$_{2017}$0.5 billion) per reactor, equivalent to ¥600/MWh or ~US$5/MWh[1045]. Sure enough, a mid-2019 Japanese report[1046] based on surveys of the ten nuclear owners quintupled those safety upgrade costs from ¥0.9 trillion to ¥4.8 trillion (US$8.32 billion to US$44.2 billion)—on the order of US$1–1.5 billion per reactor.

Conversely, the same 2015 government study assumed utility-scale solar power costing ¥24,200/MWh (US$$_{2015}$200/MWh) in 2014 would cost ~¥14,000/MWh (US$$_{2015}$120) in 2030, while onshore wind power would fall from ¥21,600 to ~¥18,000/MWh (from US$$_{2015}$180 to ~US$$_{2015}$150/MWh); yet Japanese developers achieved those 2030 projections in 2019. Those prices are also manyfold higher than recent unsubsidized international bids that are now below

1042 - Power Generation Cost Analysis Working Group, "Report on Analysis of Generation Costs, Etc. for Subcommittee on Long-term Energy Supply-demand Outlook", Ministry of Economy, Trade and Industry, Provisional Translation, May 2015, see www.meti.go.jp/english/press/2015/pdf/0716_01b.pdf.

1043 - Using April–March Fiscal Years, Prof. Kenichi Oshima, Personal Communications to Amory B. Lovins, 1, 3 and 7 August 2019.

1044 - Considering the strong variation of the exchange rate over the period, a US$ value is not meaningful here.

1045 - Romain Zissler, "The Beginning of the End for Nuclear Power in France", Renewable Energy Institute, 16 November 2017, see www.renewable-ei.org/en/activities/column/20171116.html.

1046 - Suguru Kurimoto, "Nuclear safety costs in Japan surge to staggering heights", *Nikkei Asian Review*, 9 July 2019, see https://asia.nikkei.com/Business/Energy/Nuclear-safety-costs-in-Japan-surge-to-staggering-heights.

US$20/MWh or ¥2,100/MWh for both technologies, in resource zones not greatly inferior to Japan's (see **Figure 51** above and **Nuclear Power vs. Renewable Energy Deployment**). Thus even pre-Fukushima nuclear operating costs, let alone much higher post-Fukushima ones, can beat Japan's artificially inflated 2019 renewable prices, but would lose to globally competitive ones.

It would therefore appear that average Japanese nuclear operating costs are so uncompetitive with unconstrained solar and wind power that wide nuclear restarts would require intensified suppression of renewable development in Japan, contrary to the government's 2019 Basic Energy Plan, and reversal of current policies to promote free competition in liberalized power markets. This comparison does not count further repairs and upgrades likely to be needed to restart many plants that have been shut down for years, and it assumes that restarted plants will run reliably for decades more without significant mishaps.

South Korea

Though operating costs in Korea are not transparent, the EPSIS online database reports[1047] the regulated settlement prices that nuclear plants receive on the Korea Power Exchange—based not on competition but on annual reviews of fixed costs and monthly reviews of fuel costs by the Generation Cost Assessment Committee, comprising mainly interested parties, based on submissions by the generators. In nominal US$ (not adjusted for inflation), the administered nuclear prices held nearly steady around US$34/MWh during 2001–13, rose to US$59/MWh in 2016, then slightly decreased again to US$54/MWh. These prices include fuel costs that rose from ~US$2.8/MWh before 2010 to US$5/MWh in 2018. O&M and Net Capital Additions data do not seem to be available. Subtracting the reported capacity payment[1048] of KRW9.15–10.07/MWh (US$7.9–8.7/MWh) from the US$54/MWh total payment in 2018 implies that regulated operating-cost payments may be around US$45/MWh—high enough to call into question nuclear operations' competitiveness with renewables and certainly with efficiency.

However, US$45/MWh is about 2.5 times the operating cost reported by South Korean officials to the OECD's Nuclear Energy Agency (NEA)[1049] as US$18.2/MWh.[1050,1051] Thus South Korean nuclear operating costs are incompletely reported, just like the South Korean construction costs that several scholars found unanalyzable[1052]—useful to recall when low values are cited.

1047 - KPX, "EPSIS–Settlement > by Fuel Type", Undated, see http://epsis.kpx.or.kr/epsisnew/selectEkmaStmBftChart.do?menuId=050601&locale=eng.

1048 - Joonki Yi, Chin Pyo Park, "Electricity Regulation in South Korea", Bae, Kim & Lee LLC, 26 March 2019, see www.lexology.com/library/detail.aspex?g=4a7f6594-b6b4-4249-a928-a0e02ed683e5.

1049 - IEA/NEA, "Projected Costs of Generating Electricity 2015", September 2015, op. cit.

1050 - NEA says South Korea's 2015 levelized cost of nuclear energy was US$201351.37/MWh at a 10 percent discount rate. That includes fuel and waste costs of US$8.58/MWh, O&M of US$9.65/MWh (apparently all variable, as it does not depend on discount rate), refurbishment (apparently equivalent to Net Capital Additions) of zero, and decommissioning of zero. That value also does not seem to include provisions for the compensation fund (limited accident insurance), probably waste management, or lifetime extension.

1051 - Vara Ha, "Nuclear Power Plant Policy Comparison between the U.S. and Republic of Korea", International Development, Community and Environment (IDCE), Clark University, 17, May 2016, see https://commons.clarku.edu/idce_masters_papers/17.

1052 - See MIT Energy Initiative, "The Future of Nuclear Energy in a Carbon-Constrained World", op. cit., pp 34–35: "Of greatest concern are data from the Chinese and South Korean builds, where a lack of transparency and detail makes it difficult to scrutinize and validate available cost estimates. For example, there is some uncertainty in the cost of the South Korean build in the United Arab Emirates because it may not include all of the owner's cost…." See also p 223.

Similarly, operating-cost data exist for China, now the world's third largest fleet, and Russia, the fifth largest, but are unavailable to independent analysts and are considered unreliable without extensive but published supporting detail.

Climate Implications of Substantial Nuclear Operating Costs

The foregoing evidence suggests that closing many, perhaps most, operating nuclear units will not directly save CO_2, but can indirectly save *more* CO_2 than closing a coal-fired plant, *if the nuclear plant's larger saved operating costs are reinvested* in efficiency or cheap modern renewables that in turn displace more fossil-fueled generation. Therefore, closing *both* coal plants *and* costly-to-run nuclear plants (with reinvestment of avoided operating costs and subsidies) makes sense—the former to save carbon directly, and the latter to save money whose climate-effective reinvestment can then save more carbon.

> *"closing both coal plants and costly-to-run nuclear plants makes sense"*

Specifically, using the latest available U.S. data shown above (for 2014–16), half the operating U.S. reactors had average operating costs over US$40/MWh, one-fourth over US$51/MWh. These generating costs can all be avoided by closing the reactors[1053]. So can the billions of dollars' new subsidies to induce those plants' owners to keep them running, such as US$16.5/MWh in Illinois (see **United States Focus** and Annex 4 in WNISR2018 for a state-by-state analysis). Those avoided costs can then be reallocated, voluntarily by the owner or compulsorily by regulators, to more climate-effective investments that cost less and hence save more carbon per dollar. To make up a simple example:

> If a reactor costing US$50/MWh (US$5¢/kWh) to run is closed, the regulator can require the saved operating cost (ignoring any avoided subsidy) to be reinvested in helping customers use electricity more efficiently. If that efficiency investment costs the utility a typical average of US$25/MWh (US$2.5¢/kWh), two kWh will be saved for each nuclear kWh not generated, saving twice as much carbon and thus doubling climate-effectiveness. Shopping carefully for 1¢/kWh efficiency could stretch that advantage to fivefold.

Renewables at those prices could do the same and are interchangeable with efficiency, but efficiency is already delivered to the retail customer, avoiding delivery costs averaging ~US$41/MWh. Even if most of that delivery cost is fixed and sunk, efficiency adds value by freeing existing grid assets to serve new loads without building more facilities.

This argument about "climate opportunity cost," straightforwardly applying bedrock economic principles, has been published but ignored for more than a decade, and lately elaborated in the *Electricity Journal*.[1054] The nuclear industry, like nearly all financial and economic reportage (and now the IEA), instead describes the uncompetitiveness of its product as a market failure—a claim that the market does not properly recognize or value nuclear power's low-carbon generation. Its increasingly adopted remedy—new state-level long-term subsidies for

1053 - Decommissioning costs must be paid later anyhow, and increase with longer operation. Greater discounting for later timing affects accounting values but not real resource costs.

1054 - Amory B. Lovins, "Do coal and nuclear generation deserve above-market prices?", *The Electricity Journal*, July 2017, op. cit., §2.

nuclear power alone, with little or no showing of financial need, no competition, and often a disruptive prompt-closure gun held to the legislators' heads—does not correct a market failure but creates it.[1055] It is a deliberate and direct attack on the very markets that are rejecting nuclear power in favor of its cheaper competitors.

The new around-market subsidies restrict competition, slow innovation, and destroy market mechanisms painstakingly built over decades to guide efficient choices. The new subsidies also "distort pool-wide prices, crowd out competitors, discourage new entrants, destroy competitive price discovery, reduce transparency, reward undue influence, introduce bias, pick winners, and invite corruption."[1056] Two deans of electricity regulation warned such targeted subsidies may "unravel U.S. power markets altogether."[1057] This is a high price to pay for results that a superior market-based way to acquire low- or no-carbon resources could readily yield without burdening customers or taxpayers. It is also intrusive and unnecessary. No political intervention to go around markets is needed or appropriate if existing markets are properly used. As the eminent retired utility and nuclear regulator Peter Bradford counsels,

> Instead of having political leaders and regulators make pin-the-tail-on-the-donkey-type[1058] guesstimates of how much nuclear power we'll need, how long we'll need it, and how much we should pay for it, we should adjust our power markets to procure the needed low-carbon electricity. Beyond that, we can regulate emission results where necessary. We should minimize mandating the continued use of existing power plants. Instead, our power markets can prioritize low-carbon technology just as they have proven themselves capable of doing with reliability and demand response.[1059]

The new nuclear subsidies have convulsed state politics, scrambled federal grid regulation, distracted market actors from doing their jobs, and damaged competition, competitors, customers, and markets to achieve only a slight climate effect. The 13 reactors so far rescued or likely to be rescued for some number of years generate a few percent of U.S. electricity and will likely be matched in output by a few years' renewable growth; indeed, those low-carbon renewables would otherwise have increasingly occupied the same market space if allowed to (Midwest wind power developers complain of blocked grid access meant to shield legacy assets from competition). Any climate benefit is also temporary, because the relentless drop in renewable prices will once more undercut nuclear costs.

Often unnoticed is that climate is just the latest of many rationales successively adduced for customers to pay again for the same assets. First, the nuclear industry was created, its fueling infrastructure built, and the reactor fleet financed by a vast array of often-opaque taxpayer-funded federal subsidies that rivaled or exceeded the plants' construction cost and

1055 - Peter A. Bradford, "Wasting time: Subsidies, operating reactors, and melting ice", *Bulletin of the Atomic Scientists*, Volume 73, 12 December 2016, see https://doi.org/10.1080/00963402.2016.1264207.

1056 - Amory B. Lovins, "Do coal and nuclear generation deserve above-market prices?", *The Electricity Journal*, July 2017, op. cit.

1057 - The United States District Court for the Southern District of New York, "Wood And Bradford's Amicus Brief", Case 1:16-cv-08164-VEC, Doc. 125-1, Filed 24 March 2017, posted in Tim Knauss, "NY nuclear subsidies kick in Saturday, but high-stakes legal challenge looms", *Syracuse.com*, 27 March 2017, see www.syracuse.com/news/index.ssf/2017/03/ny_nuclear_subsidies_kick_in_saturday_but_high-stakes_legal_challenge_looms.html.

1058 - An old American party game in which a series of blindfolded children, spun around to disorient them, try to pin a paper tail onto the back end of a wall-mounted picture of a donkey.

1059 - Peter A. Bradford, "Wasting time: Subsidies, operating reactors, and melting ice", Bulletin of the Atomic Scientists, December 2016, op. cit.

exceeded the value of their output.[1060] Second, decades of regulated electricity tariffs already covered the plants' entire construction, financing, and operating costs, including a just and reasonable return on investment. Third, when owners like Illinois-based Exelon (the largest U.S. nuclear operator) later insisted on creating competitive wholesale markets where they expected to earn more profit than under regulation, customers reimbursed them for the "transition costs" (excess capital costs) of stranded assets totaling ~US$135 billion[1061], mostly—at least US$70 billion—for nuclear plants. Then, when many nuclear plants couldn't compete in those wholesale markets, the owners (while reporting robust profits to Wall Street) demanded and generally got from their host states new multi-billion-dollar-a-year subsidies to keep running their distressed reactors. Then Exelon's successful request to Federal regulators for greater capacity payments—because many plants couldn't clear power-pool auctions, and the state subsidies had upset the delicate balance between state and federal regulation—harvested a fifth stream of payments.

The owners naturally try to get paid as much and as many times as possible for the same assets, and they're doing so with great skill and formidable political muscle. The climate emergency offers them a new opportunity for payment, so long as decisionmakers focus only on carbon, not dollars. But why should electricity markets and climate protection become collateral damage—the practical effect of escalating nuclear subventions? How could the agreed goal of climate protection instead be achieved by technology-neutral market mechanisms that let nuclear power compete fully and fairly with other solutions?

PRACTICAL SOLUTIONS FOR CLIMATE-EFFECTIVENESS

An obvious and attractive process would be for power pools or other authorities to run an annual series of laddered all-resource auctions to elicit bids for demand- or supply-side carbon-saving electrical resources. Connecticut has already established such a low-carbon-resources auction, though only on the supply side—a big omission, since a third of the U.S. does compete demand-side options in normal all-resource auctions, and an unbought efficiency potential four times total U.S. nuclear output costs less than one-third as much as the average U.S. nuclear

1060 - In 2011, Doug Koplow assessed these at ~US¢0.8–4.6/kWh for shareholder-owned and US¢1.7–6.3/kWh for public utilities, excluding ~US¢8.3/kWh of historic subsidies that originally launched the U.S. nuclear enterprise, see Doug Koplow, "Nuclear Power: Still Not Viable Without Subsidies", Earth Track Inc, Union of Concerned Scientists, February 2011, see http://www.ucsusa.org/nuclear-power/cost-nuclear-power/nuclear-power-subsidies-report, accessed 30 August 2019. New U.S. nuclear plants already get slightly higher federal operating subsidies per kWh than new U.S. wind farms, plus far larger capital subsidies (~US¢5–12/kWh); even existing nuclear plants' capital subsidies often exceed the wholesale price they receive. And historically, nuclear power has been far more subsidized per kWh than renewables. See Nancy Pfund, Ben Healey, "What Would Jefferson Do?—The Historical Role of Federal Subsidies in Shaping America's Energy Future", DBL Investors, September 2011, see http://i.bnet.com/blogs/dbl_energy_subsidies_paper.pdf, as cited in Jeff Johnson, "Long History Of U.S. Energy Subsidies", Chemical & Engineering News, Volume 89, Issue 51, 19 December 2011, see https://cen.acs.org/articles/89/i51/Long-History-US-Energy-Subsidies.html, accessed 19 July 2019.

1061 - B.A. Holden, "Deregulation May Cost Electric Utilities US$135 Billion Over 10 Years, Study Says", *The Wall Street Journal*, 7 August 1995, summarizing P.B. Fremont & R.K. Hornstra, "Stranded Costs Will Threaten Credit Quality of U.S. Electrics", Moody's Investors Service Research, August 1995. The US$70 billion estimate is from M.D. Yokell, D. Doyle & R. Koppe, "Stranded Nuclear Assets and What to Do About Them", Presentation to DOE-NARUC Electricity Forum, April 1995, cited by Office of Coal, Nuclear, Electric and Alternate Fuels, "Changing Structure of the Electric Power Industry: An Update", DOE/EIA-0562 (96), Department of Energy, U.S.EIA, December 1996, p.79, which said nuclear stranded costs could decline to US$43–63 billion if restructuring were completed by 1996 or 2000 respectively.

operating cost[1062]. California also acquires resources by competitive bid, and plans to use that process to replace the retiring Diablo Canyon nuclear units with other low-carbon resources at least cost.

> *"an unbought efficiency potential four times total U.S. nuclear output costs less than one-third as much as the average U.S. nuclear operating cost"*

Continued nuclear operations might initially win such auctions, perhaps for a year or two, until cheaper new efficiency and renewables could ramp up (a delay of virtually no or even favorable climate consequence, as discussed below), but ultimately the market, not state legislators, would choose the cheapest ways to avoid the most time-integrated carbon.

Another economically sensible way to enable low-carbon resources to compete fairly with gas-fired combined-cycle power plants would be for market-makers and regulators to count the market value of fuel-price volatility[1063] when comparing fossil-fueled with constant-price resources, notably efficiency and renewables, whose price is set 20–30 years ahead by contract (making those assets financially riskless except insurable and diversifiable counterparty risk). Basic financial economics absolutely requires such risk adjustment; ignoring it—today's common practice—is guaranteed to misallocate risk and capital. Counting fuel-price volatility would probably help nuclear power compete with natural gas even more than carbon pricing could, so it's puzzling that the nuclear industry isn't backing this reform.

However, even without this risk adjustment, and even with low-priced U.S. fracked gas, the once-strong business case for new and even most existing combined-cycle gas plants has collapsed: a "clean portfolio" of efficiency, flexible demand, renewables, and storage can provide all the same outcomes more cheaply and without CO_2.[1064] Even some new gas-fired plants in gas-rich Texas are going broke. Contrary to old assumptions that solar power is more capital-intensive up front than gas power, today they have nearly identical cashflow profiles. Both in the U.S. and in countries with costlier natural gas, whether or not dangerous methane escape is properly valued and abated, and with or without nuclear power, long-run gas-fired generation and its climate impact look likelier to trend down than up.

Pricing carbon and counting the market value of price volatility would help nuclear power to compete against natural gas and coal—but not against modern renewables or efficiency, because they emit no carbon and burn no fuel. The nuclear industry tends to blame its competitive woes more on gas than on renewables[1065], which it often seems reluctant to recognize as a legitimate and effective competitor—perhaps because that would call into

1062 - Amory B. Lovins and Rocky Mountain Institute, "Reinventing Fire—Bold Business Solutions for the New Energy Era", 2011. It found that "efficient end use, using 2010 technologies adopted at a historically reasonable pace, could quadruple 2010 electric end-use efficiency by 2050 at an average levelized technology cost of US$20170.72¢/kWh, i.e.<1¢ including normal transaction costs"; see Amory B. Lovins, "Response to D. Murphy & M. Berkman, 'Efficiency and nuclear energy: Complements, not competitors, for a low-carbon future", Electricity Journal, Volume 30, Issue 8, October 2017, see https://doi.org/10.1016/j.tej.2017.09.012.

1063 - Amory B. Lovins, Jon Creyts, "Hot Air About Cheap Natural Gas", Rocky Mountain Institute, 6 September 2012, see https://rmi.org/hot-air-cheap-natural-gas/.

1064 - Mark Dyson et al., "The Economics of Clean Energy Portfolios", Rocky Mountain Institute, May 2018, see https://rmi.org/insight/the-economics-of-clean-energy-portfolios/.

1065 - The 2018 MIT nuclear study previously cited considers competitiveness only against coal or gas, not renewables or demand-side resources. Solar and wind competition is later considered only under outdated and constrained assumptions unrelated to modern energy system design. See MIT Energy Initiative, "The Future of Nuclear Energy in a Carbon-Constrained World", 2018, op. cit.

question many nuclear advocates' claims (reviewed above) that renewable power at scale is infeasible[1066], requiring nuclear "baseload" power for grid stability. But competitors can win whether or not you believe they work. Claims that renewables can't scale will become as discredited by increasingly ubiquitous real-world experience as claims that climate change is a hoax. And if carbon is properly priced, nuclear power will remain as exposed as now to its most formidable competitors—low-carbon renewables and efficiency.

Substitution for Existing Nuclear Plants: 5 Case Studies from the U.S.

In substituting non-nuclear low-carbon resources for nuclear power, one timing issue bears mention. Closing a nuclear plant is often claimed to increase CO_2 emissions by requiring an immediate, and impliedly a long-term, shift to fossil-fueled generation, typically by natural gas. Five U.S. states where reactors were rather hastily closed were analyzed by the Union of Concerned Scientists (UCS)[1067] to test this hypothesis through 2017 (with efficiency data through 2016 and power-sector CO_2 data through 2015):

- **Nebraska**'s time-series was too short to be meaningful, as the Fort Calhoun reactor was only closed in October 2016.
- **Wisconsin** closed the Kewaunee reactor May 2013, cutting nuclear generation by 5 TWh/y. In addition, it cut coal-fired generation by 5 TWh/y. It substituted 5 TWh/y with gas-fired generation and 3 TWh/y with efficiency plus renewables (three-fourths of the nuclear loss), and cut power-sector CO_2 emissions 4 percent.
- **Florida**, another state with relatively unfavorable policies, closed Crystal River-3 in September 2009, lost 3 TWh/y (vs. 2008) net of 0.4 GW of upratings, raised gas-fired generation by 57 TWh/y, cut coal-fired by 16 TWh/y, raised efficiency and renewables by 4 TWh/y, and cut 2008–15 power-sector CO_2 emissions by 11 percent.
- **California**, with strong efficiency and renewable policies and institutions, closed the two San Onofre reactors in January 2012, losing 19 TWh/y, while cutting both coal-fired generation (by 2 TWh/y) and gas-fired (by 0.1 TWh/y), but also raised efficiency and renewables by 47 TWh/y or 2.5 times the nuclear loss, which it erased by the end of 2014; power-sector CO_2 emissions fell 7 percent during 2009–15 (not measured from the exceptionally high-hydro, low-gas year 2011).
- In the two years after **Vermont** Yankee closed in December 2014, that hydro-dominated state cut gas generation, raised other generation, raised efficiency and renewables, and put its tiny power-sector CO_2 emissions back into decline. A separate Rocky Mountain Institute analysis of data for the whole New England power pool (ISO-NE) found that during 2015–16, the nuclear loss was offset 91 percent by renewables and hydro-dominated

1066 - The nuclear industry's positioning itself as a carbon-free replacement for coal and gas power when seeking U.S. state subsidies on climate grounds also sits uneasily with its alliance with coal when seeking US federal subsidies based on the current administration's fondness for both coal and nuclear plants' supposedly resilient attributes. Many major utilities also own both nuclear and coal plants.

1067 - Steve Clemmer, UCS, personal communication, 6 October 2018.

imports *plus* another 69 percent by reduced sales; the pool's CO2 emissions rose by one-tenth as much as the 2001–15 reduction, but only for a little over one year.[1068]

Such comparisons are complex and sometimes ambiguous due to interfering effects such as price-driven fuel-switching. Nonetheless, this state-level evidence suggests that *if* abrupt nuclear closure raises CO_2 by switching from nuclear to fossil generation, that rise lasts just a few years—or less in states that allow and encourage efficiency and renewables to compete fully with fossil-fueled generation.

Even this temporary CO_2 blip can be avoided altogether by providing enough lead time for orderly replacement of retiring nuclear units. Nuclear owners have tended to threaten abrupt closure that would emit more carbon (even if temporarily), cause political shocks from job losses, and perhaps disrupt grids, all in the hope of pressing politicians to provide new subsidies. In essence, such extortionate tactics hold the climate, for which the owners express such concern, hostage to short-term commercial gain. But responsible and accountable owners can and do take the opposite course. Pacific Gas and Electric Company (PG&E) and its stakeholders all agreed to an 8–9-year closure lead time for Diablo Canyon[1069]—similar to the planned phase-out in Germany (see **Figure 27**)—leaving ample time to ramp up competitive procurement of low-carbon replacements and honorable transitions for workers and communities.

Temporarily burning more gas while efficiency and renewables fill a brief nuclear-retirement gap is also unimportant, because most surplus gas-fired plants are very efficient and CO_2's effects are long-term[1070]: what matters is its *cumulative* long-term release. Gas abatement by efficiency and renewables will last far longer than the retired (generally elderly) nuclear plant's remaining economic life, so the abatement will be at least equal in quantity but longer-lasting, bringing greater climate benefit. Moreover, where efficiency or renewables cost less than continued nuclear operations and are bought instead, that shift will save more carbon per dollar. On both cost *and* speed, therefore, the time-integrated climate benefit will exceed the climate benefit of continued nuclear operation.

NON-NUCLEAR OPTIONS SAVE MORE CARBON *PER YEAR*

If new or old nuclear power is generally not cheaper than efficiency and renewables, and hence cannot save as much carbon per dollar, might it still be desirable or necessary because it's faster to deploy at scale to help deal with the climate emergency? That claim is often made but seldom analyzed. For the past decade, WNISR has been illustrating the fact that renewables have been outpacing nuclear in added kilowatt-hours year after year (e.g. **Nuclear Power vs. Renewable Energy Deployment** and **Figure 40**, **Figure 41** and **Figure 42**). In 2016, a nuclear advocacy group suggested that in some countries *historically* nuclear power would have been rolled out faster than renewables. That image of nuclear power's allegedly rapid deployment speed has been encapsulated by The Breakthrough Institute and promoted by a *Science*

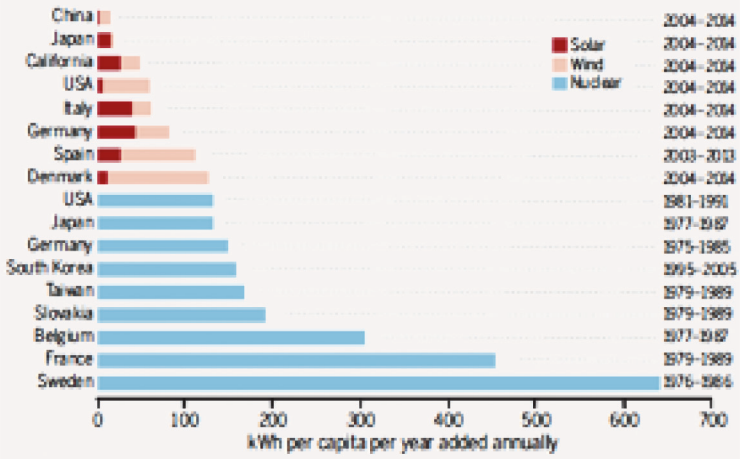
1068 - ISO New England, "Net Energy and Peak Load Report", Editions 2000, 2015 and 2016, see www.iso-ne.com/isoexpress/web/reports/load-and-demand/-/tree/net-ener-peak-load, accessed 7 May 2017.

1069 - Amory B. Lovins, "Closing Diablo Canyon Nuclear Plant Will Save Money and Carbon", *Forbes*, 22 June 2016, op. cit.

1070 - The opposite is true of associated methane releases, but the gas infrastructure is already in place, U.S. gas is in surplus, and little or no upstream development will be required to fuel the brief extra gas burn.

paper[1071], which received withering technical criticism[1072]. Its key meme claims that nuclear growth is generically "much faster" than renewable growth (see **Figure 52**):

Figure 52 | Average Annual Increase of Nuclear, Wind, and Solar—Using Breakthrough Institute Methodology



Average annual increase of carbon-free electricity per capita during decade of peak scale-up. Energy data from (6) except California renewables data from (7). Population data from (8). See supplementary materials.

Source: Cao *et al.*, *Science*, 5 August 2016, Op. Cit.

Rocky Mountain Institute's Amory B. Lovins[1073] has redrawn that seemingly convincing graph—adopting for the sake of argument its highly problematic per-capita metric—to correct its many analytic errors and include its omitted same-country comparisons, where seven of ten countries grew renewables faster than they grew nuclear (see **Figure 53**).[1074] Here we update that corrected graph with three more years' data (2016–18). While the previous chart implies that all nuclear programs outpace all renewable programs, the next chart shows no clear advantage to either—but the rapid nuclear growth was decades ago and long ended, while the rapid renewable growth is here, now, and accelerating (see **Nuclear Power vs. Renewable Energy Deployment**).

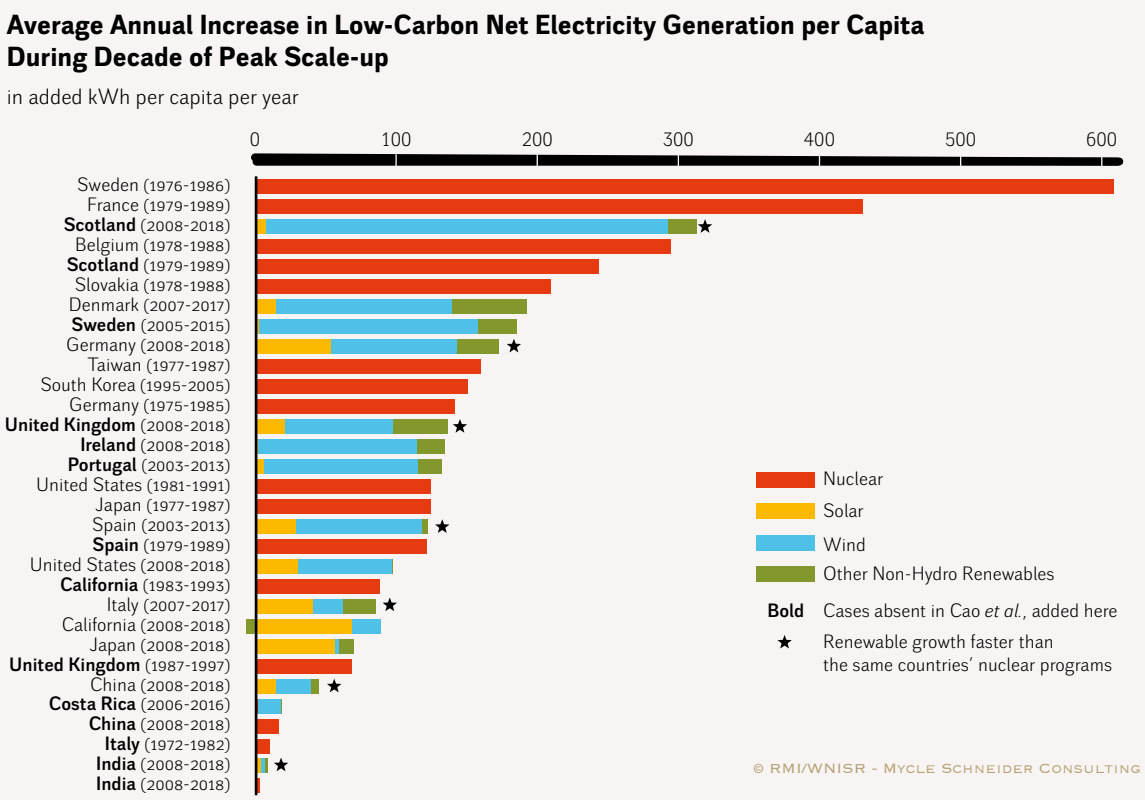
1071 - Junji Cao, Armond Cohen, et al., "China-U.S. cooperation to advance nuclear power", *Science*, Volume 353, 5 August 2016, see https://doi.org/10.116/science.aaf7131.

1072 - Philip Johnstone, Benjamin K. Sovacool, et al., "Nuclear power: serious risks", *Science*, Volume 354, 02 December 2016, see https://doi.org/10.1126/science.aal1777 ; Amory B. Lovins, "Nuclear power: deployment speed", *Science*, Volume 354, 2 December 2016, see https://doi.org/10.1126/science.aal1808 ; Junji Cao, Armond Cohen, et al., "Nuclear power: Deployment speed—Response", *Science*, Volume 354, 2 December 2016, see https://doi.org/10.1126/science.aal2561; Amory B. Lovins, T. Palazzi, et al., "Relative deployment rates of renewable and nuclear power: A cautionary tale of two metrics", *Energy Research & Social Science*, Volume 38, April 2018, see https://doi.org/10.1016/j.erss.2018.01.005; Amory B. Lovins, "Corrigendum to 'Relative deployment rates of renewable and nuclear power: A cautionary tale of two metrics'", *Energy Research & Social Science*, Volume 46 (correcting a minor Supplementary Materials point affecting no content in the main paper), December 2018, see https://doi.org/10.1016/j.erss.2018.08.001.

1073 - Amory B. Lovins is a contributing author to WNISR2019.

1074 - Amory B. Lovins, "Corrigendum to 'Relative deployment rates of renewable and nuclear power: A cautionary tale of two metrics'", *Energy Research & Social Science*, Volume 46, December 2018, see https://doi.org/10.1016/j.erss.2018.08.001.

Figure 53 | Average Annual Increase of Nuclear, Wind, and Solar—According to Rocky Mountain Institute*



Sources: Various (see citation), compiled by Amory B. Lovins, Rocky Mountain Institute, July 2019[1075]

Note

*This graph represents RMI revision of Cao et al.'s Figure S2. See Figure 52.

The same nine nuclear and eight renewable cases are shown; seven nuclear (Scotland, Spain, California, United Kingdom, Italy, China, and India) and seven renewable cases (Scotland, Sweden, Ireland, Portugal, United Kingdom, Costa Rica, and India) are added (bold), using data through 2015. Scotland is part of the UK grid and electricity market, and its nuclear plants were built under UK policy, but Scotland does have autonomy in choosing renewable energy, which grew faster per capita.

This chart was first described, documented, and published in A.B. Lovins, "Corrigendum to 'Relative deployment rates of renewable and nuclear power: a cautionary tale of two metrics'", *Energy Research and Social Science*, 2018, 38:188–192, doi: 10.1016/j.erss.2018.08.001, then updated through 2018 by Jacob W. Glassman using the mid-2019 versions of the same data sources.

Through 2015, modern renewable energy globally was growing faster than nuclear power ever had; through 2018, ten countries moved up in the chart. The world's most aggressive nuclear program (in China) has been outgenerated by China's wind power since 2013, and 2.2:1 by China's non–hydro renewable portfolio in 2018. The corresponding Indian factor is 3.1-fold. (See also **Nuclear Power vs. Renewable Energy Deployment**.) Though the Swedish and French nuclear power programs were uniquely aggressive relative to those nations' populations, those programs were not economically successful—France can scarcely afford to modernize its existing nuclear fleet, let alone replace it—and both nations are now shrinking nuclear and growing renewables to fit today's economics, politics and EU legal obligations.

Deployment speed depends on both installation rate and project lead time. A new assessment[1076] finds that new nuclear plants take 5–17 years longer to build than utility-scale

1075 - All data shown are from BP, "Statistical Review of World Energy 2019", except for Costa Rica and Scotland, taken from online national statistics. BP nuclear outputs are divided by 1.0546 to convert gross to net.

1076 - Mark Z. Jacobson, "Evaluation of Nuclear Power as a Proposed Solution to Global Warming, Air Pollution, and Energy Security", *Cambridge University Press*, 15 June 2019, see https://web.stanford.edu/group/efmh/jacobson/WWSBook/WWSBook./html.

solar or onshore wind power, so existing fossil-fueled plants emit far more CO_2 while awaiting substitution—62–102 gCO_2/kWh more, equivalent to 11–18 percent of average U.S. grid carbon intensity; thus if China had invested its nuclear capital in wind power instead, the quicker deployment could have cut its CO_2 emissions by ~3–6 percentage points. While some may quibble about calculational details, these estimates suggest a sound principle—a significant climate penalty for buying slow rather than fast resources. For resources that are both slow *and* costly, that climate opportunity cost is compounded.

> *"If nuclear power is neither cheaper nor faster than modern renewables and energy efficiency, it fails both tests of climate-effectiveness, so its substitution would reduce and retard climate protection"*

In addition, in illustrative countries with major nuclear power programs, the institutional "formative phases" needed to support scaleup took about 30 years (in France and China—the two most concerted efforts), compared with nine years for comparable renewable milestones (in China and Germany)[1077]. The extra twodecade delay for countries lacking mature nuclear institutional and industrial infrastructures would make their nuclear scaleup far too late.

If nuclear power is neither cheaper nor faster than modern renewables and energy efficiency, it fails both tests of climate-effectiveness, so its substitution would reduce and retard climate protection. How does that square with continued calls for nuclear continuation and expansion, on grounds that over decades have evolved from replacing insecure oil to replacing polluting coal to fighting poverty and protecting the Earth's climate?

IS NUCLEAR POWER A CLIMATE IMPERATIVE?

Michael Liebreich, an eminent energy commentator who founded and led the data and analytic pioneer Bloomberg New Energy Finance (BNEF), recently encapsulated many popular arguments that despite nuclear power's acknowledged challenges, its continued use is vital for climate protection.[1078] In paraphrase: After investments nearing US$3 trillion, solar and wind power supply just 7 percent of the world's electricity. Solar and wind power are unlikely to add as much capacity in the next decade—2–4 times their growth so far—as basic climate goals require. Decarbonizing heating, transport and industry proportionately would need even more electricity, raising that goal to 10–15-fold (or 5–10-fold with more-efficient use). So to "have any hope of...[2C°, let alone 1.5C°], we need to keep as many existing nuclear power stations as possible operating, and to extend their lives for as long as possible," though new-builds should switch to Small Modular Reactors or other designs yet to be developed.

In fact, nobody claims that just wind and solar, or efficiency, or any single option, can "decarbonize the economy in the near term". Though solar and wind are ~84 percent of recent non-hydro *electric* capacity additions, modern (excluding big hydro) renewable *energy* not

1077 - Amory B. Lovins, Titiaan Palazzi, et al., "Relative deployment rates of renewable and nuclear power: A cautionary tale of two metrics", *Energy Research & Social Science, Volume 38*, April 2018, see https://doi.org/10.1016/j.erss.2018.01.005.

1078 - Michael Liebreich, "Liebreich: We Need To Talk About Nuclear Power", Bloomberg New Energy Finance, 3 July 2019, see https://about.bnef.com/blog/liebreich-need-talk-nuclear-power.

only outgenerates nuclear electricity, but also covers three-fourths more global final *energy* consumption (in all forms, not just electricity) than nuclear power delivers after 65 years' effort.[1079]

The math about needing far more electricity to decarbonize all sectors appears to double-count difficulties. Electric cars and trucks are severalfold more efficient than fueled ones, and severalfold more efficient still if light and low-drag[1080]; with smart charging, electric vehicles wouldn't need materially more electric capacity, but could earn back (some practitioners assert) up to half their sticker price by selling their distributed storage's valuable services back to the grid. Likewise, the far greater efficiency of modern electric heating and cooking can cut primary energy use by several- to manyfold, saving fossil fuels both in direct use and in power generation.

Liebreich overlooks important parallel abatements of greenhouse gases other than CO_2: *e.g.*, OECD's International Energy Agency (IEA)[1081] says upstream hydrocarbon industries can *profitably* abate methane emissions sufficient to stabilize the global methane cycle—equivalent, if sustained to 2100, to instantly abating every Chinese coal-fired power plant's emissions. Such complementary efforts can shrink the climate challenge and buy more time to abate carbon emissions.

The models that simulate ways to reverse climate change were at least as conservative as the climate-science models that predict it, especially understating the practical scope for profitable energy efficiency[1082]. Liebreich assumes only modest efficiency. IPPC's 1.5°C Special Report[1083] features an important 2018 low-energy-demand scenario[1084] that robustly reaches 1.5° with no overshoot, no engineered carbon-removal technologies, and severalfold lower supply investments. Yet it looks technically conservative in both demand and supply. The latest evidence across all sectors[1085] reveals that the energy efficiency resource is severalfold bigger and cheaper than had been thought, and can often yield increasing returns, just like modern renewables. Thus an efficiency-centric approach makes Liebreich's daunting renewable expansions much smaller, easier, and cheaper.

1079 - REN21, "Renewables 2019–Global Status Report", June 2019, see www.ren21.net, shows from IEA data that modern renewables—which exclude hydropower (3.6 percent) and traditional biomass (7.5 percent)—covered 7 percent of the world's total final energy consumption in 2017: modern renewable heat 4.2 percent, non-hydro electricity 2.0 percent, and mobility biofuels 1 percent. For electricity generation alone at the end of 2018, nuclear power provided 10 percent, vs. wind 5.5 percent, photovoltaics 2.4 percent, biopower 2.2 percent, geothermal and others 0.4 percent—a total of 10.5 percent, excluding 15.8 percent from hydropower (of which roughly a fifth is small hydro, <50 MW, which most analysts consider a modern renewable source).

1080 - Amory B. Lovins, "Oil-Free Transportation", AIP Conference Proceedings, Volume 1652:129–139, 2 April 2015, see https://doi.org/10.1063/1.4916175; Transportation Research Board, "Superefficient Vehicles and Easier Electrification", January 2018 annual meeting, session 466, presentation P18-21428, see http://amonline.trb.org/2017trb-1.3983622/t009-1.3999602/466-1.4125818/p18-21428-1.4116638/p18-21428-1.4125823?qr=1; Amory B. Lovins, "Reframing Automotive Fuel Efficiency", in journal review, 2019.

1081 - IEA, "World Energy Outlook 2017", Chapter 10, pp. 399–436, see https://webstore.iea.org/world-energy-outlook-2017.

1082 - Amory B. Lovins, Diana Ürge-Vorsatz, et al., "Recalibrating Climate Prospects", *Environmental Research Letters*, in review as of August 2019. Nearly all Integrated Assessment Models greatly understate efficiency potential, and none properly models and can account for actual renewable growth.

1083 - IPCC, "Special Report: Global Warming of 1.5°C", 2018, op. cit.

1084 - Arnulf Grübler, Charlie Wilson, et al, "A Low Energy Demand Scenario for Meeting the 1.5°C Target and Sustainable Development Goals without Negative Emission Technologies", Nature Energy, 3:517–525 , 4 June 2018, see https://doi.org/10.1038/s41560-018-0172-6. Rocky Mountain Institute plans 2019 publications showing the technical conservatism of some key assumptions, particularly in mobility and industry.

1085 - Amory B. Lovins, "How big is the energy efficiency resource?", *Environmental Research Letters*, 13:090401, 18 September 2018.

Yet his essay does help focus on important questions about cost, timing, and decision making. First, cost: Shouldn't investments seek to deliver the most climate solution with limited money? Life-extending existing reactors, let alone building more, would fail that basic test.

Next, speed: How can new reactors help meet Liebreich's 2030 need when it takes about that long to build one and far longer to build hundreds or thousands? when newcomer countries need two decades more to build the institutions for nuclear than for renewable scaleup? and when only a few outlier countries (even using the deeply flawed per-capita metric) have ever built nuclear faster than they built renewables? Liebreich therefore suggests new kinds of reactors, allegedly quicker to license and build; but how is it a practical and urgent climate solution to divert massive public resources from proven, off-the-shelf energy options to speculative reactor types and fuel chains that do not exist, may never exist, have unknown costs and public acceptance, and (history suggests) will take one or more decades just to develop and test (see **Small Modular Reactors**)? Aren't resources, attention, and time devoted to nuclear new-build therefore diverted from faster and more climate-effective solutions?

The first TW of modern renewables, excluding the 1 TW of hydropower existing in 2013, took about 15 years to install to mid-2018. BNEF expects the second TW will take ~5 years, to 2023, but cost 46 percent or ~US$1 trillion less.[1086] It won't stop there (see **Nuclear Power vs. Renewable Energy Deployment**). If the increasing returns that drive this exponential growth are even partly sustained, as most experts expect, order-of-magnitude scaleups of solar and wind power by 2030 are reasonable[1087], and have already been achieved or surpassed in industries like semiconductors. Practical trajectories for 5–10 TW of PVs alone by 2030 have been expertly compiled.[1088] What about those careful analyses is implausible?[1089]

Finally, decisions and risks: Liebreich's question "are you still sure you want to be shutting down existing nuclear power stations at the same time?" is only about carbon, not also dollars. If IEA's claimed US$40–55/MWh cost for life-extension is correct; if reliability, safety, and public confidence can be sustained; and if owners forego ~US$15–20/MWh of subsidies demanded to cover claimed economic losses; then that nuclear solution will still cost several times today's best unsubsidized renewable prices, so it will abate severalfold less carbon per dollar. If any of those hopes aren't realized, that disadvantage will rise.

Sustaining existing reactors *sounds* easier, faster, and cheaper than replacing their output with new efficiency and renewables. Yet the conditions owners are demanding for continued

1086 - Bloomberg New Energy Finance, "World Reaches 1,000 GW of Wind and Solar, Keeps Going", 2 August 2018, see https://about.bnef.com/blog/world-reaches-1000gw-wind-solar-keeps-going/.

1087 - Felix Creutzig, Peter Agoston, et al., "The underestimated potential of solar energy to mitigate climate change", Nature Energy, 25 August 2017, see https://doi.org/10.1038/nenergy.2017.140; Christian Breyer, Dmitrii Bogdanov, et al., "On the Role of Solar Photovoltaics in Global Energy Transition Scenarios", Conference Paper, 32nd EU PVSEC (Munich), June 2016, see https://www.researchgate.net/publication/304350788_On_the_Role_of_Solar_Photovoltaics_in_Global_Energy_Transition_Scenarios, summarized at http://www.neocarbonenergy.fi/wp-content/uploads/2016/02/13_Breyer.pdf.

1088 - Nancy M. Haegel, Robert Margolis, et al., "Terawatt-scale photovoltaics: Trajectories and challenges", *Science,* Volume 356, 14 April 2017, see https://doi.org/10.1126/science.aal1288.

1089 - Historic learning curves are proving overly conservative; e.g. Rocky Mountain Institute's and its industry partners' three successive halvings of unsubsidized PV system cost (now at ~US$20–25/MWh for streamlined community-scale groundmount installations entering the market) suggest continuing radical system-cost drops not yet in market prices. This and other nested positive feedback loops could greatly speed the energy transition: see M. Abramczyk et al., "Positive Disruption: Limiting Global Temperature Rise to Well Below 2 C°", Rocky Mountain Institute, 2017, see https://rmi.org/insight/positive_disruption_limiting_global_temperature_rise/; and Amory B. Lovins, "Additional sensitive intervention points in the post-carbon transition", in submission as of August 2019.

operation aren't just for billions of dollars a year in new subsidies; they also impose heavy costs and constraints on the fast, widespread, job-rich, and popular renewable solutions. Nuclear power's relationship with modern renewables and efficiency is rhetorically complementary but in practice zero-sum or worse. How can slowing and blocking the cheapest and fastest solutions—confining them to smaller markets and putting them at an artificial price disadvantage—yield better climate outcomes? Why should a particular low-carbon solution, unable to compete after half a century, be awarded walled-garden markets and new subsidies unavailable to other low-carbon solutions? How does this fit IEA's correct call for policy to be technology-neutral?

BNEF's 2019 annual analysis of global electricity[1090] concluded that the global power sector remains on track to meet the basic 2°C Paris Agreement goal (though not yet the safer 1.5°C aspirational goal). But though the report "is fundamentally policy-agnostic,... it does assume that markets operate rationally and fairly to allow lowest-cost providers to win," said BNEF's spokesperson. Nuclear power's advocates have the opposite goal—to replace the market processes that reject their business with political choices their lobbying power can shape. Mandating nuclear choices that the market has rejected also cripples the market-based decision frameworks that underpin the modern energy transformation BNEF so effectively tracks. How can that anti-market U-turn speed our urgent journey beyond fossil fuels?

CONCLUSION ON CLIMATE CHANGE AND NUCLEAR POWER

Stabilizing the climate needs solutions that are "granular, modular, mass-producible, fungible, quickly installable by diverse actors with little institutional preparation, and—most importantly—propelled by the powerful feedback of increasing returns and learning-by-doing."[1091] That describes energy efficiency and modern renewables but not nuclear power. Stabilizing the climate is urgent, but nuclear power is slow. It meets no technical or operational need that these low-carbon competitors cannot meet better, cheaper, and faster. Even sustaining economically distressed reactors saves less carbon per dollar and per year than reinvesting its avoidable operating cost (let alone its avoidable new subsidies) into cheaper efficiency and renewables. Whatever the rationales for continuing and expanding nuclear power, for climate protection it has become counterproductive, and the new subsidies and decision rules its owners demand would dramatically slow this decade's encouraging progress toward cheaper, faster options, more climate-effective solutions.

1090 - See BNEF "New Energy Outlook 2019", 18 June 2019,see https://about.bnef.com/new-energy-outlook.

1091 - Amory B. Lovins, "Additional sensitive intervention points in the post-carbon transition", in submission as of August 2019.

ANNEXES

TABLE OF ANNEXES

ANNEX 1 | OVERVIEW BY REGION AND COUNTRY 258

ANNEX 2 | STATUS OF CHINESE NUCLEAR FLEET 302

ANNEX 3 | STATUS OF JAPANESE NUCLEAR FLEET 304

ANNEX 4 | ABOUT THE AUTHORS 306

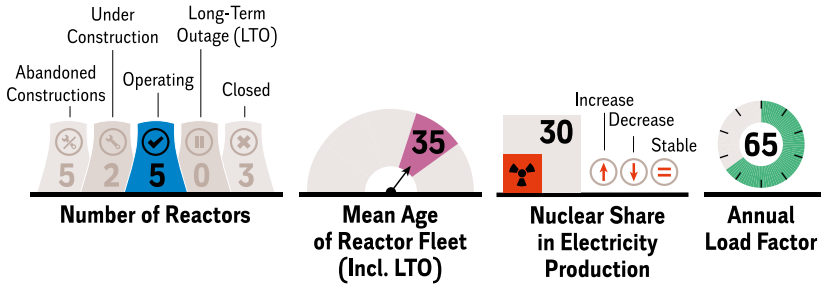
ANNEX 5 | ABBREVIATIONS 310

ANNEX 6 | STATUS OF NUCLEAR POWER IN THE WORLD 318

ANNEX 7 | NUCLEAR REACTORS IN THE WORLD "UNDER CONSTRUCTION" 319

ANNEX 1 OVERVIEW BY REGION AND COUNTRY

These "quick view" indicators will be used in the country sections throughout the report.

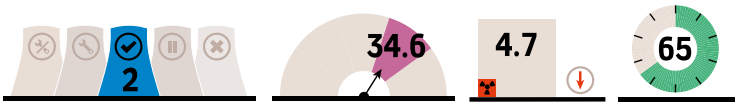


This annex provides an overview of nuclear energy worldwide by region and country that is not covered as Focus Country in the main text (Belgium, China, France, Finland, Germany, Japan, South Korea, Taiwan, U.K. and U.S.).

Unless otherwise noted, data on the numbers of reactors operating and under construction and their capacity (as of mid-2019) and nuclear's share in electricity generation are from the International Atomic Energy Agency's Power Reactor Information System (PRIS) online database.[1092] Historical maximum figures indicate the year that the nuclear share in the power generation of a given country was the highest since 1986, the year of the Chernobyl disaster. Unless otherwise noted, the load factor figures are from Nuclear Engineering International (NEI).[1093]

AFRICA

South Africa



South Africa operates two French (Framatome) 900 MW reactors. They are both located at the Koeberg site, north of Cape Town, and generated 10.5 TWh in 2018, providing 4.7 percent of the country's electricity, a significant fall from 15.1 TWh the previous year, providing 6.7 percent of electricity (the historical maximum was 7.4 percent in 1989).

The Koeberg plant is the only nuclear power station on the African continent.

The Koeberg reactors are increasingly struggling with ageing issues, having started up in 1984 and 1985 respectively. The reactors have been given permission to operate for 40 years and are undertaking a series of replacement and upgrading work, during routine outages. The decision to replace all six steam generators of the two units was taken in 2010. This is reflected in their load factor for 2018, which dropped from averaging 92.7 percent in 2017 for the two reactors to 65 percent, below their lifetime average of 72 percent. The plant has been operating

1092 IAEA-PRIS, "Nuclear Share of Electricity Generation in 2018", see https://pris.iaea.org/PRIS/WorldStatistics/NuclearShareofElectricityGeneration.aspx, accessed July 2019. In this table, the nuclear electricity supplied is the sum of monthly electricity production of individual reactor units (net). The share of nuclear in electricity generation is provided by the countries, and the basis can differ from the electricity production provided by PRIS, according to statistical method used in each country, and can be based on gross or net production.

1093 *NEI*, "Load factors to end December 2018", June 2019, Caroline Peachey, personal communication, email dated 10 June 2019.

at low temperatures to reduce the pace of corrosion in the steam generator tubes. Replacement work is still to begin in 2019 after AREVA was awarded the contract in 2014[1094] and a lengthy legal battle with competitor Westinghouse. In 2018, the Parliament began investigations into the actions of several Eskom officials relating to a number of issues, including the steam generator contracts. The Parliament committee report concluded that the former chairmen and executives of Eskom "reasonably ought to have known or suspected" that their failure to report the flouting of governance rules relating to some contracts, including those relating to the steam generator replacement "may constitute criminal conduct".[1095]

The state-owned South African utility and Koeberg operator Eskom had considered acquiring additional large Pressurized Water Reactors (PWRs) and had made plans to build 20 GW of generating capacity by 2025. However, in November 2008, Eskom scrapped an international tender because the government was unwilling to give the loan guarantees demanded by potential financiers, and credit-rating agencies threatened downgrades. In 2011, the Department of Energy (DOE) published an Integrated Resource Plan (IRP) for future power generation investments that contained a 9.6 GW target, or six nuclear units, by 2030. Startup would have been one unit every 18 months beginning in 2022.[1096] The total price of the project was estimated to be in the range of US$37–100 billion.[1097]

In April 2017, the Western Cape division of South Africa's High Court upheld two NGOs, the Southern African Faith Communities Environment Institute (SAFCEI) and Earthlife Africa, in their cases against two Government actions: a December 2015 decision to proceed with the procurement of 9.6 GW of new nuclear capacity, and the nuclear co-operation agreements that the government had signed with Russia, South Korea and the United States, annulled by a South African court in 2017.[1098] The court concluded that the lack of public consultation on the decisions "rendered its decision procedurally unfair" and breached its statute.[1099] In May 2017, the Government announced that it would not appeal the verdict. The 2018 Goldman environmental prize was awarded to grassroots activists Makoma Lekalakala and Liz McDaid for the successful legal challenge in this case.[1100]

In parallel to these developments, the South African government has been reviewing the expected demand and need for different energy sources[1101]. The November-2013 update of IRP for electricity generation investments concluded that "the nuclear decision can possibly be

1094 - *NEI*, "AREVA to replace steam generators at Koeberg", 19 August 2014, see http://www.neimagazine.com/news/newsareva-to-replace-steam-generators-at-koeberg-4346550/, accessed 1 May 2018.

1095 - Renee Bonorchis, Ana Monteiro, "Three former Eskom chairmen to be criminally probed", *Bloomberg*, 28 November 2018, see https://www.biznews.com/briefs/2018/11/28/eskom-chairmen-criminal-probe, accessed 23 April 2019.

1096 - Department of Energy, "Revised strategic plan, 2011/12-2015/16", Republic of South Africa, 2012, see http://www.energy.gov.za/files/aboutus/DoE_RevisedStrategicPlan_2011_12-2015_16%20.pdf, accessed 1 May 2018.

1097 - *NEI*, "Eskom plans RFP for new reactors by mid-year", 15 March 2017, see http://www.neimagazine.com/news/newseskom-plans-rfp-for-new-reactors-by-mid-year-5761595/, accessed 1 May 2018.

1098 - *BBC*, "South Africa's nuclear deals 'unlawful'", 26 April 2017, see https://www.bbc.com/news/world-africa-39717401, accessed 27 April 2019.

1099 - Phil Chaffee, "Legal, High Court Upends South African Newbuild Plans", *NIW*, 28 April 2017.

1100 - Jonathan Watts, "Goldman prize awarded to South African women who stopped an international nuclear deal", *The Guardian*, 23 April 2018, see http://www.theguardian.com/world/2018/apr/23/goldman-prize-awarded-to-south-african-women-who-stopped-an-international-nuclear-deal, accessed 1 May 2018.

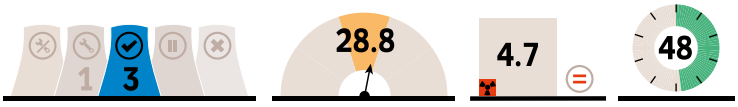
1101 - Amory B. Lovins, Anton Eberhard, "South Africa's Electricity Choice", *Occasional Paper Theories*, Management Programme in Infrastructure Reform & Regulation, Graduate School of Business, University of Cape Town, January 2018, see http://www.gsb.uct.ac.za/files/South_Africas_Electricity_Choice_Final_2_Jan_2018.pdf, accessed

delayed".[1102] In October 2016, the DOE began consultations on a revision of the IRP, in which it is suggested that commissioning of new nuclear would, under their base-case scenario, be only in 2037, and only 1,359 MWe, equivalent to one reactor. However, the plan then assumes a massive commissioning program with 20 GW of new nuclear capacity by 2050, but only because the contribution of solar and wind had been capped arbitrarily, meaning that nuclear had to make up the generation gap. The nuclear program was forced into every draft of the IRP even though it was not cost-competitive.

In January 2018, President Cyril Ramaphosa said in Davos that "we have no money to go for major nuclear plant building."[1103] Even the chief financial officer of Eskom stated: "I can't go and commit to additional expenditure around a nuclear program."[1104] In August 2018, the Government published its draft IRP 2018[1105], in which new nuclear is absent in the period up to 2030.[1106]

THE AMERICAS

Argentina



Argentina has three nuclear reactors. In 2018 the operating units provided 6.5 TWh or 4.7 percent of the country's electricity (down from a maximum of 19.8 percent in 1990).

The operating nuclear plants were supplied by foreign reactor builders: Atucha-1, which started operation in 1974, was supplied by Siemens, and the CANDU (CANadian Deuterium Uranium) type reactor at Embalse was supplied by the Canadian Atomic Energy of Canada Limited (AECL) and started operating in 1983. In April 2018, the regulatory authority gave a license to enable Atucha-1 to continue to operate until 2024, which if completed would thus allow for a 50-year operating life.[1107]

The Embalse plant was shut down at the end of 2015 for major overhaul, including the replacement of hundreds of pressure tubes, to enable it to operate for up to 30 more years. Reportedly, contracts worth US$444 million were signed in August 2011 with the bulk of the work done during a 20-month shutdown starting in November 2013.[1108] According to the World Nuclear Association (WNA), the reactor was shut down in January 2016 and at the time

1102 - Department of Energy, "Integrated Resource Plan for Electricity (IRP) 2010-2030—Update Report 2013", Republic of South Africa, see http://www.doe-irp.co.za/content/IRP2010_updatea.pdf, accessed 1 May 2018.

1103 - *Reuters*, "South Africa has no money for major nuclear expansion, Ramaphosa says", 25 January 2018, see https://af.reuters.com/article/commoditiesNews/idAFL8N1PK6S9, accessed 1 May 2018.

1104 - *NIW*, "Weekly Roundup", 2 February 2018.

1105 - Despite there being half a dozen versions of the IRP, only one, the revision of 2011 was 'promulgated' so all the other versions including the August 2018 version have no policy status.

1106 - *NEI*, "South Africa cancels nuclear expansion plans", 30 August 2018, see https://www.neimagazine.com/news/newssouth-africa-cancels-nuclear-expansion-plans-6728356/, accessed 23 April 2019.

1107 - *WNN*, "Atucha 1 operating licence renewed", 16 April 2018, see http://www.world-nuclear-news.org/RS-Atucha-1-operating-licence-renewed-1604184.html, accessed 7 May 2018.

1108 - *WNN*, "Embalse refurbishment contracts signed", 25 August 2011, see http://www.world-nuclear-news.org/C-Embalse_refurbishment_contracts_signed-2508114.html, accessed 7 May 2018.

was expected to come back online in the second half of 2018.[1109] The reactor was eventually restarted on 4 January 2019 and is now expected to operate for another 30 years.[1110] However, it is unclear when electricity production resumed.

Atucha-2 was ordered in 1979 and was listed as "under construction" in 1981. Construction was on and off for the next decades, but finally grid connection was announced on 27 June 2014. However, it took until 19 February 2015 for the unit to reach full capacity[1111] and until 26 May 2016 to enter commercial operation.[1112]

For the past decade discussions have been held on the construction of a fourth reactor. In February 2015, Argentina and China ratified an agreement to build an 800 MW CANDU-type reactor at the Atucha site, when Atucha-3 was expected to cost US$5.8 billion.[1113]

A framework agreement was also signed in 2015 between the two companies for the construction of a Hualong One reactor, China's new, and as yet unoperated, Generation-III design, without a site being specified.[1114] In May 2017, a co-operation agreement was signed between Argentina and China, whereby China would help build and mainly finance the construction of the two reactors, with the CANDU-6 starting construction in 2018 and the Hualong reactor in 2020.[1115] However, the site for the Hualong reactor has not been agreed on, as the Governor of Rio Negro—the Government's preferred location—said that the reactor would not be located in his province, citing a lack of social acceptance for the project.[1116] Despite this, the Government insisted in October 2017 that construction on both projects would begin in the 2nd half of 2018.[1117] The total cost of the Hualong and Atucha-3 projects were expected to be US$12.5 billion, financed with a 20-year loan from China at an interest rate of 4.5 percent.[1118] In May 2018, the government announced that it was suspending talks with China regarding the construction of both reactors for at least four years.[1119] Then, in the run up to the G-20 summit in Buenos Aires at the end of 2018, there was more optimism that the project could be revised, due to a better financial offer from the Chinese and the conclusion of a wider bailout deal with the International Monetary Fund (IMF). During 2019, discussions were said to be still ongoing and centered around interest rates, although this was said to be just one of many

1109 - WNA, "Nuclear Power in Argentina—Argentinian Nuclear Energy", see http://www.world-nuclear.org/information-library/country-profiles/countries-a-f/argentina.aspx, accessed 7 May 2018.

1110 - *NEI*, "Argentine's Embalse nuclear plant restarts following life extension work", 11 January 2019, see https://www.neimagazine.com/news/newsargentines-embalse-nuclear-plant-restarts-following-life-extension-work-6932719/, accessed 23 April 2019.

1111 - *WNN*, "Atucha 2 reaches 100% rated power", 19 February 2015, see http://www.world-nuclear-news.org/NN-Atucha-2-reaches-100-percent-rated-power-19021502.html, accessed 7 May 2018.

1112 - *WNN*, "Atucha 2 receives full operating licence", 31 May 2016, see http://www.world-nuclear-news.org/RS-Atucha-2-receives-full-operating-licence-3105165.html, accessed 7 May 2018.

1113 - *WNN*, "Argentina and China sign contract for two reactors", 18 May 2017, see http://www.world-nuclear-news.org/NN-Argentina-and-China-sign-contract-for-two-reactors-1805175.html, accessed 21 March 2018.

1114 - Phil Chaffee, Jason Fargo, "Moving closer to Atucha-3 and HPR1000 Newbuilds", *NIW*.

1115 - CNNC, "CNNC to build heavy water reactor and HPR 1000 units in Argentina", 19 May 2017, see http://en.cnnc.com.cn/2017-05/19/c_77725.htm, accessed 7 May 2018.

1116 - Phil Chaffee, "Argentina", *NIW*, 29 September 2017.

1117 - Sylvia Westall, "Argentina to start building two new nuclear reactors in 2018", *Reuters*, 31 October 2017, see https://www.reuters.com/article/argentina-nuclearpower/argentina-to-start-building-two-new-nuclear-reactors-in-2018-idUSL8N1N67EG, accessed 7 May 2018.

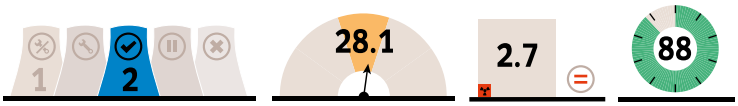
1118 - Phil Chaffee, "Argentina", *NIW*, 29 September 2017.

1119 - Phil Chaffee, "The Fallout From Argentina's Newbuild Retreat", *NIW*, 25 May 2018.

issues to be resolved.[1120] According to a January 2019 note by the French Economy and Finance Ministry, the Hualong One project with a 750 MW reactor could be entirely financed by China and started up by 2027 or 2028.[1121] In June 2019 the Argentine government expressed ongoing support for the project following official meetings with the Chinese, with Argentina's cabinet chief Marcos Pena saying "there is an intention to move forward."[1122]

After repeated delays, construction of a prototype 27 MWe Pressurized Water Reactor (PWR), the domestically designed CAREM25 (Central Argentina de Elementos Modulares—a pressurized-water Small Modular Reactor) began near the Atucha site in February 2014, with startup initially planned for 2018. The reactor was said to cost US$446 million[1123]. It is now scheduled to begin operating in 2022.[1124] The costs have risen to an estimated US$700 million or about US$26,000 per installed kWe.[1125]

Brazil



Brazil operates two nuclear reactors that provided the country with 14.8 TWh or 2.7 percent of its electricity in 2018, just as in 2017 and well below the maximum of 4.3 percent in 2001. Construction of a third reactor was suspended in late 2015.

The first contract for the construction of a nuclear power plant, Angra-1, was awarded to Westinghouse in 1970. The reactor eventually went critical in 1981. Angra-2 was completed and was finally connected to the grid in July 2000, 24 years after construction started. Preparatory work for the construction of Angra-3 started in 1984 but was abandoned in June 1991. Then, in May 2010, Brazil's Nuclear Energy Commission issued a construction license and the International Atomic Energy Agency (IAEA) noted that a "new" construction started on 1 June 2010. In early 2011, the Brazilian national development bank (BNDES) approved a 6.1 billion-real-(US$3.6-billion)-loan for work on the project.[1126] Reportedly, in November 2013, Eletrobras Eletronuclear signed a €1.25 billion (US$1.425 billion) contract with French builder AREVA for the completion of the plant.[1127] Commissioning was previously planned for July 2016

1120 - *NIW*, "Argentina—Briefs", 5 April 2019.

1121 - Direction générale du Trésor, "Le secteur nucléaire en Argentine", French Ministry for the Economy and Finance, 28 January 2019, see https://www.tresor.economie.gouv.fr/Articles/2019/01/28/le-secteur-nucleaire-en-argentine, accessed 16 May 2019.

1122 - Cassandra Garrison, Hugh Bronstein "Argentine official, in China, talks nuclear deal and soymeal", *Reuters*, 25 June 2019, see https://www.theguardian.pe.ca/business/argentine-official-in-china-talks-nuclear-deal-and-soymeal-326387/, accessed 9 July 2019.

1123 - *WNN*, "Construction of CAREM underway", 10 February 2014, see http://www.world-nuclear-news.org/NN-Construction-of-CAREM-underway-1002144.html, accessed 7 May 2018.

1124 - Agencia TSS, "CAREM: Reactor en alta tensión", 21 February 2019, see http://www.unsam.edu.ar/tss/carem-reactor-en-alta-tension/, accessed 16 May 2019.

1125 - Jim Green, "Small and Medium Nuclear Reactors (SMRs) – cost estimates, and what they cost to build", *Nuclear Monitor, Nuclear News Net*, 7 March 2019, see https://nuclear-news.net/2019/03/25/small-and-medium-nuclear-reactors-smrs-cost-estimates-and-what-they-cost-to-build/#more-147114, accessed 12 May 2019.

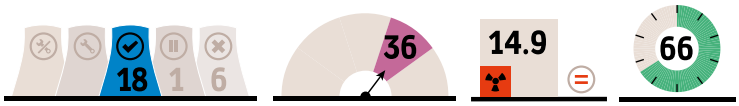
1126 - However, it is surprising to note that AREVA's 400-page Reference Document 2012 does not even contain the word "Angra"; see AREVA, "2012—Reference Document", 2013, see http://www.sa.areva.com/mediatheque/liblocal/docs/groupe/Document-reference/2012/DDR_AREVA_2012_EN.pdf, accessed 7 May 2018.

1127 - *WNN*, "Areva contracted to complete Angra 3", 8 November 2013, see http://www.world-nuclear-news.org/C-Areva-contracted-to-complete-Angra-3-081134.html, accessed 7 May 2018.

but was delayed to May 2018 in 2015[1128] and then to May 2019.[1129] However, construction was halted in the fall of 2015, as a consequence of a huge corruption scandal.[1130, 1131] The scandal has engulfed even the former Brazilian President Michel Temer, who was arrested, along with others, in March 2019, for allegedly diverting 1.8 billion reais ($475 million) from Eletronuclear's Angra-3 new-build project.[1132]

In January 2017, the Brazilian Official Journal registered Eletronuclear's decision to annul the bidding process and the contracts for the electromechanical assembly of Angra-3.[1133] CNNC, EDF, Rosatom and Mitsubishi Heavy Industries' joint venture Atmea SAS are now bidding to construct and more importantly finance the project.[1134] The Government was hoping to have a new business plan completed in mid-2019 with the aim of completion by 2025, although the key issue remains construction cost and the need to significantly raise power prices to pay for it.[1135] The Government in early 2019 said that it was committed to the development of nuclear power, including the completion of Angra-3, which would depend on a complex process of decisions but that the "challenges ahead were enormous".[1136] The government has previously said it wanted to see Angra-3 completed by 2026.[1137] On 21 May 2019, the Government issued a statement qualifying Angra-3 for the public investment plan and announced the creation of an interministerial committee, coordinated by the Ministry of Mines and Energy (MME), which should develop the "legal and operational model of the enterprise".[1138]

Canada



Canada has 19 CANDU reactors, one of which is in Long-Term Outage (LTO). In 2018 they produced 94.5 TWh or 14.87 percent of Canada's total electricity. The nuclear share remained practically stable (+0.3 percent). Eighteen out of the 19 nuclear reactors are located in the province of Ontario, where nuclear power constituted 35 percent of installed capacity and

1128 - *NIW*, "Briefs—Brazil", 9 January 2015.

1129 - *NIW*, "Newbuild: Sobriety, Secrecy and Reluctance", 24 June 2016.

1130 - Jeb Blount, "Brazil police arrest 19 in Eletrobras nuke-plant bribe probe", *Reuters*, 6 July 2016, see https://www.reuters.com/article/us-brazil-corruption/brazil-police-arrests-nine-over-corruption-at-nuclear-plant-idUSKCN0ZM13N, accessed 7 May 2018.

1131 - Reese Ewing, "Brazil Eletronuclear CEO gets 43-year sentence for corruption -paper", *Reuters*, 4 August 2016, see https://www.reuters.com/article/brazil-corruption-eletrobras/brazil-eletronuclear-ceo-gets-43-year-sentence-for-corruption-paper-idUSL1N1AL16E, accessed 7 May 2018.

1132 - *NIW*, "Brazil: 'Radioactivity' Probe Nets Ex-President; Shoot-Out Near Angra", 22 March 2019.

1133 - *NEI*, "Contracts for work at Brazil's Angra 3 declared void", 6 February 2017, see http://www.neimagazine.com/news/newscontracts-for-work-at-brazils-angra-3-declared-void-5732236, accessed 7 May 2018.

1134 - *NIW*, "Brazil", 15 September 2017.

1135 - Luciano Costa, Rodrigo Viga Gaier, "Brazil struggles to find investors in on-again, off-again nuclear project", *Reuters*, 12 January 2018, see https://af.reuters.com/article/commoditiesNews/idAFL4N1P74IW, accessed 7 May 2018.

1136 - *WNN*, "Brazilian government committed to nuclear, says energy minister", 5 April 2019, see http://www.world-nuclear-news.org/Articles/Brazilian-government-committed-to-nuclear-minister, accessed 9 April 2019.

1137 - *NIW*, "Briefs - Brazil", 1 March 2019.

1138 - Eletrobras Eletronuclear, "Resolução oficializa inclusão de Angra 3 no PPI", Press Release, 24 May 2019, see http://www.eletronuclear.gov.br/Imprensa-e-Midias/Paginas/Resolu%C3%A7%C3%A30-oficializa-inclus%C3%A30-de-Angra-3-no-PPI.aspx, accessed 29 May 2019.

contributed 61 percent of the electricity produced in 2018.[1139] The Darlington-2 reactor entered long-term refurbishment outage in October 2016.[1140]

Most of Canada's electricity, however, comes from renewable sources—in 2018, 66 percent of the total electricity generated.[1141] This is dominated by hydro power, which contributed over 59 percent of the total; of the remaining, wind contributed 4.9 percent, biomass 2.0 percent, and solar 0.5 percent. According to IRENA, in the past decade, between 2009 and 2018, Canada's total installed renewable energy capacity has grown from 79.6 GW to 99 GW, hydropower from 74.7 GW to 80.7 GW, wind from 3.3 GW to 12.8 GW, and solar from 95 MW to 3.1 GW.[1142]

The Canadian National Energy Board (NEB) projects a declining trend for nuclear power; in its 2018 "energy future" report, the reference case scenario envisions nuclear power capacity declining from 9.8 percent of total installed capacity in 2016 to 6.4 percent by 2040; the fraction of all electricity generated is expected to come down to around 12.3 percent in 2040.[1143] In contrast, wind energy is projected to double in capacity and share of electricity generation, and solar energy is projected to nearly triple in the reference scenario.

The decline of nuclear power could be more rapid than NEB's projections. The reason that the NEB projects this continued electricity share for nuclear power is that some of the older reactors are being refurbished in order to keep them operational. However, refurbishment is contingent on a number of factors. In the case of the Bruce nuclear plant, the contract includes "two types of off-ramps"; one allows the Independent Electricity System Operator "the option to terminate refurbishments if the estimates provided by Bruce Power prior to each refurbishment exceed cost or duration thresholds" and the other allows it "to terminate all remaining refurbishments due to reduced electricity demand or the emergence of more cost-effective electricity generation resources".[1144] Given declining renewable costs, the latter contingency might well come to pass.

Ontario Power Generation (OPG) is refurbishing Unit 2 of the Darlington nuclear power plant. According to OPG, this has continued to be on time and on budget throughout the first quarter of 2019, with "more than 82 percent" of the work complete.[1145]

Canadian government agencies continue to promote small modular reactors. A spokeswoman from Natural Resources Canada (NRCan), for example, described Small Modular Reactors (SMRs) as a "promising potential area of energy innovation that could provide electricity, both on- and off-grid" that supports the "transition to low-carbon energy

1139 - IESO, "Supply Overview", Independent Electricity System Operator, 11 June 2019, see http://www.ieso.ca/Power-Data/Supply-Overview/Transmission-Connected-Generation, accessed 11 June 2019.

1140 - OPG, "Darlington Refurbishment", Undated, see https://www.opg.com/strengthening-the-economy/our-projects/darlington-refurbishment/, accessed 14 June 2019.

1141 - BP, "Statistical Review of World Energy", June 2019, op. cit.

1142 - IRENA, "Renewable Capacity Statistics 2019", see https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2019/Mar/IRENA_RE_Capacity_Statistics_2019.pdf, accessed 6 June 2019.

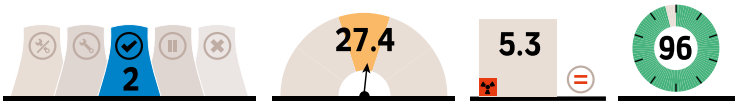
1143 - NEB, "Canada's Energy Future 2018—An Energy Market Assessment—Energy Supply and Demand Projections to 2040", 2018, see http://www.neb.gc.ca/nrg/ntgrtd/ftr/2018/2018nrgftr-eng.pdf, accessed 27 May 2019.

1144 - FAO, "An Assessment of the Financial Risks of the Nuclear Refurbishment Plan", Financial Accountability Office of Ontario, 2017.

1145 - OPG, "Darlington Refurbishment performance update - Q1 2019", May 2019, see https://www.opg.com/news/darlington-refurbishment-performance-update-q1-2019/, accessed 6 June 2019.

solutions".[1146] In November 2018, a group of Canadian provincial governments, territorial governments, and power utilities put out the Canadian Small Modular Reactor Roadmap, a document seeking to advance SMRs in Canada.[1147] Canada's promotion of SMRs is discussed in more detail in the **Small Modular Reactor Chapter**.

Mexico



In Mexico, two General Electric (GE) reactors operate at the Laguna Verde power plant, located in Alto Lucero, Veracruz. The first unit was connected to the grid in 1989 and the second unit in 1994. In 2018, nuclear power generation increased by 25 percent to a new maximum of 13.2 TWh, providing 5.3 percent of the country's electricity, compared to 6 percent in 2017. The two reactors achieved an average load factor of 96.1 percent in 2018—the highest of any country that year—up from 77.1 percent in 2017. The power plant is owned and operated by the state utility Federal Electricity Commission (Comisión Federal de Electricidad—CFE).

The International Atomic Energy Agency (IAEA) completed a long-term operational safety review of the Laguna Verde nuclear power plant in March 2019. The IAEA team has made recommendations as part of the process to extend the operating lives of the reactors, as the CFE has requested that the units be granted a 30-year life extension to enable each unit to operate for a total of 60 years.[1148]

In 2013 the Mexican Congress began restructuring the power sector, to move away from a vertically integrated utility to enable private actors to enter the sector, for private financing for the transmission and distribution networks and eventually to enable retail competition. The role of CFE was also modified as it was unbundled into different supply, distribution and retail arms, which included a separate entity to operate Laguna Verde. According to the Wilson Centre, "The reform allows all participants in the newly created power market to compete under equal conditions to sell generation supply contracts in a competitive bidding process and gives open access to the grid. The sole exception to this new open market is nuclear power generation, which remains controlled by CFE".[1149]

In May 2018, President Trump transmitted to Congress a formal nuclear co-operation agreement (a "123 agreement") needed before any nuclear material or equipment export from the U.S. can take place. Congress had 90 days to review to approve or reject the proposal,[1150]

1146 - Zi-Ann Lum, "Canada Risks 'Climate Change Detour' If New Nuclear Reactors Get Built: Advocacy Group", *Huffington Post Canada*, 6 November 2018, see https://www.huffingtonpost.ca/2018/11/06/canada-small-modular-nuclear-reactors-climate_a_23581936/, accessed 11 June 2019.

1147 - Canadian SMR Roadmap Steering Committee, "A Call to Action: A Canadian Roadmap for Small Modular Reactors", November 2018, see https://smrroadmap.ca/wp-content/uploads/2018/11/SMRroadmap_EN_nov6_Web-1.pdf, accessed 14 June 2019.

1148 - *NEI*, "IAEA reviews long term operation of Mexico's Laguna Verde", 25 March 2019, see https://www.neimagazine.com/news/newsiaea-reviews-long-term-operation-of-mexicos-laguna-verde-7057990/, accessed 23 April 2019.

1149 - Duncan Wood, "Mexico's New Energy Reform", Mexico Institute, Woodrow Wilson International Center for Scholars, October 2018, see https://www.wilsoncenter.org/sites/default/files/mexicos_new_energy_reform.pdf, accessed 23 April 2019.

1150 - Arms Control Association, "The U.S. Atomic Energy Act Section 123 At a Glance", Fact Sheets & Briefs, Updated April 2019, see https://www.armscontrol.org/factsheets/AEASection123, accessed 12 May 2019.

but it entered into force in September 2018. The agreement also enabled broader nuclear co-operation, including for greater support for Laguna Verde.[1151]

United States

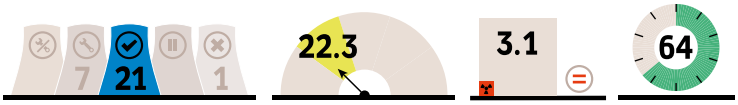
See Focus Countries – **United State Focus.**

ASIA AND MIDDLE EAST

China

See Focus Countries – **China Focus**.

India



The International Atomic Energy Agency (IAEA) lists India as operating 22 nuclear power reactors, with a total net generating capacity of 6.2 GW. However, according to WNISR criteria, the Rajasthan-1 reactor—in the Long-Term Outage (LTO) category as it has not generated power since 2005—was moved to "closed" in WNISR2018, as its final closure had been officially announced.[1152] The two units of the Kakrapar power plant were in the LTO category last year but have since been brought back to operational status.[1153] The operating nuclear power plants generated 35.4 TWh in 2018, marginally more than the 34.9 TWh in 2017; the share of nuclear power has declined from 3.4 percent in 2016 to 3.2 percent in 2017, to 3.1 percent in 2018.

India's main electricity management organization, the Central Electricity Authority, reports that for the period from April 2018 to March 2019, nuclear power generated 37.7 TWh, slightly below the 38.3 TWh from April 2017 to March 2018.[1154] In comparison, during the period from April 2018 to March 2019, renewable energy sources, other than large hydro, together generated 126.8 TWh.[1155] That is nearly 25 percent more than the corresponding contribution from renewables from April 2017 to March 2018 or 3.4 times the amount provided by nuclear power plants—and that ratio is up from 2.7 just one year earlier.

What was new about the year to March 2019 is that with 39.3 TWh, for the first time, solar energy fed more electricity to the grid than nuclear energy. Wind energy, which has exceeded

1151 - NPAC, "FY 2018 – Impact Report", NNSA, March 2019, see https://www.energy.gov/sites/prod/files/2019/03/f60/NPAC%202018%20impact%20report.pdf, accessed 9 June 2019.

1152 - *Deccan Herald*, "End of the road for RAPS 1", 6 September 2014, see http://www.deccanherald.com/content/429550/end-road-raps-1.html, accessed 16 June 2016

1153 - *WNN*, "Kakrapar unit restarts after modernisation", 21 May 2019, see http://www.world-nuclear-news.org/Articles/Kakrapar-restarts-after-modernisation, accessed 21 May 2019; and NPCIL, "KAPS-1 connected to the grid ahead of schedule", Nuclear Power Corporation of India Ltd, Press Release, 24 May 2019, see https://www.npcil.nic.in/writereaddata/Orders/201905240159202891124News_24052019_01.pdf, accessed 25 May 2019; and NPCIL, "KAPS-2 poised for startup", Press Release, 28 August 2018, see http://www.npcil.nic.in/writereaddata/Orders/201808280201113192041news_28aug2018_01.pdf, accessed 29 August 2018.

1154 - CEA, "Executive Summary on Power Sector", Central Electricity Authority, Ministry of Power, Government of India, March 2019, see http://www.cea.nic.in/monthlyexesummary.html, accessed 22 June 2019.

1155 - CEA, "Executive Summary on Power Sector", Central Electricity Authority, Ministry of Power, Government of India, April 2019, see http://www.cea.nic.in/monthlyexesummary.html, accessed 22 June 2019.

nuclear energy for many years now, contributed 62 TWh. These differences between renewables and nuclear will increase in the coming years, because of the rapid growth of solar and wind capacity, and stagnation in the nuclear sector.

“ for the first time, solar energy fed more electricity to the grid than nuclear energy ”

No new reactor was connected to the grid in the past year. Seven reactors with a combined net capacity of 4.8 GW remain under construction. These include two Russian VVER-1000s being constructed at the Kudankulam site since October 2017, two Pressurized Heavy Water Reactors each at Kakrapar (since November 2010) and at Rajasthan (since September 2011), and a Prototype Fast Breeder Reactor (PFBR) whose construction started in October 2004. All projects started before 2017 are delayed. Construction start of the two Kudankulam reactors was delayed, but the expected commercial operation officially remains 2023.[1156]

The PFBR was supposed to be completed by 2010 but its start date has been repeatedly postponed. The last official update comes from a government statement presented in the Indian Parliament in February 2019 that says that the PFBR is in an advanced “stage of integrated commissioning and it is expected to approach first criticality by the year 2020”.[1157] However, criticality does not mean that the reactor will be connected to the grid. That is now projected to happen in October 2021, according to India’s Ministry of Statistics and Programme Implementation Infrastructure and Project Monitoring Division. Early 2018, the official date for “expected completion” of the PFBR was still within the year.[1158] The projected cost of the PFBR has also risen from the initially anticipated Rs. 34.9 billion to Rs. 56.7 billion and then to Rs. 68.4 billion.[1159] Thus, the PFBR cost-estimate has practically doubled and the project is currently 11 years behind schedule.[1160]

Kakrapar-3 and -4 are now projected to cost Rs. 165.8 billion, up from Rs. 114.6 billion; the dates of commissioning have been revised from 2015 to 2020.[1161] According to the Ministry of Statistics and Programme Implementation Infrastructure and Project Monitoring Division, the

1156 - NPCIL, “Status of Project under Construction - Kudankulam Atomic Power Project”, Undated, see https://www.npcil.nic.in/content/831_1_KudankulamNuclearPowerProject.aspx, accessed 25 June 2019.

1157 - Department of Atomic Energy, “Starred Question No.59—Nuclear Power Reactors—Answer by The Minister of State for Personnel, Public Grievances & Pensions and Prime Minister’s Office (Dr. Jitendra Singh)”, Governmet of India, 6 February 2019, see http://dae.nic.in/writereaddata/lssq59.pdf, accessed 23 June 2019.

1158 - Department of Atomic Energy, “Unstarred Question No.4226—Issues Concerning Installation Of New NPPs—Answer by The Minister of State for Personnel, Public Grievances & Pensions and Prime Minister’s Office (Dr. Jitendra Singh)”, 21 March 2018, see http://dae.nic.in/writereaddata/parl/budget2018/lsus4226.pdf, accessed 15 May 2018.

1159 - Ministry of Statistics and Programme Implementation, “Flash Report on Central Sector Projects (Rs. 150 crore and above) March 2019”, Government of India, 2019, see http://www.cspm.gov.in/english/flr/Fr_mar_Report_2019.pdf, accessed 20 June 2019.

1160 - Currently, the conversion rate to US dollars is nearly Rs. 70 per US dollar. However, the PFBR costs are in mixed-year Rupees, so directly converting it into other currencies using the currency conversion figure for any given year is misleading.

1161 - According to Nuclear Power Corporation of India Ltd (NPCIL), the original schedule dates for Commercial Operation were June and December 2015, respectively. As of July 2019, they are expected to be December 2019 and December 2020. See NPCIL, “Status of Project under Construction—Kakrapar Atomic Power Project”, n.d., see https://www.npcil.nic.in/content/301_1_KakraparAtomicPowerProject.aspx, last accessed 24 June 2019.

other reactors under construction are also delayed[1162] but have not had their projected budgets revised.[1163]

The next Pressurized High Water Reactors (PHWRs) (2 x 700 MW) to be constructed will be at the Gorakhpur site in the northern state of Haryana. Excavation work for two reactor units started in March 2018 and are said to be at "an advanced stage" with orders being "placed for long delivery equipment".[1164] The government also has "accorded administrative approval and financial sanction" for constructing ten 700 MW PHWRs at various sites around the country and two more VVER-1000s at Kudankulam, but construction has not started anywhere.

The status of the reactors to be imported from the United States and France after the so-called U.S.-India nuclear deal is more tentative. In Parliament, the Government says that they have been "accorded 'in principle' approval...for setting up nuclear power plants in future".[1165] This suggests that construction is not imminent at any of these. The government's projection for "installed nuclear power capacity" is "22,480 MW by 2031", which would indicate that none of these imported reactors will be operational before 2031.

At Jaitapur, the site chosen to set up EPRs from France, the last official update was in December 2018 when French Foreign Minister Jean-Yves Le Drian and India's External Affairs Minister Sushma Swaraj announced that "both sides are working towards starting the Jaitapur...project as soon as possible".[1166] This does not suggest any rapid progress.

The last major imported reactors operating in India are Kudankulam-1 and -2. But their performance has been poor and they have received much media criticism and concern among even officials from the Nuclear Power Corporation of India. Kudankulam-1 had a load factor of 54 percent, and Kudankulam-2 had a load factor of just 35.2 percent in 2018. The problems have continued in 2019. Unit 1 had "not generated power in the entire month of March" and according to Tamil Nadu Generation and Distribution Corporation (Tangedco), the state's distribution company, "only one unit was functioning...at any given time last year".[1167] An unnamed senior director of the Nuclear Power Corporation "with decades of experience in designing and commissioning nuclear power reactors" reportedly said that Kudankulam-1 "has been facing problems since the day it was commissioned and had undergone many breakdowns and closures. The unit 1 has been shut down for most of the time since its commissioning and

1162 - According to NPCIL, the original scheduled dates for Commercial Operation for Rajasthan-7 & -8 were June and December 2016, respectively. As of June 2019, they are expected to be December 2020 and December 2021. NPCIL, "Status of Project under Construction—Rajasthan Atomic Power Project", Undated, see https://www.npcil.nic.in/content/300_1_RajasthanAtomicPowerProject.aspx, accessed 24 June 2019.

1163 - Ministry of Statistics and Programme Implementation, "Flash Report on Central Sector Projects (Rs. 150 crore and above) March 2019", Government of India, 2019, Op. cit.

1164 - Department of Atomic Energy, "Lok Sabha—Unstarred Question No.3565—Gorakhpur Atomic Power Plant - Answer by The Minister of State for Personnel, Public Grievances & Pensions and Prime Minister's Office (Dr. Jitendra Singh)", Government of India, 2 January 2019, see http://dae.nic.in/writereaddata/parl/winter2018/lsus3565.pdf, accessed 23 June 2019.

1165 - Department of Atomic Energy, "Lok Sabha—Unstarred Question No.1822—Gorakhpur Atomic Power Plant - Answer by The Minister of State for Personnel, Public Grievances & Pensions and Prime Minister's Office (Dr. Jitendra Singh)", Government of India, 13 February 2019, see http://dae.nic.in/writereaddata/lsusq1822.pdf, accessed 23 June 2019.

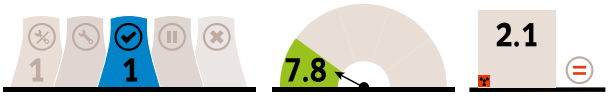
1166 - *The Hindu*, "France, India working on Jaitapur nuclear power project", 15 December 2018, see https://www.thehindu.com/news/national/france-india-working-on-jaitapur-nuclear-power-project/article25753453.ece, accessed 23 June 2019.

1167 - B. Sivakumar, "Mired in problems, two units of K-plant perform below par", *The Times of India*, 13 May 2019, see https://timesofindia.indiatimes.com/city/chennai/two-units-of-kudankulam-perform-below-par/articleshow/69312650.cms, accessed 23 June 2019.

this is a matter of serious concern" while another reactor engineer was quoted as saying that the "frequent shut downs are causing apprehension".[1168]

These frequent shutdowns were causing its generation to be so uncertain that Kudankulam was being tarred with the brush of "intermittent" renewable sources of electricity. An official from the Tamil Nadu Generation and Distribution Corporation (Tangedco) was quoted as saying "we are not able to prepare any schedule based on Kudankulam supply. It is as good as not being there."[1169]

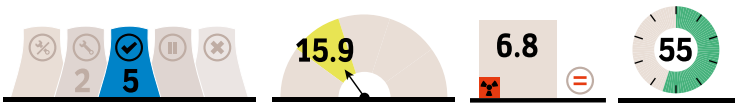
Iran



Iran has a single operating nuclear power plant (Bushehr-1) which generated 2.1 percent (6.30 TWh) of Iran's total electricity in 2018. The share of nuclear energy is almost identical to the 2.2 percent share in 2017. Although excavation for the foundation of the second unit at Bushehr started on 31 October 2017,[1170] concrete has not been poured and the project is not marked as under construction by the International Atomic Energy Agency (IAEA).[1171] Nevertheless authorities continue to maintain that "Bushehr units 2 and 3 are to be completed in 2024 and 2026, respectively".[1172]

The bulk of Iran's electricity comes from natural gas followed by oil. However, Iran has been expanding its renewable capacity. In addition to hydropower with a capacity of 13 GW (2018), Iran has been focused on wind power, whose capacity has grown from 92 MW in 2009 to 282 MW in 2018 in the last decade.[1173] Likewise, solar energy capacity has gone from 1 MW in 2013 to 286 MW in 2018. However, this may be slowing as a result of the sanctions imposed on Iran by the United States under President Donald Trump. One report from August 2018 recorded that solar projects amounting to 2,600 MW of capacity had been stalled because of U.S. sanctions.[1174]

Pakistan



Pakistan operates five nuclear reactors with a combined capacity of 1.3 GW. In 2018, Pakistan's electricity production from nuclear energy was 9.3 TWh which represented 6.8 percent of the total electricity generated in the country. This contribution was higher than the corresponding

1168 - Kumar Chellappan, "Kudankulam nuclear plant breakdown raises safety concern", *The Pioneer*, 6 June 2019, see https://www.dailypioneer.com/2019/india/kudankulam-nuclear-plant-breakdown-raises-safety-concern.html, accessed 23 June 2019.

1169 - Sivakumar, "Mired in Problems, Two Units of K-Plant Perform below Par", Op. cit.

1170 - *NIW*, "Iran", 3 November 2017.

1171 - However, Bushehr-2 was listed as "under construction" by the IAEA for more than 10 years, before it disappeared from the list in the late 1990s. It is still considered as "cancelled construction" (since 1978) by WNISR and will remain in this category until its official construction restarts.

1172 - *WNN*, "Rosatom committed to Iranian plant project", 9 May 2019, see http://world-nuclear-news.org/Articles/Rosatom-committed-to-Iranian-plant-project, accessed 13 June 2019.

1173 - IRENA, "Renewable Capacity Statistics 2019", March 2019, see https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2019/Mar/IRENA_RE_Capacity_Statistics_2019.pdf, accessed 3 April 2019.

1174 - Tsvetomira Tsanova, "US sanctions hit 2.6 GW of solar projects in Iran - report", *Renewables Now*, 14 August 2018, see https://renewablesnow.com/news/us-sanctions-hit-26-gw-of-solar-projects-in-iran-report-623522/, accessed 13 June 2019.

figures of 8.1 TWh and 6.2 percent from 2017, almost entirely because the fourth unit at Chashma was connected to the grid in July 2017 and thus operated for a full year in 2018 as opposed to 2017.

The construction of two Hualong One reactors continued near Karachi, the most populous city in Pakistan with over 16 million inhabitants. Construction of these started in 2015 and 2016 and these are "scheduled for commercial operation in 2021 and 2022, respectively".[1175] These are being financed by loans from China, and in May 2019, Pakistan's government stated that it received US$628.4 million "for the construction of two ongoing nuclear power plants in the past 10 months".[1176]

Pakistan has been rapidly expanding its renewable energy capacity, in particular solar and wind, and has high ambitions to accelerate further. Over the past five years, solar energy capacity increased by a factor of 15, from 101 MW in 2013 to 1.6 GW in 2018.[1177] Wind energy capacity has grown by a factor of 10 during the same period, from 106 MW to 1.2 GW. Some of the financing for these projects comes from China and possibly Saudi Arabia.[1178]

South Korea

See Focus Countries – **South Korea Focus**.

Taiwan

See Focus Countries – **Taiwan Focus**.

EUROPEAN UNION (EU28)

About half of the European Union (EU28) member states have gone through three nuclear construction waves (see **Figure 54**)—two small ones in the 1960s and the 1970s and a larger one in the 1980s (mainly in France).

The region has not had any significant nuclear building activity since the 1990s. There were no construction starts in Western Europe since 1991, prior to Olkiluoto-3 (2005) and Flamanville-3 (2007), and only one after with the first unit of Hinkley Point C (2018). Only five reactors were connected to the EU-grid over the past 20 years, four in Eastern Europe (two in the Czech Republic and one each in Romania and Slovakia) and one in France, none since Cernavoda-2 started up in Romania in 2007.

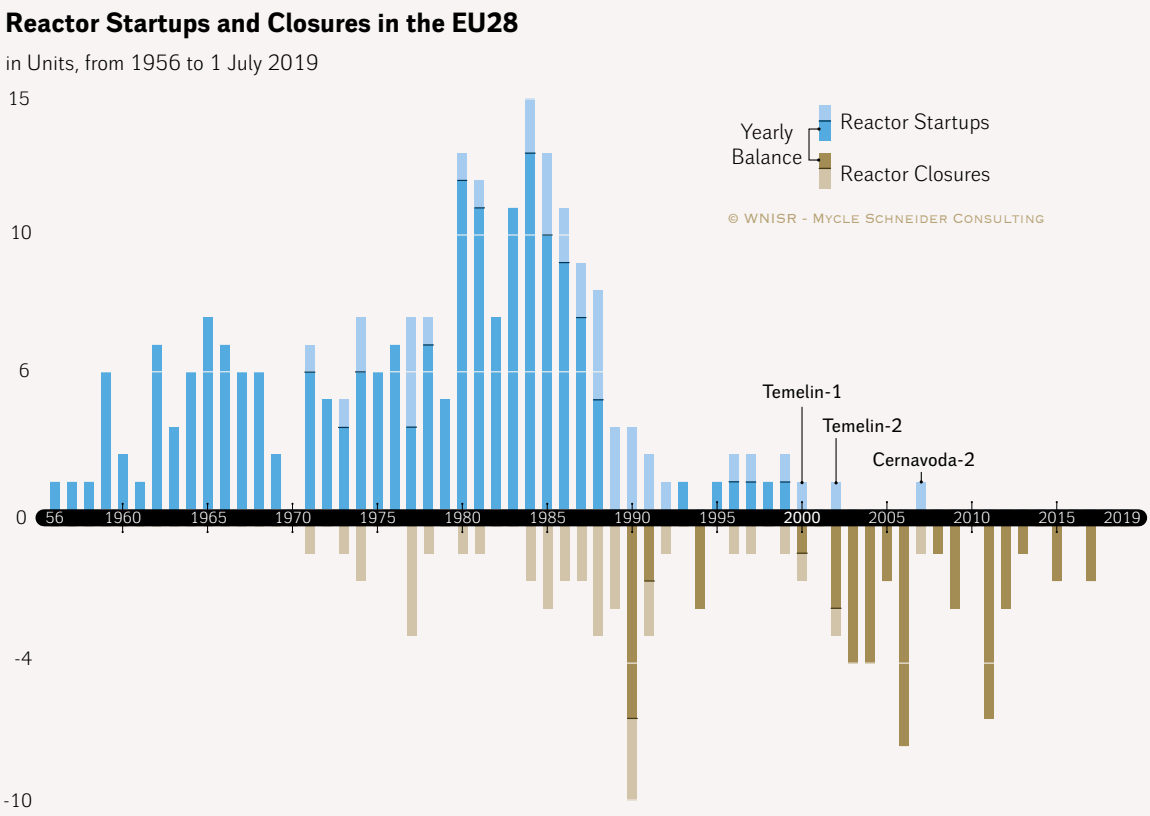
1175 - *WNN*, "Karachi 2 reactor internals in place", 31 January 2019, see http://world-nuclear-news.org/Articles/Karachi-2-reactor-internals-in-place, accessed 15 June 2019.

1176 - *Business Today*, "Pakistan has taken $6.5 billion loan from China in July-April: Report", 23 May 2019, see https://www.businesstoday.in/current/economy-politics/pakistan-has-taken-65-billion-loan-from-china-in-july-april-report/story/349611.html, accessed 15 June 2019.

1177 - IRENA, "Renewable Capacity Statistics 2019", March 2019, see https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2019/Mar/IRENA_RE_Capacity_Statistics_2019.pdf, accessed 3 April 2019.

1178 - *REVE*, "CPEC contributes 300MW wind energy in Pakistan", 1 January 2019, see https://www.evwind.es/2019/01/01/cpec-contributes-300mw-wind-energy-in-pakistan/65652, accessed 15 June 2019; and Hamsa Zakir, "Saudi Arabia in talks with Pakistan to invest $4 billion in solar energy project", *TechJuice*, 12 June 2019, see https://www.techjuice.pk/saudi-arabia-in-talks-with-pakistan-to-invest-4-billion-in-solar-energy-project/, accessed 15 June 2019.

Figure 54 | Nuclear Reactors Startups and Closures in the EU28, 1956–1 July 2019



Sources: WNISR, IAEA-PRIS, 2019

No reactor was closed in the EU since WNISR2018. The total number of permanently closed units remains at 94 in the European Union, and, as of 1 July 2019, the 28 countries in the enlarged EU operated 126 reactors, about one-third of the world total, 49 less than the historic maximum of 175 units in 1988[1179] (see **Figure 55**), but one more than one year earlier: The French Paluel-2 reactor was restarted in July 2018, after an extended outage of 1,154 days since May 2015 and therefore in Long-Term Outage or LTO (see France Focus in WNISR2018 for details).

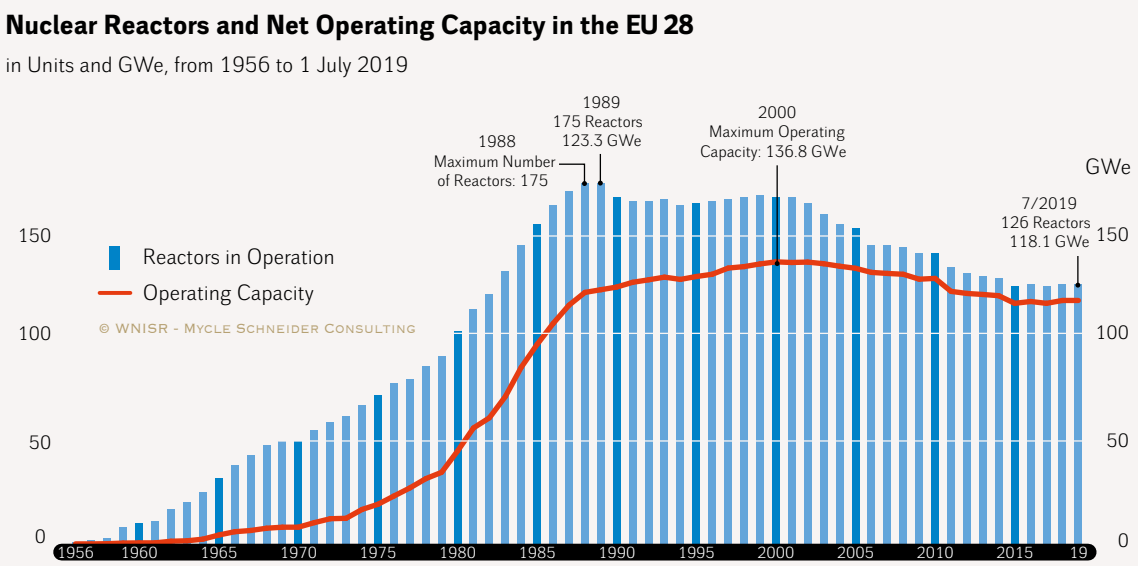
The vast majority of the operating facilities, 107 units or over 80 percent, are located in eight of the western countries, and only 19 are in the six newer member states with nuclear power.

In 2018, nuclear plants have generated 787 TWh, quasi stable (-0.3 percent) compared to the previous year. While the nuclear's share in net power production is not yet available, BP indicates a 25 percent share in gross generation.[1180]

1179 - Note: In previous editions of the WNISR, the peak for the EU was indicated as 177 reactors in operation in 1988–1989. However, in the wake of the Italian referendum in 1987, two reactors (Caorso and Trino/Fermi), then off-line, were never brought back online, and although their official closure date is 1990, the WNISR considers them closed as of last production day. This was not fully reflected in previous versions of this graph. Similar adaptations of our database also affect some other reactors in other countries. This is in particular the case for earlier closure dates for two German reactors (Krümmel and Brunsbüttel) that were officially closed in 2011 as a consequence of the Fukushima accident but had not been providing electricity to the grid since 2009 and 2007 respectively.

1180 - BP, "Statistical Review of World Energy–Workbook", Statistics Work Book, June 2019, op. cit.

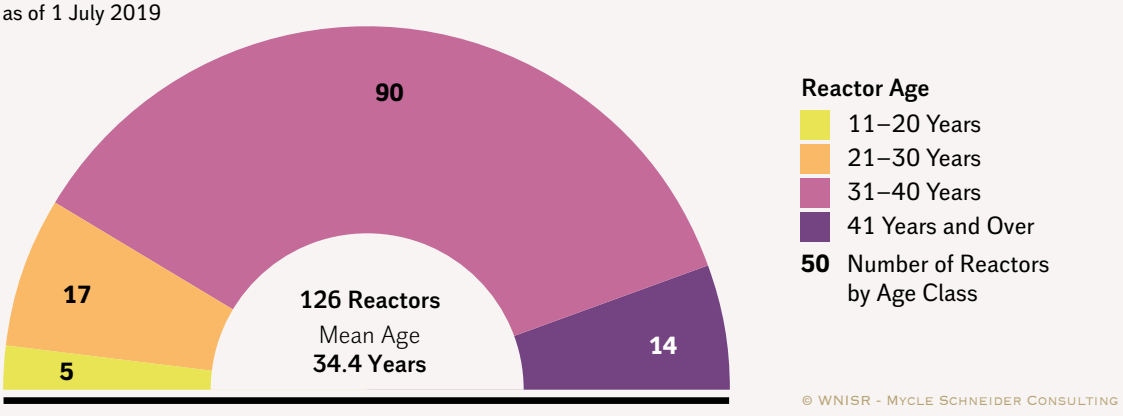
Figure 55 | Nuclear Reactors and Net Operating Capacity in the EU28



Sources: WNISR, with IAEA-PRIS, 2019

In the absence of any new-build program, the average age of nuclear power plants keeps increasing and at mid-2019 stands at 34.4 years (see Figure 56). The age distribution shows that now over 82 percent—104 of 126—of the EU's operating nuclear reactors have been in operation for 31 years and beyond.

Figure 56 | Age Distribution of the EU28 Reactor Fleet



Sources: WNISR, with IAEA-PRIS, 2019

WESTERN EUROPE

As of 1 July 2019, 107 nuclear power reactors operated in the EU15, 48 units fewer than in the peak years of 1988/89. As stated above, Paluel-2 in France restarted generating power after a particularly long shutdown and was thus moved from the Longt-Term Outage (LTO), back to the operating-category.

Three reactors are currently under construction in the older member states, one each in Finland (Olkiluoto-3), France (Flamanville-3) and the U.K. (Hinkley Point C-1). All of these projects are European Pressurized water Reactors (EPR) and all of them are many years behind their initial schedule and billions of Euros over budget (details are discussed in other chapters of the report).

The following section provides a short overview by country (in alphabetical order).

Belgium

See Focus Countries – **Belgium Focus**.

Finland

See Focus Countries – **Finland Focus**.

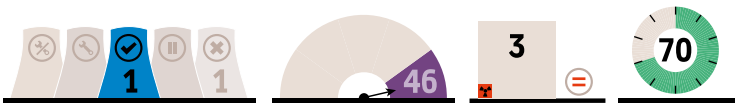
France

See Focus Countries – **France Focus**.

Germany

See Focus Countries – **Germany Focus**.

The Netherlands



The Netherlands operates a single, 46-year-old 480 MW Pressurized Water Reactor (PWR) at Borssele that provided 3.34 TWh and 3 percent of the country's electricity in 2018, compared with 3.26 TWh or 2.9 percent in 2017 and a maximum of 6.2 percent in 1986. In late 2006, the operator and the Government reached an agreement to allow operation of the reactor to continue until 2033.[1181]

In January 2012, the utility DELTA announced it was putting off the decision on nuclear new-build "for a few years" and that there would be "no second nuclear plant at Borssele for the time being".[1182] In 2009 it had proposed 2500 MW of new nuclear capacity at Borssele with

1181 - WNA, "Nuclear Power in the Netherlands", Updated February 2017, see http://www.world-nuclear.org/info/inf107.html, accessed 17 June 2019.

1182 - DELTA, "DELTA puts off decision for a few years, no second nuclear plant at Borssele for the time being", Press Release, 23 January 2012.

a startup date of 2018.[1183] No utility is currently showing any interest in pursuing new-build. On the contrary, the nuclear utilities are struggling with shrinking income and increasing costs. German utility Rheinisch-Westfälisches Elektrizitätswerk AG or RWE AG, that holds 30 percent of Borssele operator EPZ (Elektriciteits Produktiemaatschappij Zuid-Nederland), reported for 2017 a €58 million (US$62 million) impairment loss for EPZ, just as in 2016.[1184] In May 2019, EPZ announced losses of €50 million (US$56 million) for 2018.[1185]

The company predicted nevertheless that with rising electricity prices, it expected to return to profit from 2021. However, an assessment in 2017 by financial management consultancy Spring Associates demonstrated that electricity prices would have to double to make the nuclear plant profitable again, an unlikely scenario. The most economic scenario identified would be immediate closure of the reactor and delayed decommissioning, according to the analysts.[1186] EPZ is required to establish a €600-million (US$673 million) decommissioning fund three years prior to reactor closure currently scheduled for 2033, which would be even more problematic if the reactor was to close earlier. As of 2018 the fund stood at €247.2 million (US$277 million), with a deposit made of €45.9 million (US$51.5 million) during the year.[1187]

In 2014, EPZ started using uranium-plutonium Mixed Oxide (MOX) fuel at Borssele. EPZ is currently the only remaining foreign customer for commercial spent fuel reprocessing of Orano's La Hague plant. The plan is to consume all of the plutonium that is separated in as much as 40 percent MOX in the core.[1188] Short-term closure would jeopardize the plan.

As in other countries, the Dutch power sector is undergoing profound restructuring. EPZ owner Delta was renamed PZEM (Provinciale Zeeuwse Energie Maatschappij N.V.) in early 2017, parts (not Borssele) of which then have been sold to Stedin Holding, as part of the unbundling of production and networking activities.[1189] In January 2019, it was announced that Vattenfall had acquired DELTA Energie.[1190]

In October 2018, the Dutch government was found to be in non-compliance with the Aarhus Convention when it failed to conduct a public consultation on extending the operating life of

1183 - LAKA Foundation, "Dutch utility Delta wins court case Borssele-I and announces Borssele-II", *Nuclear Monitor*, 16 July 2009, see https://wiseinternational.org/nuclear-monitor/691/dutch-utility-delta-wins-court-case-borssele-i-and-announces-borssele-ii, accessed 14 June 2019.

1184 - RWE, "Annual Report 2017", 2018, see http://www.rwe.com/web/cms/mediablob/en/3876342/data/3759768/6/rwe/investor-relations/reports/2017/RWE-annual-report-2017.pdf, accessed 14 June 2019.

1185 - Frank Balkenende, "PZEM's birthday is full of confidence again", PZC, 2 May 2019 (in Dutch), see https://www.pzc.nl/zeeuws-nieuws/jarig-pzem-blaakt-weer-van-het-zelfvertrouwen~a8cd3352/, accessed 12 June 2019.

1186 - *DutchNews*, "Government investment in nuclear power plant financially risky: report", 4 October 2016, see http://www.dutchnews.nl/news/archives/2016/10/government-investment-in-nuclear-power-plant-financially-risky-report/, accessed 14 June 2019.

1187 - EPZ, "Annual Report 2018", 2019 (in Dutch), see https://epzjaarverslag.nl/portfolio/items/economie/, accessed 15 June 2019.

1188 - Jan Wieman, "Borssele moves to MOX", Fuel Cycle Manager, EPZ, published in *NEI*, 11 March 2015, see http://www.neimagazine.com/features/featureborssele-moves-to-mox-4530062/, accessed 14 June 2019.

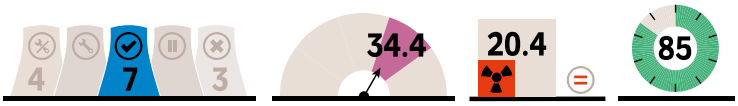
1189 - Stedin Group, PZEM, "Delta Network Continues as Part of the Stedin Group", Press Release, 31 March 2017, see https://www.pzem.nl/sites/default/files/Press Release Stedin Groep PZEM.pdf, accessed 14 June 2019.

1190 - Vattenfall, "Vattenfall acquires Dutch electricity and gas sales company DELTA Energie", Press Release, *POWER*, 19 January 2019, see https://www.powermag.com/press-releases/vattenfall-acquires-dutch-electricity-and-gas-sales-company-delta-energie/, accessed 14 June 2019.

Borssele.[1191] The convention is an international environmental agreement under the auspices of the UN Economic Commission for Europe (UNECE) which addresses access to information and public participation. The ruling requires the Dutch government to conduct an Environmental Impact Assessment (EIA) involving stakeholders in the Netherlands, but also in neighboring states. The evidence of non-compliance was submitted to Aarhus by Greenpeace Netherlands, which had lost previous claims in Dutch courts on the public consultation process.

The ruling governing party, VVD, announced in January 2019 that it was developing new ideas for nuclear power in Netherlands.[1192] The options under consideration were further extension of operations at Borssele, construction of a new plant, or realizing new nuclear power plants in a European context. The response from industry in the Netherlands was to dismiss the initiative as wholly unrealistic. "The business case for nuclear energy is all in all very unattractive," said energy company Eneco, as "the cost of nuclear energy is currently two to three times higher than renewable energy from wind and solar."[1193] The operator of Borssele in May 2019 stated that any new nuclear plant would "never happen" without government financing.[1194]

Spain



Spain operates seven reactors, following the decision to close the 47-year-old Garoña reactor in August 2017, when the then government refused to approve license renewal.[1195] Nuclear plants provided 53.4 TWh in 2018, a 4-percent decline from the 55.6 TWh in 2017, representing 20.4 percent of the country's electricity in 2018 (21.2 percent in 2017 and a maximum of 38.4 percent in 1989). Spain's reactors have a mean operating age of 34.4 years as of 1 July 2019.

The end of the conservative government of Mariano Rajoy and the formation of a new government in May 2018 under Socialist Party (PSOE) leader Pedro Sánchez led to a major shift in energy and climate policy.[1196] The PSOE policy platform in 2016 had focused on energy efficiency and renewable energy, while reducing fossil fuel use and a commitment to permit operation of Spain's reactors for a maximum of forty years.[1197] In March 2018, prior to entering government, the PSOE had issued a report that proposed the closure of coal-fired and nuclear

1191 - UNECE, "Findings and recommendations with regard to communication ACCC/C/2014/104 concerning compliance by the Netherlands Adopted by the Compliance Committee on 4 October 2018", Economic Commission for Europe, Meeting of the Parties to the Convention on Access to Information, Public Participation in Decision-making and Access to Justice in Environmental Matters Compliance Committee Sixty-third meeting Geneva, 11–15 March 2019, Item 9 of the agenda, see https://www.unece.org/fileadmin/DAM/env/pp/compliance/CC-63/ece.mp.pp.c.1.2019.3.en.pdf, accessed 12 June 2019.

1192 - David Bremmer, "VVD starts again about nuclear energy: fewer mills, more nuclear power stations", *AD*, 19 January 2019 (in Dutch), see https://www.ad.nl/politiek/vvd-begint-weer-over-kernenergie-minder-molens-meer-kerncentrales~a0b36295/, accessed 12 June 2019.

1193 - David Bremmer, "Energy giants fill the VVD proposal for new nuclear power stations", *AD*, 6 November 2018 (in Dutch), see https://www.ad.nl/economie/energiereuzen-fileren-vvd-voorstel-voor-nieuwe-kerncentrales~a93c015e/, accesed 12 June 2019.

1194 - PZC, 2 May 2019, Op. cit.; and Laka, "PZEM: "profit again in 2021; no new nuclear power plant without a subsidy", 3 May 2019 (in Dutch), see https://www.laka.org/nieuws/2019/pzem-in-2021-weer-winst-geen-nieuwe-kerncentrale-zonder-subsidie-10626, accessed 12 June 2019.

1195 - Ministry of Energy, "Energy denies the renewal of Garoña's operating authorization", 1 August 2017 (in Spanish), see http://www.minetad.gob.es/es-ES/GabinetePrensa/NotasPrensa/2017/Paginas/denegacion-garona20170801.aspx, accessed 14 June 2019.

1196 - *El País*, "Spain's new PM signals change of tack on climate change", 6 June 2018 (in Spanish), see https://elpais.com/elpais/2018/06/06/inenglish/1528270804_597351.html, accessed 14 June 2019.

1197 - PSOE, "Programa Electoral Elecciones Generales 2016", 2016 (in Spanish), see http://www.psoe.es/media-content/2016/05/PSOE- Programa-Electoral-2016.pdf, accessed 5 June 2018.

plants by 2025.[1198] Shortly after forming a coalition government, it restated that a four year nuclear phase-out would take place between 2024–2028.[1199]

In late January 2019, after months of negotiation, a nuclear phase-out plan was agreed between the then PSOE-led government and utilities Endesa, Iberdrola and Naturgy. The phase-out was part of the overall Integrated Energy and Climate Plan (PIEC) which was approved by the Cabinet meeting on 22 February 2019.[1200] The details of the reactor closure dates were published in February 2019 by newspaper *Cincodías*.[1201] All of Spain's reactors would be closed by 2035 (see **Table 22**); however, the policy also secures lifetime extension of all reactors beyond 40 years, in contrast to previous stated PSOE policy. On 3 March 2019, Teresa Ribera, Minister for the Ecological Transition, confirmed that agreement had been reached with Iberdrola, Endesa and Naturgy that in effect extends operation of their reactors.[1202] The plan was one of the last policies proposed before parliamentary elections in April 2019. Following the election, when the PSOE won the most seats but without an overall majority, negotiations between the PSOE and other parties to form a government were still deadlocked as of early August 2019.

Table 22 | Spain's Nuclear Phase-Out Timetable

Reactor	Capacity	Reactor Type	Owner	Percentage ownership	Grid connection (Age)	Current Operational License	Scheduled Closure
Almaraz-1	900	PWR	Ibedrola	53	1 May 1981 (38 years)	June 2020	2027
			Endesa	36			
			Naturgy	11			
Almaraz-2	900	PWR	Ibedrola	53	8 October 1983 (36 years)	June 2020	2028
			Endesa	36			
			Naturgy	11			
Asco-1	888	PWR	Endesa	100	13 August 1983 (36 years)	September 2021	2029
Asco-2	888	PWR	Endesa	85	23 October 1985 (34 years)	September 2021	2030
			Ibedrola	15			
Cofrentes	939	BWR	Ibedrola	100	14 October 1984 (35 years)	March 2021	2033
Vadellos-2	930	PWR	Endesa	72	12 December 1987 (32 years)	July 2020	2034
			Ibedrola	28			
Trillo-1	990	PWR	Ibedrola	48	23 May 1988 (31 years)	November 2024	2035
			Naturgy	35.4			
			EDP	15.5			
			Nuclenor	2			

Sources: Cincodias and WNISR, 2019.

1198 - Ibidem.

1199 - Ibidem.

1200 - Carmen Monforte, "The Government closes the calendar with the closing dates of each nuclear power plant", *Cincodías*, *EL PAÍS*, 11 February 2019 (in Spanish), see https://cincodias.elpais.com/cincodias/2019/02/08/companias/1549647160_807281.html, accessed 15 June 2019.

1201 - Ibidem.

1202 - *Público*, "Minister Ribera affirms that it is necessary to prolong the life of nuclear power plants", 3 March 2019 (in Spanish), see https://www.publico.es/politica/energia-nuclear-prolonga-vida-centrales-nucleares.html, accessed 14 June 2019.

A major point of tension between the utilities was over the amortization of their reactors. Iberdrola had accounted for the nuclear plants' operating until 40 years, whereas Endesa had planned for 50-year operation in its accounts. Iberdrola has said that it also has no financial incentive to continue nuclear operations if the business continues to lose money.[1203] Iberdrola and Naturgy had put forward plans for extension of the Almaraz reactors to 2027, of which they jointly share ownership together with Endesa, on the condition that they would be able to withdraw if there was a requirement to make further investments. Endesa, which was not in favor of reactor closure before 50 years, set no conditions. Endesa's Chief Financial Officer stated in February 2019 that closure could increase its annual depreciation and amortization costs by €50–60 million (US$56–67.8 million).[1204] On 22 March 2019, Iberdrola confirmed that it had reached agreement for the extension of the Almaraz-1 and -2 reactors to operate until 1 November 2027 and 31 October 2028 respectively, and that it had applied for license extension.[1205] The agreement is based on the condition that Iberdrola will spend no more than €600 million (US$677 million) during the remaining operational life of the reactors.[1206]

Environmental groups criticized the agreement to extend the lifetime of Spain's reactors, including in terms of unresolved safety issues of aging reactors and the issue of a significant shortfall in decommissioning funds, in particular for Endesa, which they argued was a major factor in its seeking life extensions.[1207] As with nations worldwide operating nuclear reactors, there has been longstanding questioning of the adequacy of Spain's decommissioning funds.[1208]

Under the nuclear regulation, utilities' operational licenses must be applied for every ten years, and both Almaraz reactors were required to apply for license renewal before 31 March 2019, and secure approval prior to the expiration of their licenses in June 2020.

On 28 March 2019, it was confirmed that Asociación Nuclear Ascó-Vandellós II, known as ANAV, the operator of Vandellos-2, had applied for 10-year license renewal taking it to 2030.[1209] Under the recently agreed PIEC, Vandellos-2 is scheduled to operate until 2034, and therefore a further license extension may be sought prior to 2030.

1203 - MW, "Spain's Endesa to apply to renew all reactor licenses in 2019, 2020", 7 March 2019.

1204 - Isla Binnie, "Power firms at odds over how to shut down Spain's oldest nuclear plant", *Reuters*, 13 March 2019, see https://www.reuters.com/article/us-spain-energy-nuclear/power-firms-at-odds-over-how-to-shut-down-spains-oldest-nuclear-plant-idUSKCN1QU2OY, accessed 14 June 2019.

1205 - Iberdrola, "Iberdrola finalises the Almaraz renewal agreement, which guarantees economic activity and employment at the plant for the next 25 years", 22 March 2019, see https://www.iberdrola.com/press-room/news/detail/iberdrola-finalises-almaraz-renewal-agreement-which-guarantees-economic-activity-employment-plant-next-years, accessed 14 June 2019.

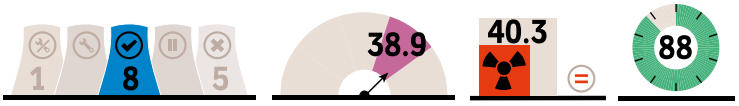
1206 - Isla Binnie, "Power firms agree on route to close Spain's oldest nuclear plant", *Reuters*, 22 March 2019, see https://www.reuters.com/article/us-spain-energy-nuclearpower/power-firms-agree-on-route-to-close-spains-oldest-nuclear-plant-idUSKCN1R325G, accessed 14 June 2019.

1207 - Greenpeace Spain, "Proposals for a horizon without nuclear in Spain", February 2019 (in Spanish), see https://es.greenpeace.org/es/wp-content/uploads/sites/3/2019/02/Dossier-informativo-para-medios-propuesta-cierre-nuclear-revision-1.pdf; and Renewables Foundation, "Greenpeace and the Renewables Foundation ask the Government for social participation in the nuclear closure and accelerate the ecological transition", 19 February 2019, see https://fundacionrenovables.org/notas/greenpeace-y-la-fundacion-renovables-piden-al-gobierno-participacion-social-en-el-cierre-nuclear-y-acelerar-la-transicion-ecologica/; both accessed 14 June 2019.

1208 - Mycle Schneider et al., "Country Report Spain—Comparison among different decommissioning funds methodologies for nuclear installations", Wuppertal Institute on behalf of the Directorate-General Energy and Transport, European Commission, 31 October 20016, see https://epub.wupperinst.org/frontdoor/deliver/index/docId/2597/file/2597_EUDecommFunds_ES.pdf, accessed 14 June 2019.

1209 - *Platts Nuclear News Flashes*, "Operator of Spain's Vandellos-2 applies for 10-year license renewal", 28 March 2019.

Sweden



Sweden's nuclear fleet of eight reactors generated 65.87 TWh or 40.3 percent of the country's electricity production in 2018, compared with 63.1 TWh and 39.6 percent in 2017. Wholly state-owned utility Vattenfall co-owns seven reactors,[1210] while OKG (Oskarshamns Kraftgrupp AB)[1211] owns the eighth, Oskarshamn-3. The respective majority owner operates each plant. Vattenfall also holds shares in three German nuclear power plants, two which were never restarted after 3/11 (Brunsbüttel, Krümmel) and one scheduled for closure in 2021 (Brokdorf).

The past year has seen calls by the right-of-center opposition parties for a new long-term energy strategy, including overturning the 2016 policy that would see nuclear power phased out by 2040. This included calls in May 2019 for the scrapping of the closure of the Ringhals-1 and -2 reactors, scheduled for December 2020 and December 2019 respectively.[1212] The call to revisit the nation's energy policy was led by the conservative Moderate Party, which had signed in support of the 2016 policy when it called for a fossil-free energy policy.[1213] This prompted Magnus Hall, CEO of Vattenfall, to dismiss the prospects as not economic, noting the problem with a containment plate in Ringhals-2.[1214] The Ringhals-2 reactor was brought back online in November 2016, after over two years of shutdown for repairs. The reactor restarted in spite of a "corroded reactor containment liner" after the Swedish Radiation Safety Authority (SSM) had granted an "exemption from its official regulations" for its remaining lifetime.[1215]

Sweden decided in a 1980 referendum to phase out nuclear power by 2010. Sweden retained the 2010 phase-out date until the middle of the 1990s, but an active debate on the country's nuclear future continued and led to a new inter-party deal to start the phase-out earlier but abandon the 2010 deadline. The first reactor (Barsebäck-1) was closed in 1999 and the second one (Barsebäck-2) in 2005. In June 2010, the parliament voted by a tight margin (174–172) to abandon the phase-out legislation. As a result, theoretically, a new plant could again be built—but only if an existing plant is closed. The latest "traditional Swedish compromise", in June 2016, saw an agreement reached on future energy policy.[1216] The Red-Green Government and three opposition parties confirmed the baseline of the 2010 agreement and fixed a 2040 target for a 100-percent renewable electricity mix. In October 2015, OKG decided the early closure of Oskarshamn-1 and -2.[1217] Oskarshamn-2 had been off-grid since May 2013 and was never restarted. On 22 December 2016, the 40-year-old Oskarshamn-2 was officially closed, followed on 17 June 2017 with the closure of the 46-year-old Oskarshamn-1.[1218]

1210 - Ringhals-1–4 (Vattenfall 70.4%, E.ON 29.6%), Forsmark-1–3 (FKG, Vattenfall 66%, Mellansvensk Kraftgrupp 25.5%, E.ON 8.5%)

1211 - OKG is owned by Uniper Sverige (formerly Sydkraft), an E.ON spinoff, for 54.5% and Fortum for 45.5%.

1212 - *Svenska Dagbladet*, "M and KD want to see more nuclear power in settlement", 15 May 2019 (in Swedish), see https://www.svd.se/m-och-kd-vill-se-mer-karnkraft, accessed 24 June 2019.

1213 - *NW*, "Swedish conservatives call for continued use of nuclear power", 11 April 2019.

1214 - Birgitta Forsberg, "The climate threat: Vattenfall's CEO: More nuclear power not the solution", *Svenska Dagbladet*, 20 May 2019 (in Swedish), see https://www.svd.se/vattenfalls-vd-mer-karnkraft-inte-losningen, accessed 24 June 2019.

1215 - *WNN*, "Daily", 4 November 2016.

1216 - Government Offices of Sweden, "Framework agreement between the Swedish Social Democratic Party, the Moderate Party, the Swedish Green Party, the Centre Party and the Christian Democrats", 16 June 2016, see https://www.government.se/49d8c1/contentassets/8239ed8e9517442580aac9bcb00197cc/ek-ok-eng.pdf, accessed 24 June 2019.

1217 - OKG, "Decision Made Regarding Premature Shutdown of Units Oskarshamn 1 and Oskarshamn 2", 14 October 2015, see https://www.okg.se/en/Media/Archive-2015/Decision/, accessed 26 June 2019.

1218 - WNISR, "Sweden Retires First Commercial Nuclear Reactor (Oskarshamn-1)", 21 June 2017, see https://www.worldnuclearreport.org/Sweden-Retires-First-Commercial-Nuclear-Reactor-Oskarshamn-1.html, accessed 24 June 2019.

“ the disadvantage of nuclear power is that it has become so expensive to build that it is difficult to motivate to build new nuclear power ”

To operate reactors into the 2040s, owners need to win approval during ten-year periodic safety reviews. The first to do so under the new 2016 policy were the 39-year-old Forsmark-1 and 38-year-old Forsmark-2, which secured approval on 18 June 2019 SSM to operate for 10 more years until 2028.[1219] The SSM approved continued operation for the reactors, while also finding “deficiencies regarding the containment and aging of concrete structures deemed as small in the current situation, but it may increase in the long term if the deficiencies are not remedied since serious degradations….may occur in the reactor containment and other building structures of importance for radiation safety.”[1220]

The 2016 policy agreement also allows for the building of new reactors, but, as in the previous agreement, only for replacement and not in addition to existing units. The agreement also stipulates: “Government support for nuclear energy, in the form of direct or indirect subsidies, cannot be counted upon”.[1221] Vattenfall CEO Hall stated in May 2019 that “the disadvantage of nuclear power is that it has become so expensive to build that it is difficult to motivate to build new nuclear power.”[1222]

Currently, six of Sweden’s reactors are scheduled for 60-year operation into the 2040s, with closure of the last reactor in 2045,[1223] when Sweden plans to have 100 percent of its electricity generated by renewable energy. Vattenfall has now a modest total of 2.8 GW of renewables in operation in various countries but has another 7 GW under development. The company plans a €5 billion (US$5.7 billion) investment in renewables in the coming years.[1224]

On 1 July 2017, the Swedish government started phasing out its capacity tax on nuclear power production. Utilities had warned the government that without the repeal of the tax they may shut more reactors permanently.[1225] “The tax reduction will be 3 billion crowns per year (US$343 million)… This tax relief is (for us) more pointed towards investments on

1219 - SSM, “Forsmark has the potential to continue driving F1 and F2 radiation-safe until 2028”, 24 June 2019 (in Swedish), see https://www.stralsakerhetsmyndigheten.se/press/nyheter/2019/forsmark-har-forutsattningar-att-fortsatta-driva-f1-och-f2-stralsakert-till-2028/, accessed 25 June 2019.

1220 - SSM, “Events global assessment / Forsmark Group AB / Forsmark 1 and 2 Oversight Report”, 18 June 2019 (in Swedish), see https://www.stralsakerhetsmyndigheten.se/contentassets/6b998f90ef4c4dda8a5914ce3c3ca982/granskning-av-aterkommande-helhetsbedomning-av-forsmark-1-och-2.pdf, accessed 24 June 2019.

1221 - Government Offices of Sweden, “Framework agreement between the Swedish Social Democratic Party, the Moderate Party, the Swedish Green Party, the Centre Party and the Christian Democrats”, 16 June 2016, op.cit.

1222 - Birgitta Forsberg, “The climate threat: Vattenfall’s CEO: More nuclear power not the solution”, Svenska Dagbladet, 20 May 2019, op.cit.

1223 - IAEA, “Asset Management At Nuclear Power Plants—With International Standards And Principles”, Vattenfall, IAEACN-246-14, October 2017, see https://www.iaea.org/NuclearPower/Downloadable/Meetings/2017/2017-10-23-10-27- NPTDS/054_Frojd_Presentation.pdf, accessed 24 June 2019.

1224 - Vattenfall, “Increase renewables“, 19 April 2018, see https://corporate.vattenfall.com/sustainability/production/increase-renewables/; and Vattenfall, “Annual and Sustainability Report 2018—Fossil-free living within one generation”, March 2019, see https://group.vattenfall.com/siteassets/corporate/investors/annual-reports/2018/vattenfall_annual_and_sustainability_report_2018_eng.pdf, both accessed 24 June 2019.

1225 - Nerijus Adomaitis, “Vattenfall puts pressure on Swedish government to cut nuclear tax”, *Reuters*, 28 April 2016, see https://www.reuters.com/article/vattenfall-nuclear-idUSL5N17V5HN, accessed 24 June 2019.

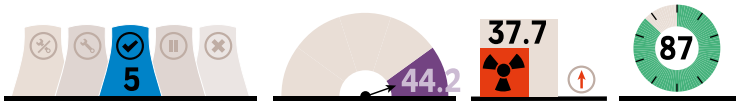
the prolongation of Swedish nuclear" Vattenfall stated.[1226] The decision prompted Vattenfall on 17 November 2017 to announce that it would invest SEK900 million (US$105.8 million) in the installation of independent core cooling systems at Ringhals-3 and -4.[1227] Following the Fukushima Daiichi nuclear accident the Swedish Radiation Safety Authority required the installation of such systems by 2020 as a condition of granting approval for continued operation.[1228]

A critique of the so called stress tests performed on European nuclear reactors following the Fukushima accident concluded: "In their current state, the four Ringhals reactors are not able to withstand a design basis earthquake (DBE)."[1229] Vattenfall decided in June 2016 to install independent core cooling systems at its three Forsmark reactors.[1230] Installation is planned to be completed in 2019.[1231]

Note

WNISR has decided to add the Marviken reactor to its reactor database as "abandoned construction project". Marviken was a 100 MWe boiling water reactor moderated by heavy water and was located at Vikbolandet, east of Norrköping in Östergötland. Its construction was completed and cold-tested. It was designed for natural uranium fuel but never loaded. It was built as a potential plutonium production reactor for the Swedish weapons program, but the construction turned out to have safety problems. The project was cancelled in 1970. Sweden gave up its nuclear weapons program, and its signature of the 1968 Non-Proliferation Treaty (NPT) also made the reactor obsolete.

Switzerland



Switzerland is the only non-EU Western European country generating nuclear power. Nuclear output was 24.4 TWh in 2018, a significant improvement (close to +5 TWh) over the performance in 2017 that had been the lowest level since 1984. The average load factor jumped to 86.5 percent, up from 66.1 percent in 2017. Nuclear represented 37.7 percent of the

1226 - Lefteris Karagiannopoulos, "Sweden's nuclear tax phase-out to save Vattenfall SEK 3 bln/yr -CEO", *Reuters*, 7 July 2017, see https://www.reuters.com/article/sweden-nuclear-vattenfall-idAFL8N1JY30H, accessed 24 June 2019.

1227 - *NW*, "Vattenfall to install extra core cooling at Ringhals units", 23 November 2017.

1228 - IAEA, "Post-Fukushima Safety Upgrade Of Ringhals Unit 3 And 4, Technical Meeting on Operational Experience with Implementation of Post-Fukushima Actions in Nuclear Power Plants", 27–29 March 2017, see https://www.iaea.org/NuclearPower/Downloadable/Meetings/2017/2017-03-27-03-29-NPES/16_Lindback.pdf; and Vattenfall, "Vattenfall invests in Ringhals upgrade", Press Release, 17 November 2017, see https://group.vattenfall.com/press-and-media/news--press-releases/pressreleases/2017/vattenfall-invests-in-ringhals-upgrade, both accessed 24 June 2019.

1229 - Antonia Wenisch, Oda Becker, "Critical Review of the EU Stress Test performed on Nuclear Power Plants", Greenpeace, May 2012, see https://www.greenpeace.de/sites/www.greenpeace.de/files/20120613-Critical-Review-of-EU-Stress-Test-Greenpeace.pdf, accessed 24 June 2019.

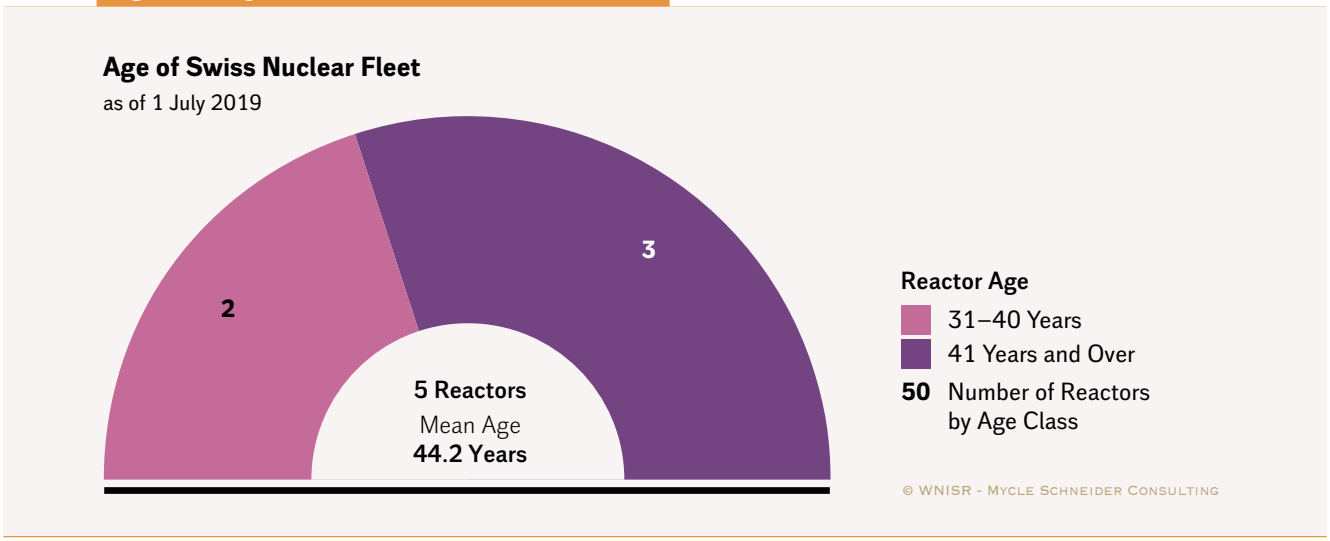
1230 - *NW*, "Vattenfall to install extra core cooling at Ringhals units", 23 November 2017.

1231 - Caterpillar, "Forsmarks Kraftgrupp AB Selects Caterpillar, Zeppelin Power Systems To Supply Engines For Independent Core Cooling At Nuclear Power Plant", Press Release, 17 April 2018, see https://www.cat.com/en_GB/news/engine-press-releases/Forsmarks-kraftgrupp-ab-selects-caterpillar-zeppelin-power-systems.html, accessed 24 June 2019.

country's electricity (maximum of 43 percent in 1996).[1232] With an average age of 44.2 years (see Figure 57), Switzerland operates the oldest nuclear fleet and—with Beznau-1, age 50 since grid connection as of 17 July 2019—the third oldest reactor in the world by length of commercial operation.

On 21 May 2017, 58 percent of Swiss voters adopted the Energy Strategy 2050 that provides a long-term policy framework based on the dynamic development of energy efficiency and renewable energies. The strategy does not fix any closure dates for nuclear power plants and aims to keep the existing reactors operating "as long as they are safe". However, it prohibits the construction of new nuclear power plants and the reprocessing of spent fuel. The "totally revised energy legislation" was adopted by the Swiss parliament on 1 November 2017 and entered into force on 1 January 2018.[1233]

Figure 57 | Age Distribution of the Swiss Nuclear Fleet



Sources: WNISR, with IAEA-PRIS, 2019

The new legislation is comprehensive, providing a framework for grid development regulation, renewable energy incentives, auto-consumption, energy efficiency and the "organic phase-out" of nuclear power. The efficiency targets are ambitious, with reduction of per-capita energy consumption levels—compared to the 2000 baseline—by 16 percent by 2020 and 43 percent by 2035, while per-capita electricity consumption is to decrease by 3 percent by 2020 and 13 percent by 2035. According to the "Energy Strategy 2050 Monitoring Report 2018", final energy consumption per capita (weather-adjusted) had decreased by 16.3 percent as of the end of 2017, while per-capita power consumption had decreased by 5 percent, so both indicators are already exceeding the 2020 targets.[1234] In addition, per-capita power consumption decreased

1232 - SFOE, "Schweizerische Elektrizitätsstatistik 2018", Swiss Federal Office of Energy, June 2019 (in German), see https://www.bfe.admin.ch/bfe/de/home/versorgung/statistik-und-geodaten/energiestatistiken/elektrizitaetsstatistik/_jcr_content/par/tabs/items/tab/tabpar/externalcontent.external.exturl.pdf/aHRocHM6Ly9wdWJkYi5iZmUuYWRtaW4uY2gvZGUvcHVibGljYX/Rpb24vZG93bmxvYWQvOTc0OC5wZGY=.pdf, accessed 21 June 2019. The official national figures vary slightly from the IAEA-PRIS statistics that give 44.4 percent as the historic maximum.

1233 - SFOE, "Wichtigste Neuerungen im Energierecht ab 2018", 2 November 2017 (in German), see https://www.newsd.admin.ch/newsd/message/attachments/50166.pdf, accessed 12 July 2018.

1234 - OFEN, "Stratégie énergétique 2050—Rapport de Monitoring 2018", November 2018.

by another 2.15 percent in 2018, so Switzerland demonstrates that significantly more ambitious targets would be achievable.

By 2020, domestic production of non-hydro renewable-energy based electricity is to reach a modest target of 4.4 TWh, 75 percent of which was achieved as of the end of 2017 with 3.65 TWh and the level increased to 3.9 TWh in 2018.[1235]

In October 2013, operator BKW announced that it would close its Mühleberg reactor in 2019, due to "indefinable and unquantifiable... technical, economic and political uncertainties [that] could increase the economic risks of long-term operation."[1236] In March 2016, BKW communicated the date when Mühleberg will be disconnected from the grid as of 20 December 2019.[1237] On 20 June 2018, the Federal Energy Department issued the formal closure decision and granted a general decommissioning license.[1238]

Following the reactor pressure vessel problems identified at the Belgian Doel-3/Tihange-2 reactors (see **Belgium Focus**), inspections have been carried out at the two Beznau units, both 365 MW Westinghouse Pressurized Water Reactors (PWRs). In the pressure vessel of Beznau-1, a total of 925 crack indications, up to 7.5 x 7.5 mm in size and 60 mm in depth, have been identified. According to operator Axpo, with a high degree of confidence, the faults would not be hydrogen flakes, as in the Belgian cases, but aluminum oxide enclosures from the fabrication process. In the pressure vessel of Beznau-2, 77 crack indications have been found with a maximum size of 20 x 50 mm.[1239] After evaluation of the identified defects in Unit 2, in December 2015, the Swiss Federal Nuclear Safety Inspectorate (ENSI) granted restart permission for the reactor, while Unit 1 remained offline for further studies until 20 March 2018. The restart decision was given in spite of a highly critical report by two nuclear experts from Öko-Institut, Darmstadt, that found numerous "safety-relevant technical deficiencies", if compared with the German reactor safety standards.[1240] Franz Untersteller, Environment Minister of Baden-Württemberg, who commissioned the study, stated: "Considering the results of the [expert report] the nuclear power plant in Beznau should be closed at the earliest point in time."[1241]

A three-quarter majority of the Swiss population remains in favor of abandoning nuclear power. In a June 2019 poll for the Swiss Energy Foundation, 76 percent of the people polled were in favor of a nuclear phase-out against 22 percent opposed.[1242]

1235 - SFOE, "Schweizerische Elektrizitätsstatistik 2018", Swiss Federal Office of Energy, June 2019, op. cit.

1236 - *NIW*, "Switzerland—News Briefs", 1 November 2013.

1237 - BKW, "Kernkraftwerk Mühleberg geht am 20. Dezember 2019 definitiv vom Netz—Endgültige Einstellung des Leistungsbetriebs", Press Release, 2 March 2016 (in German), see http://www.bkw.ch/en/about-us/press-releases/detail/news/detail/News/kernkraftwerk-muehleberg-geht-am-20-dezember-2019-definitiv-vom-netz, accessed 15 June 2016.

1238 - UVEK, "Stilllegungsverfügung Kernkraftwerk Mühleberg vom 20 Juni 2018", Eidgenössisches Departement für Umwelt, Verkehr, Energie und Kommunikation, SFOE, 20 June 2018 (in German), see https://bkw-portal-static.s3.amazonaws.com/Webcontent/bkw.ch/fileadmin/user_upload/Stilllegungsverf%C3%BCgung%20Kernkraftwerk%20M%C3%BChleberg%20vom%2020.%20Juni%202018.pdf, accessed 13 July 2018.

1239 - Christoph Pistner, "Beznau: Finding on the RPV", Presentation at INRAG, 27 February 2016.

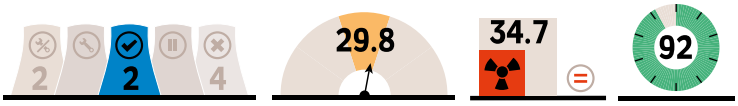
1240 - Christoph Pistner, Simone Mohr, "Sicherheitsstatus des Kernkraftwerks Beznau", Öko-Institut, Darmstadt, August 2017.

1241 - Umweltministerium Baden Württemberg, "Folgegutachten zum Sicherheitsstandard im Atomkraftwerk Beznau (Schweiz): Öko-Institut sieht trotz Verbesserungen nach wie vor gravierende Mängel", Press Release, 13 October 2017 (in German), see https://um.baden-wuerttemberg.de/de/service/presse/pressemitteilung/pid/folgegutachten-zum-sicherheitsstandard-im-atomkraftwerk-beznau-schweiz-1/, accessed 26 May 2018.

1242 - Schweizerische Energie-Stiftung, "Klare Mehrheit der Bevölkerung für den Atomausstieg", Press Release, 21 June 2019 (in German), see https://www.energiestiftung.ch/medienmitteilung/gfs-umfrage-klare-mehrheit-fuer-den-atomausstieg.html, accessed 22 June 2019.

CENTRAL AND EASTERN EUROPE

Bulgaria



In Bulgaria, nuclear power provided 15.44 TWh or 34.7 percent of the country's electricity in 2018, down from a maximum of 47.3 percent in 2002. At the country's only nuclear power plant, Kozloduy, there are now just two reactors operating, where originally there were six; the other four were closed after a 1992 agreement by the G7, as part of the agreement for Bulgaria to join the EU, that these reactors were not sufficiently upgradable. The average load factor of the two remaining reactors reached an excellent 91.9 percent, the third highest in the world.

The two VVER1000 reactors are undergoing a relicensing program to extend their operating lifetimes for up to 60 years. In July 2018, Rusatom Service, part of Russian Rosatom, completed an assessment of Unit 6 and concluded that it could operate for 60 years; however, the Bulgarian regulator is expected to grant only a 10-year lifetime extension to enable operation until 2029 (the unit was connected to the grid in 1991). The programs for upgrading and extending the operational lives of Kozloduy-5 and -6 were launched in 2015, and total costs are estimated at €360 million (US$420 million).[1243]

In November 2015, the Bulgarian Prime Minister, Boyko Borisov, during a visit to China, held talks on potential nuclear cooperation, which was followed by a Chinese delegation visiting Kozloduy in December 2015. In 2016, it was suggested that Westinghouse, prior to its economic collapse, would team up with State Power Investment Corporation (SPIC) to construct further units at Kozloduy.[1244] Discussions were said to be also ongoing with CNNC, with a delegation meeting with the Prime Minister in Sofia in December 2016.[1245]

There have been ongoing attempts since the mid-1980s to build another nuclear power plant at Belene in Northern Bulgaria, but so far, all of them failed. Belene was to consist of two VVER1000/AES-92 reactors, a design that is no longer marketed by Rosatom. After the Bulgarian government decided to cancel the project in 2012, it lost an international arbitration case started by Rosatom, which forced it to pay €620 million (US$$_{2012}$806 million) in compensation, for which it received already produced and unsalable equipment, including two reactor pressure vessels, heat exchangers and emergency water vessels, in return. These are now stored at the Belene site. Since that moment, there were suggestions to use this equipment either in Kozloduy or in a restarted Belene project.

In August 2017, the Bulgarian Energy Minister, Temenuzhka Petkova, announced that the government planned to hold in early 2018 a tender for the sale of the partially constructed Belene project, which would be separated from the assets of the National Electric Company. The Government also said there would be no state guarantees or long-term power purchase

1243 - *NEI*, "Bulgaria's Kozloduy 6 to operate until 2051", 1 August 2018, see https://www.neimagazine.com/news/newsbulgarias-kozloduy-6-to-operate-until-2051-6271568, accessed 18 April 2019.

1244 - C.F. Yu, "Will SPI Team Up with Westinghouse in Bulgaria?", *NIW*, 26 February 2016.

1245 - Georgi Gotev, "China eyes nuclear project in Bulgaria", *Euractiv*, 9 December 2016, see https://www.euractiv.com/section/energy/news/china-eyes-nuclear-project-in-bulgaria/, accessed 26 April 2018.

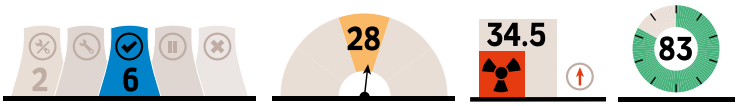
agreements[1246]—conditions that will restrict and likely rule out any potential private investors. However, the Government is also seeking to support new-build by separating the assets and the liabilities of Belene, therefore attempting to increase the chances that the facility could be privatized.

The Bulgarian Academy of Science produced a report at the request of the government to assess whether there are viable financial ways to continue the Belene project. An early version leaked in mid-2017 made clear that these did not exist. But in November 2017, the Academy came up with a report containing one potential avenue to complete Belene: it had to be cheaper than under the previous project at a cost of €10.15 billion (US$12.4 billion), and the price of capital below 4.6 percent interest.[1247]

The Bulgarian Government is reportedly also looking to Chinese sources, namely the Commercial Bank of China, to finance the completion of Belene,[1248] and in March 2018, CNNC were reported to have sent a letter, "declaring an interest" in the Belene project.[1249] But at the end of 2018, Energy Minister Temenuzhka Petkova said that three potential investors—China Nuclear Corp., Korea Hydro & Nuclear Power, and France's Framatome—had expressed an interest in Belene and the goal was to select a winner by the end of 2019.[1250] However, EU requirements—the project would require approval from the EU under Article 41 of the Euratom Treaty—and experience of over-optimistic government announcements in Bulgaria and internationally, would suggest the timetable is unrealistic.

In March 2019, the Government announced that it was preparing to select a single strategic investor for the project and started a tender procedure[1251], which officially starts after publication in the EU Official Journal. Initial interest has been expressed by CNNC and Rosatom.

Czech Republic



The Czech Republic has six Russian-designed reactors in operation at two sites, Dukovany and Temelín. The former houses four VVER-440-213 reactors, the latter two VVER-1000-320 units. In 2018, nuclear plants generated 28.3 TWh or 34.5 percent of the electricity, up from 26.8 TWh or 33.1 percent in 2017. The Czech Republic has the lowest load factor of any country in Central and Eastern Europe, except for Russia, and in 2018 the reactors averaged 83.3 percent, up from 74.9 percent availability.

1246 - *NEI*, "Bulgaria plans privatisation and sale of Belene NPP project", 22 August 2017, see http://www.neimagazine.com/news/newsbulgaria-plans-privatisation-and-sale-of-belene-npp-project-5906032/, accessed 26 April 2018.

1247 - *NucNet*, "Reviving Bulgaria's Belene Project Could Be Economically Viable, Says Academy Report", 17 November 2017, see https://www.nucnet.org/all-the-news/2017/11/17/reviving-bulgaria-s-belene-project-could-be-economically-viable-says-academy-report, accessed 22 May 2018.

1248 - Gary Peach, "Can Bulgaria tempt the Chinese with Belene?", *NIW*, 16 December 2016.

1249 - *NEI*, "Bulgaria's Belene NPP sparks Chinese interest", 27 March 2018, see http://www.neimagazine.com/news/newsbulgarias-belene-npp-sparks-chinese-interest-6096463/, accessed 26 April 2018.

1250 - *NIW*, "Bulgaria Prepares Tender for Belene - With No Guarantees", 14 December 2019.

1251 - Ministry of Energy, "Launch of the procedure for a strategic investor for 'Belene' NPP project", Republic of Bulgaria, 11 March 2019, see https://www.me.government.bg/en/theme-news/startira-procedurata-za-izbor-na-strategicheski-investitor-po-proekta-aec-belene-2706-m0-a0-1.html, accessed 4 May 2019.

The country was a net exporter of 13.9 TWh of electricity in 2018, equivalent to around half of the nuclear output, comparable to the output of Temelín. Czech electricity exports strongly increased to this level after Temelín was brought to the grid in 2000 and have been roughly stable ever since.

The Dukovany units were started up during 1985–87 and have already undergone a lifetime extension upgrading program under the expectation they would operate until 2025. In March 2016, the state regulator extended the operating license of Dukovany-1 indefinitely[1252], with a similar request granted for Unit 2 in July 2017 and for Units 3 and 4 in January 2018.[1253] However, in February 2018, the head of the Czech State Office for Nuclear Safety, Dana Drábová, said that there was pressure from the EU to restrict the operation life of the reactors to 40 years.[1254] Furthermore, the fact that the lifetime extension was decided without an environmental impact assessment is contested by Czech and Austrian NGOs under the Espoo and Aarhus Conventions.

In 2004, Government plans proposed the construction of at least two more reactors. After a series of unsuccessful attempts to tender out the project, in February 2014, the Government made it clear that it wouldn't offer a price guarantee for nuclear electricity, and ČEZ abandoned its plans to issue tenders for new-build. Despite this, the Czech Industry and Finance Ministries continued to promote nuclear power. But there is little incentive or rationale for pushing for new construction in the short term. In principle, new capacity is foreseen for both locations, Dukovany and Temelín, to maintain employment after the closure of existing reactors. In the case of Dukovany, this would theoretically require commissioning new nuclear capacity between 2025 and 2037. ČEZ started preparatory work and, in November 2017, an application for an Environmental Impact Assessment was filed[1255,1256,] without clear indication which design is envisaged or when this project is to be realized. ČEZ also announced plans to prolong the lifetime of the Temelín power plant to 60 years.[1257]

In June 2016, the Government appointed former nuclear regulator Ján Štuller as Commissioner for Nuclear Energy to enable nuclear new-build. The Government stated that they are looking for a strategic partner for nuclear power in the Czech Republic, with interest in co-operation seen from Russia and South Korea.[1258] In addition, in March 2016, ČEZ signed a Memorandum of Understanding (MoU) with China General Nuclear Power Corporation (CGN) on the development of nuclear power and renewables, including on the assistance of ČEZ in the

1252 - *NucNet*, "Dukovany-2 And -3 To Undergo Extended Checks On Pipe Welds", 13 May 2016, see https://www.nucnet.org/all-the-news/2016/05/13/dukovany-2-and-3-to-undergo-extended-checks-on-pipe-welds, accessed 29 April 2018.

1253 - ČEZ, "CEZ Group Annual Report 2017", 2018, see https://www.cez.cz/edee/content/file/investori/vz-2017/vz-2017-en.pdf, accessed 29 April 2018.

1254 - *NEI*, "Czech Republic under European pressure over Dukovany", 26 February 2018, see http://www.neimagazine.com/news/newsczech-republic-under-european-pressure-over-dukovany-6065809/, accessed 29 April 2018.

1255 - ČEZ, "CEZ Group Annual Report 2017", 2018, op. cit.

1256 - ČEZ, "ČEZ Asks for Environmental Impact Assessment of New Nuclear Units at Dukovany", 14 November 2017, see https://www.cez.cz/en/power-plants-and-environment/nuclear-power-plants/dukovany/construction-of-new-nuclear-power-sources/current-news/6.html, accessed 22 May 2018.

1257 - Chris Johnstone, "Czech power giant bolsters arguments for 60 year lifespan of nuclear plants", Radio Praha, 11 May 2018, see http://www.radio.cz/en/section/curraffrs/czech-power-giant-bolsters-arguments-for-60-year-lifespan-of-nuclear-plants, accessed 22 May 2018.

1258 - *NIW*, "Czech Republic", 29 January 2016.

licensing in Europe of the Chinese Hualong design.[1259] In March 2017, it was reported that ČEZ had held talks with Westinghouse, Rusatom Overseas, EDF, AREVA-Mitsubishi, CGN and Korea Hydro and Nuclear Power, with the companies expressing an interest in building reactors in the Czech Republic.[1260]

In March 2018, the Standing Committee on Nuclear Energy published its options on the future plans for financing nuclear new-build; these include:

- creating a new subsidiary of ČEZ to build the units with state backing;
- the purchase by the state of an existing part of ČEZ to build the plants; and
- splitting ČEZ to transfer its nuclear plants to a state-owned company.[1261]

In May 2018, it was reported that the government had postponed a decision, saying it needed more time to evaluate the impact on its budget and find out EU views on state aid for such a project.[1262] In January 2019, Ján Štuller was replaced by former ČEZ CEO Jaroslav Míl[1263], followed by a government announcement in February 2019 that it was willing to give a contract to ČEZ to build further units at Dukovany, but without guaranteed purchase price for electricity. The proposed plan is expected to be finalized during 2019, with the opening of tenders in 2020 or 2021 and eventual start of construction not until 2029.[1264]

ČEZ is said to be increasingly nervous about the cost of construction of new units, with the *Financial Times* reporting that building new reactors would cost at least 100 billion Czech koruna (US$4.4 billion) each—or about a third of ČEZ's market capitalization[1265], something that led to vocal concern among a group of minority shareholders of ČEZ.

The considerations around restructuring of ČEZ are wider than nuclear power and the proposals are in line with similar developments of European utilities, such as RWE and E.ON in Germany, where new companies have been formed to facilitate the further development of renewable energy and distribution activities, without being exposed to negative backlash from fossil-fuel and nuclear activities.[1266] In the meantime, ČEZ announced plans to prolong the lifetime of the Temelín power plant to 60 years.[1267]

1259 - CGN, "CGN and CEZ Collaborate on Renewable and Nuclear Energy in the Czech Republic", 31 March 2016, see http://en.cgnpc.com.cn/encgn/c100101/2016-03/31/content_4f5e26ac4a92404ba5ef27c3b6a156d3.shtml, accessed 29 April 2018.

1260 - *WNN*, "ČEZ aims to restore full nuclear potential", 30 March 2017, see http://www.world-nuclear-news.org/C-CEZ-aims-to-restore-full-nuclear-potential-30031702.html, accessed 29 April 2018.

1261 - *WNN*, "Czech new build financing decision by mid-year", 27 March 2018, see http://www.world-nuclear-news.org/NN-Czech-new-build-financing-decision-by-mid-year-2703187.html, accessed 14 August 2018.

1262 - Jan Lopatka, "Czechs put off decision on building new nuclear plants", *Reuters*, 17 May 2018, see https://uk.reuters.com/article/uk-czech-nuclearpower/czechs-put-off-decision-on-building-new-nuclear-plants-idUKKCN1II2SD, accessed 22 May 2018.

1263 - *Prague Daily Monitor*, "Jaroslav Míl appointed Special Envoy for Nuclear Energy", 18 January 2019, see http://praguemonitor.com/2019/01/08/jaroslav-m%C3%Adl-appointed-special-envoy-nuclear-energy, accessed 4 May 2019.

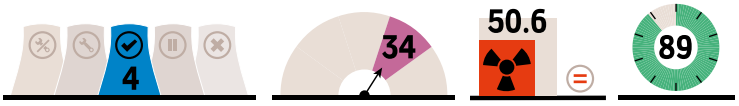
1264 - *NIW*, "Czech PM Outlines Plans for Dukovany Expansion", 22 February 2019.

1265 - James Shotter, "Prague weighs replacement options for nuclear plants", *Financial Times*, 22 November 2018, see https://www.ft.com/content/26cced6c-c8be-11e8-86e6-19f5b7134d1c, accessed 14 April 2019.

1266 - Jan Lopatka, "UPDATE 1-Czech PM Babis to appoint experts to assess CEZ split", *Reuters*, 7 February 2018, see https://af.reuters.com/article/commoditiesNews/idAFL8N1PX5HS, accessed 15 April 2018.

1267 - Chris Johnstone, "Czech power giant bolsters arguments for 60 year lifespan of nuclear plants", *Radio Praha*, 11 May 2018, see http://www.radio.cz/en/section/curraffrs/czech-power-giant-bolsters-arguments-for-60-year-lifespan-of-nuclear-plants, accessed 22 May 2018.

Hungary



Hungary has one nuclear power plant, at Paks, where four VVER 440-213 reactors provided 14.9 TWh or 50.6 percent of the country's electricity in 2018. The nuclear share in the national power mix is down from 53.6 percent in 2014. The reactors started operation in 1982–87 and have been the subject of engineering works to enable their operation for up to 50 years (compared to their initial 30-year license). The first unit received permission to operate for another 20 years in 2012, the second unit in 2014, the third in 2016 and the fourth in December 2017, enabling operation until the mid-2030s.

In March 2009, the Parliament approved a government decision-in-principle to build additional reactors and a tender was prepared according to European rules, while obliging the project developers to establish a transparent international tender during the further downstream tendering of the project. However, in 2014, the Paks II project was suddenly awarded to Rosatom without reference to the public tender, with Russia financing 80 percent of the project in loans.[1268] In February 2017, during a visit to Hungary, Russia's President Putin confirmed that it was even willing to fund 100 percent of the estimated €12 billion (US$12.9 billion) investment.[1269] The Russian-Hungarian bilateral financing agreement proposed at the time consists of a €10 billion (US$11.3 billion) loan to the Hungarian state, with repayment starting in 2026 whether or not the project will be online at that time. Hungary itself will have to invest 20 percent or €2 billion (US$2.3 billion) into the project.

In November 2016, the European Commission cleared the award of the contract to Rosatom of any infringement on its procurement rules. The European Commission accepted the Hungarian justification for the decision that the "technical and safety requirements of the project can only be met by one company".[1270] At the time, this seemed surprising given the range of reactor designs, such as the European Pressurized Water Reactor (EPR), the AP-1000 and Advanced Boiling Water Reactor (ABWR) that were under construction or under licensing review within the European Union. However, it subsequently came to light that the European Commission actively assisted Hungary in finding the right loophole in EU public procurement rules to get the green-light for the construction, and avoid having to have a tendering process, as an agreement had already been reached with the Russians.[1271]

As with other nuclear projects, the economic case continues to weaken. One report, undertaken by Rothschild & Cie for the Prime Minister's Office of the Hungarian Government in September 2015, concluded that when making assumptions on the market price of power in the order of €65/MWh (US$73/MWh), which they describe as in the "low end",[1272]

1268 - Krisztina Than, "Special Report: Inside Hungary's $10.8 billion nuclear deal with Russia", *Reuters*, 30 March 2015, see https://www.reuters.com/article/us-russia-europe-hungary-specialreport-idUSKBN0MQ0MP20150330, accessed 4 May 2019.

1269 - *NIW*, "Briefs - Hungary", 3 February 2017.

1270 - *NEI*, "EC agrees to Hungary's Paks II, but funding decision still awaited", 23 November 2016, see http://www.neimagazine.com/news/newsec-agrees-to-hungarys-paks-ii-but-funding-decision-still-awaited-5677338, accessed 23 November 2018.

1271 - Jorge Valero, "Commission told Hungary how to win approval for Russia-backed nuclear plant", *Euractiv*, 22 November 2017, see https://www.euractiv.com/section/energy/news/commission-told-hungary-how-to-win-approval-for-russia-backed-nuclear-plant/, accessed 17 July 2019.

1272 - Rothschild & Cie, "Economic analysis for the Paks II nuclear power project—A rational investment case for Hungarian State resources", September 2015.

> The operational revenues generated from the sale of the power output envisaged on benchmarked load factor assumptions can be expected to generate sufficient cash flows to cover the operational costs of running the nuclear plant, as well as contributions towards returning the invested capital.

This raises serious questions for the economics of the project as the operational costs are relatively low for nuclear power plants and the report states that investment cost can only be partially covered in their scenario, which make up a significant share of the cost of nuclear electricity. Furthermore, the report has been criticized for taking "outdated and overstated price expectations" and that under more realistic assumptions the project is "uneconomic in each tested scenario and would have to be significantly subsidized by Hungarian taxpayers".[1273] The market price for power (baseload future markets 2019) in July 2019 in Hungary is around €50/MWh (US$56/MWh).

In March 2017, the European Commission also approved the financial package for Paks II, acknowledging that it was State Aid, but satisfied that the impacts on the market would be kept to an acceptable level, if certain requirements were met, which included: any profits from the operation cannot be used to build or acquire additional generating capacity; Paks II must be legally separated from Paks I; and at least 30 percent of the power produced must be sold on the open market.[1274] However, in February 2018 the Austrian Government challenged the validity of the decision, which is now under review by the European Court of Justice.[1275] The legal challenge has subsequently been supported by the Luxembourg Government.[1276]

The plant was granted an environmental license in September 2016, and in March 2017 the Hungarian Atomic Energy Authority approved the site license for the new construction.[1277] However, since then, there has been increasing concerns over the impact of hotter summers on the cooling water availability due to higher water temperatures from the Danube river, especially if both Paks I and II are in operation. Within the EIA process the solution to this problem was to reduce output from the plants when cooling water availability was limited, which would affect the economics of the project and the demand-supply grid balance.[1278]

Concerns have been raised over the suitability of Paks for siting nuclear power plants. Even the national regulator notes that "seismic hazards have been underestimated in the siting and design of Paks NPP" and that further measures were taken to further protect the existing reactors and to ensure that they meet seismic safety requirements.[1279] Furthermore, documents obtained by the Hungarian NGO Transparent are said to show that the site was "declared to be non-compliant with IAEA [International Atomic Energy Agency] safety recommendations" as

1273 - Candole Partners, "NPP Paks II: Economic feasibility, impact on competition and subsidy costs", Prepared for Greenpeace, May 2016.

1274 - European Commission, "State Aid: Commission clears investment in construction of Paks II nuclear power plant in Hungary", 6 March 2017, see http://europa.eu/rapid/press-release_IP-17-464_en.htm, accessed 29 April 2018.

1275 - *WNN*, "Austria takes EC to court over Paks decision", 23 February 2018, see http://www.world-nuclear-news.org/NP-Austria-takes-EC-to-court-over-Paks-decision-2302184.html, accessed 29 April 2018.

1276 - Eszter Zalan, "Luxembourg backs Austria against Hungarian nuclear plant", *EU Observer*, 5 March 2018, see https://euobserver.com/energy/141202, accessed 29 April 2018.

1277 - *NIW*, "Briefs—Hungary", 31 March 2017.

1278 - Gary Peach, "Five Years on, Hungary's Paks Expansion Stumbles Along", *NIW*, 8 February 2019.

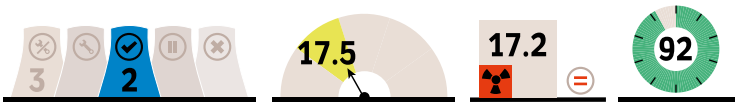
1279 - Hungarian Atomic Energy Authority, "National Report of Hungary on the Targeted Safety Re-assessment of Paks Nuclear Power Plant", December 2011, see http://www.nubiki.hu/HUN_Nat_Rep_eng_signed.pdf, accessed 12 July 2019.

a tectonic fault and traces of seismic activities within the last 10,000 years have been found in the surrounding area,[1280] and potentially that it does not even meet Russian safety standards.[1281]

In August 2017, Hungary's Foreign Minister said that construction work would begin at Paks II in January 2018 and that nothing could stop the construction.[1282] However, early 2018 reports suggested that a construction permit was expected by mid-2018[1283] with the project to be completed in 2024–25. In June 2019, a ceremony was held with representatives of Rosatom to mark the start of the erection of buildings at the site.[1284] At the event, the director for the construction of Paks-2, Alexander Khazin, said that "the building of the construction base on Paks-2 site means the beginning of the preparation of the construction of two new power units, and from now on, the work at the site will be uninterrupted".[1285]

As with other nuclear projects, suggested deadlines have come and gone, and in early 2019, it is now suggested that the construction license won't be signed until 2020 at the earliest.[1286] In consequence, there are some reports that suggest that operation will not occur before 2027–2028 (rather than in 2026). This has led to an amendment of the loan agreement, with repayment only starting once the two units are connected to the grid and electricity production has begun.[1287] Other reports put the startup even later, suggesting that 2032 is more likely, due to significant cultural, technical and safety disputes.[1288]

Romania



Romania has one nuclear power plant at Cernavoda, where two Canadian-designed CANDU reactors are in operation. In 2018—almost identical to 2016 and 2017—they provided 10.5 TWh or 17.2 percent of the country's electricity, compared to 20.6 percent in 2009. The Cernavoda reactors are amongst the top lifetime performing reactors, with Unit 2, the highest and Unit 1 in third place in the global league table of load factors. In 2018, their average load factor was 92.4 percent, one percentage point lower than in the previous year, but second only to Mexico's twin-reactor power plant.

1280 - Atlatszo, "Nem földrengésmentes a paksi atomerőmű telephelye: megszereztük a földtani kutatás eltitkolt eredményeit", July 2017 (in Hungarian), see https://atlatszo.hu/2017/07/10/nem-foldrengesmentes-a-paksi-atomeromu-telephelye-megszereztuk-a-foldtani-kutatas-eltitkolt-eredmenyeit/, accessed 12 July 2019.

1281 - Benedek Javor, "Paks II. nem épülhetne meg Oroszországban az orosz szabályok szerint", 7 November 2017 (in Hungarian), Jávor Benedek blogja, see http://javorbenedek.blog.hu/2017/11/07/paks_ii_nem_epulhetne_meg_oroszorszagban_az_orosz_szabalyok_szerint, accessed 17 July 2019.

1282 - *AFP*, "2018 start for Russia-backed nuclear plant work", 28 August 2017, see http://www.nuclearpowerdaily.com/reports/2018_start_for_Russia-backed_nuclear_plant_work_Hungary_999.html, accessed 17 April 2018.

1283 - WNA, "Nuclear power in Hungary", February 2018, see http://www.world-nuclear.org/information-library/country-profiles/countries-g-n/hungary.aspx, accessed 29 April 2018.

1284 - Rosatom, "The first construction and installation work launches at the construction base of the Paks-2 NPP (Hungary)", Press Release, 20 June 2019, see https://www.rosatom.ru/en/press-centre/news/the-first-construction-and-installation-work-launches-at-the-construction-base-of-the-paks-2-npp-hun/, accessed 21 June 2019.

1285 - Ibidem.

1286 - Gary Peach, "Five Years on, Hungary's Paks Expansion Stumbles Along", *NIW*, op. cit.

1287 - *NEI*, "Hungary and Russia renegotiate Paks-II loan", 14 May 2019, see https://www.neimagazine.com/news/newshungary-and-russia-renegotiate-paks-ii-loan-7203945, accessed 15 May 2019.

1288 - *Budapest Business Journal*, "Paks II completion may be delayed until 2032, says report", 22 November 2018, see https://bbj.hu/energy-environment/paks-ii-completion-may-be-delayed-until-2032-says-report_157482, accessed 12 July 2019.

Between 1982 and 1987, Romania started construction on five Canadian-designed reactors. Unit 1 was completed in 1996, and Unit 2 started up in 2007, respectively 14 and 24 years after construction started. The two units were partly funded by the Canadian Export Development Corporation, the second also partly by Euratom. As with other CANDU reactors, major refurbishment will be needed in the reactors; it is anticipated that this will occur in Unit 1 during 2026–28 and will cost €1.2–1.5 billion (US$1.4–1.7 billion).[1289]

Various foreign companies have been involved in the attempts to revive the construction of Units 3, 4 and 5. The penultimate involved Enel, ČEZ, GDF SUEZ (now Engie), RWE, Iberdrola and ArcelorMittal, which established a company with the State nuclear corporation Societatea Nationala Nuclearelectrica (SNN), called EnergoNuclear in 2008. However, one by one the foreign companies pulled out.[1290]

The latest attempt was launched in cooperation with China General Nuclear Power Corporation (CGN), which signed a letter of intent in November 2013 with SNN to complete the projects in 2019 and 2020. This was followed in November 2015, with the signing of a Memorandum of Understanding (MoU) between Nuclearelectrica and CGN for the construction, operation and decommissioning of Units 3 and 4. The MoU also included agreements on investments, the articles of incorporation of a new project company, the structuring of the project's financing, and remarkably, CGN was to be the majority owner of the project with at least 51 percent of the shares.[1291] In January 2016, the Romania Government formally expressed support for the project and outlined the policies and measures that it would introduce to support it; this included energy market reform, changes to the electricity tariff, commitments on state guarantees and financial incentive policies. The cost of the completion of two reactors (720 MW each) was expected to be US$7.8 billion.[1292]

During 2016 and 2017, negotiations between CGN and Nuclearelectrica were said to be ongoing, although deadlines for construction and financing agreements have continually been extended. However, by late 2017, the Government admitted that negotiations needed to be restarted, with a hope that a binding investment agreement would be signed by February or March 2018,[1293] a deadline which has been missed. In January 2019, the Romanian and Chinese partners agreed a Contract for Difference set-up (similar to the Hinkley Point C deal in the U.K.) to pave the way for the establishment of a joint company to complete the two units.[1294]

1289 - *Romania Insider*, "Romanian nuclear power plant reactor refurbishment to cost EUR 1.2-1.5 bln", 2 April 2018, see https://www.romania-insider.com/nuclear-power-plant-reactor-refurbishment-cost/, accessed 3 April 2018.

1290 - WNA, "Nuclear Power in Romania", October 2017, see http://www.world-nuclear.org/information-library/country-profiles/countries-o-s/romania.aspx, accessed 29 April 2018.

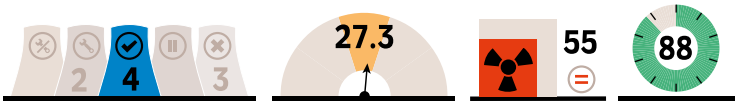
1291 - *WNN*, "Romania and China seal Cernavoda agreement", 19 November 2015, see http://www.world-nuclear-news.org/NN-Romania-and-China-seal-Cernavoda-agreement-10111501.html, accessed 29 April 2017.

1292 - *WNN*, "Romania expresses support for China's role at Cernavoda", 25 January 2016, see http://www.world-nuclear-news.org/NN-Romania-expresses-support-for-China-role-at-Cernavoda-25011601.html, accessed 20 April 2017.

1293 - Phil Chaffee, "Romania: Can SNN end stalemate with CGN over Cernavoda ?", *NIW*, 22 September 2017.

1294 - *Romania Insider*, "Romanian nuclear power plant reactor refurbishment to cost EUR 1.2-1.5 bln", 2 April 2018, Op. cit.

Slovakia



In Slovakia, the state utility Slovenské Elektrárne (SE) operates two nuclear sites, Jaslovské Bohunice, which houses two VVER440 units, and Mochovce, which has two similar reactors. In 2018, their production remained stable at 13.8 TWh or 55 percent of the country's electricity—it passed Ukraine again—and is the second highest share in the world behind France. The load factors are stable on a high level with an average of 88.3 percent in 2018, just as in the previous year.

In October 2004, the Italian national utility ENEL (Ente Nazionale per l'energia elettrica) acquired a 66 percent stake in SE and, as part of its bid, proposed to invest nearly €2 billion (US$2.7 billion) in new nuclear generating capacity, including completion of the third and fourth blocks of Mochovce, whose construction originally began in January 1985. Towards the end of 2014, ENEL announced that it was seeking to sell its share in SE and had received a number of non-binding bids. In December 2015, it was announced that EPH (Energeticky a Prumyslovy Holding) was the winner of the bid, with a preliminary price of €750 million (US$812 million). Under the deal, ENEL got €150 million (US$171 million) in the first stage, in which EPH received a share of 33 percent in the company, the remaining share and final price to be agreed one year after Mochovce is completed.[1295]

In February 2007, SE had announced that it was proceeding with the construction of Mochovce-3 and -4 and that ENEL had now agreed to invest €1.8 billion (US$$_{2007}$2.6 billion). According to the International Atomic Energy Agency's Power Reactor Information System (PRIS), construction restarted in June 2009, and, at the time, the units were expected to generate power in 2012 and 2013 respectively.[1296] However, the project was beset with problems, and by May 2016, the estimate for the total costs of completion had risen to €5.1 billion (US5.7_{2016}$ billion), with completion at the end of 2016/early 2017.[1297] However, in March 2017, SE announced a considerable further delay in the project, with operation expected only at the end of 2018 and 2019 for Units 1 and 2 respectively. This is an additional two years of construction, while the officially expected cost increase is only €300 million (US$333 million)[1298]. According to SE, by December 2018, Unit 3 was over 98 percent complete and Unit 4 about 86.5 percent.[1299] As of early 2018, completion of the projects was still expected at the end of 2018 and 2019 respectively.[1300] This schedule would have meant that the reactors were six years behind the 2009 schedule, when construction restarted, with an increase in budget from then €2.8 billion to €5.4 billion (US$3.2 bn to US$6.1 bn). In June 2018, the Slovak Prime Minister himself raised doubts if the latest schedule would be met, as he stated that "a

1295 - Tatiana Jancarikova, Jan Lopatka, "Enel sells stake in Slovak power group, including nuclear plant, to EPH", *Reuters*, 18 December 2015, see https://www.reuters.com/article/slovakia-enel-eph/enel-sells-stake-in-slovak-power-group-including-nuclear-plant-to-eph-idUSL8N14657L20151218, accessed 29 April 2018.

1296 - ENEL, "ENEL Starts Site Works at Mochovce 3–4", Press release, 3 November 2008, see https://servizi.enel.it/eWCM/salastampa/comunicati_eng/1594888-1_PDF-1.pdf, accessed 29 April 2018.

1297 - *Spravy Pravda*, "Ďalšie peniaze na Mochovce? Žiga nemá oficiálnu informáciu", 5 May 2016 (in Slovak), see http://spravy.pravda.sk/ekonomika/clanok/392783-dalsie-peniaze-na-mochovce-ziga-nema-oficialnu-informaciu/, accessed 29 April 2018.

1298 - *WNN*, "Slovak utility increases Mochovce expansion budget", 31 March 2017, see http://www.world-nuclear-news.org/NN-Slovak-utility-increases-Mochovce-expansion-budget-31031701.html, accessed 29 April 2018.

1299 - SE, "Mochovce 3 and 4 Project Completion", Undated, see https://www.seas.sk/mochovce-3-4-npp, accessed 6 July 2019.

1300 - *NIW*, "Slovakia", 16 February 2018.

number of problems arose during construction, and even now this makes us doubt whether this year's deadline for the third unit is realistic."[1301]

In April 2019, Mochovce-3 completed "hot testing" in preparation for fuel loading in the summer, although the regulatory process could take eight months. The new delay is reported to add an estimated €270 million (US$305 million) to the cost of the Mochovce-3 and -4 project, representing a 5 percent increase in costs, and bringing total costs to €5.4 billion (US$6.1 billion).[1302] In June 2019 TVEL Fuel Company, part of Rosatom, agreed to fuel the Slovakian reactors for the next five years, with the possibility of a contract extension to 2030.[1303]

On 15 April 2019, the Slovak anti-corruption police raided several SE offices, including those at Mochovce, and arrested on corruption charges the former CEO of Slovenské Elektrárne, Paolo Ruzzini, and Nicola Cotugno, former Mochovce director and Ruzzini's successor at SE, both involved in the privatization of SE to ENEL in 2004 and responsible for the restart of the Mochovce-3 and -4 construction.[1304] At the time of writing, it remains unclear whether these investigations will have repercussions on the construction timetable of Mochovce-3 and -4.

In May 2019, CEO of SE Branislav Strycek announced that startup would be delayed again to March 2020, an optimistic variant being November 2019.[1305] Unit 4 startup is now expected in 2021.[1306]

In addition to the delays and cost overruns, concerns have been raised about the state of the power market, with power prices currently at €30/MWh (US$33/MWh) and electricity demand following the sluggish economy. It is expected that, if and when the Mochovce units are completed, their capacity will mainly be used for export, so given the low electricity prices in the European market, the chance that SE will recover their ever-increasing investment seems slim.

The Slovak state-owned utility JAVYS (Jadrová A VYrad'ovacia Spoločnost') and the Czech utility ČEZ in 2009 started a joint venture JESS (Jadrová Energetická Spoločnosť Slovenska, a.s.) to construct new nuclear capacity in Jaslovské Bohunice. JAVYS is currently responsible for the decommissioning at Jaslovské Bohunice of the A1 reactor and the two V1 reactors, as well as for Slovakia's radioactive waste management. The so-called Bohunice NJZ (Nová Jadrová Zdroj) 1200 MW new-build project is proposed to be completed before 2025 at a cost of €4–6 billion (US$4.5–6.8 billion). JAVYS owns 51 percent of the shares and ČEZ 49 percent. ČEZ sought in 2013 to sell this stake to Russian Rosatom, but negotiations failed in March 2014.[1307]

1301 - *NIW*, "Slovakia: Are Mochovce's Headaches Over ?", 8 June 2018.

1302 - *WNN*, "Mochovce 3 completes commissioning test", 16 April 2019, see https://www.world-nuclear-news.org/Articles/Mochovce-3-completes-commissioning-test, accessed 18 April 2019.

1303 - Claudia Patriciolo, "Rosatom to supply fuel for Slovakia's nuclear power plants", *Emerging Europe*, 6 June 2019, see https://emerging-europe.com/news/rosatom-to-supply-fuel-for-slovakias-nuclear-power-plants/, accessed 6 July 2019.

1304 - *TASR*, "NAKA na letisku zadržala exšéfa Slovenských elektrární. Preverujú podozrenia týkajúce sa Mochoviec", *Finweb*, 15 April 2019 (in Slovak), see https://finweb.hnonline.sk/ekonomika/1924600-naka-na-letisku-zadrzala-exsefa-slovenskych-elektrarni-preveruju-podozrenia-tykajuce-sa-mochoviec, accessed 4 May 2019.

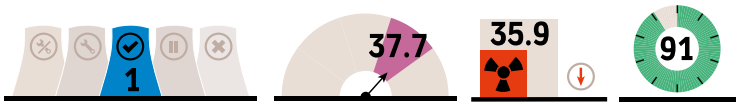
1305 - *Ekonomika*, "Na dostavbu Mochoviec sa prídu pozrieť medzinárodní experti", 29 May 2019 (in Slovak), see https://ekonomika.sme.sk/c/22132932/na-dostavbu-mochoviec-sa-pozru-medzinarodni-experti.html, accessed 2 June 2019.

1306 - *The Slovak Spectator*, "International experts to check the completion of the Mochovce plant", 29 May 2019, see https://spectator.sme.sk/c/22133351/international-experts-to-check-the-completion-of-the-mochovce-plant.html, accessed 2 June 2019.

1307 - Chris Johnstone, "ČEZ left with problematic Slovak nuclear joint venture after Rosatom talks die", *Radio Praha*, 7 March 2014, see http://www.radio.cz/en/section/business/cez-left-with-problematic-slovak-nuclear-joint-venture-after-rosatom-talks-die, accessed 29 April 2018.

Also later negotiations with China were fruitless. The Slovak Environment Ministry approved the environmental impact assessment report in April 2016, with construction scheduled to begin by 2021.[1308] The EIA process for a given project is legally valid for seven years, i.e. until 2023. In May 2019, Prime Minister Peter Pellegrini said that the project could proceed "when economic parameters and the situation on the energy market permit".[1309]

Slovenia



Slovenia jointly owns the Krško nuclear power plant with Croatia—a 696-MW Westinghouse Pressurized Water Reactor (PWR). In 2018, it provided 5.5 TWh or 35.9 percent of Slovenia's electricity, down from 6.0 TWh or 39.1 percent in 2017, and below the maximum of 42.4 percent in 2005. The load factor of Krško was the 2nd highest in the world in 2017, averaged 90.7 percent in 2018, down from 98.7 percent in 2017, but still one of only four countries whose load factor exceeded 90 percent that year.

The reactor was started in 1981 with an initial operational life of 40 years. In July 2015, an Inter-State Commission agreed to extend the plant's operational life to 60 years, so that would continue until 2043, as well as to construct a dry storage facility for the spent fuel.[1310] In May 2016, a spokeswoman for the operator NEK (Nuklearna Elektrarna Krško) said: "The lifespan of Krško has been extended providing that the plant passes a security check every 10 years with the next checks due in 2023 and 2033."[1311] In 2018, the plant announced around €50 million worth of investment (around US$$_{2018}$57 million) being planned for 2019, mostly for completing safety upgrades and replacing obsolete equipment.[1312]

In January 2010, an application was made by the nuclear operator to the Ministry of Economy to build an additional unit, but no advancement of the project has been made since.

1308 - Energia, "Nová atómka v Bohuniciach má zelenú od MŽP", 19 April 2017 (in Slovak), see http://energia.sk/dolezite/jadrova-energia/nova-atomka-v-bohuniciach-ma-zelenu-od-mzp/19850/, accessed 29 April 2018.

1309 - Martin Dargaj, "Premiér Pellegrini oživil projekt novej jadrovej elektrárne v Bohuniciach", *vEnergetike.sk*, *WebNoviny*, 2 May 2019, see https://venergetike.sk/premier-pellegrini-ozivil-projekt-novej-jadrovej-elektrarne-v-bohuniciach/, accessed 16 June 2019.

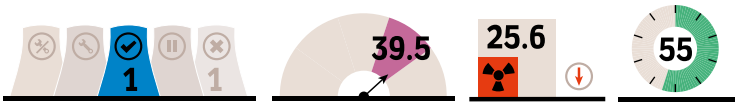
1310 - *WNN*, "Partners agree on life extension for Krsko", 21 July 2015, see http://www.world-nuclear-news.org/C-Partners-agree-on-life-extension-for-Krsko-2107154.html, accessed 20 April 2017.

1311 - *NEI*, "Life Extension for Slovenia's Krslo NPP", 6 May 2016, see http://www.neimagazine.com/news/newslife-extension-for-slovenias-krslo-npp-4885976/, accessed 1 July 2018.

1312 - *Slovenia Times*, "Krško nuclear plant operating efficiently, upgrades planned", 27 November 2018, see http://www.sloveniatimes.com/krsko-nuclear-plant-operating-efficiently-security-upgrade-on-track, accessed 18 April 2019.

FORMER SOVIET UNION

Armenia



Armenia has one remaining reactor at the Medzamor (also known as Metsamor) nuclear power plant, situated within 30 kilometers of the capital Yerevan. Armenian-2 provided 1.9 TWh or 25.6 percent of the country's electricity in 2018, a significant drop from 2017 with 2.4 TWh and 32.5 percent, and significantly below the maximum nuclear share of 45 percent in 2009. Armenia has the lowest lifetime load factor of any nuclear country in the world, averaging 53.4 percent; in 2018, the load factor was 55.2 percent. Output will fall in 2019, as the reactor is expected to be closed for most of the second half of the year for refurbishment and upgrade.

The reactor started generating electricity in January 1980 and is a first-generation, Soviet-designed VVER 440-230. In December 1988, Armenia suffered a major earthquake that killed some 25,000 people and led to the rapid closure of its two reactors in March 1989. During the early 1990s and following the collapse of the former Soviet Union, a territorial dispute between Armenia and Azerbaijan resulted in an energy blockade that led to significant power shortages. This led to the government's decision in 1993 to re-open unit 2 at Medzamor. In October 2012, the Armenian Government announced that it would operate the Medzamor unit until 2026. The extension was made possible by a Russian loan of US$270 million and a US$30 million grant.[1313] In 2011, the Armenian Nuclear Regulatory Authority granted the reactor an extension of its operating license until 2021, subject to annual safety demonstrations since 2016.[1314]

In June 2016, the European Nuclear Safety Regulators Group (ENSREG) issued the "EU Peer Review Report of the Armenian Stress Tests."[1315] The report confirms numerous safety-related problems. In September 2017, the European Commission published its proposed partnership agreement with Armenia, which included recommendations for co-operation on "the closure and safe decommissioning of Medzamor nuclear power plant and the early adoption of a road map or action plan to that effect."[1316]

In late 2018 the International Atomic Energy Agency (IAEA), at request of the Armenia Government, undertook a Safety Aspects Long-Term Operational review mission. The Government has said it will make the report public,[1317] but as of mid-2019 had not done so.

1313 - *NEI*, "Armenian NPP to close for refurb", 21 March 2019, see https://www.neimagazine.com/news/newsarmenian-npp-to-close-for-refurb-7054023/, accessed 19 April 2019.

1314 - IAEA, "IAEA Concludes Long-Term Operational Safety Review at Armenia's Nuclear Power Plant", Press Release, 10 December 2018, see https://www.iaea.org/newscenter/pressreleases/iaea-concludes-long-term-operational-safety-review-at-armenias-nuclear-power-plant, accessed 12 May 2019.

1315 - ENSREG, "EU Peer Review Report of the Armenian Stress Tests", European Nuclear Safety Regulators Group, June 2016, see http://www.ensreg.eu/sites/default/files/attachments/2016-07-20_4259241_armenia_stress_tests_report-_ensreg_template_final.pdf, accessed 1 May 2018.

1316 - European Commission, "Annex 1 to the Joint Proposal for a Council Decision on the conclusion, on behalf of the European Union, of the Comprehensive and Enhanced Partnership Agreement between the European Union and the European Atomic Energy Community and their Member States, of the one part and the Republic of Armenia, of the other part", Council of the European Union, Interistitutional File 2017/0238 (NLE), 25 September 2017, see https://eeas.europa.eu/sites/eeas/files/eu-armenia_comprehensive_and_enhanced_partnership_agreement_cepa.pdf, accessed 1 May 2018.

1317 - IAEA, "IAEA Concludes Long-Term Operational Safety Review at Armenia's Nuclear Power Plant", 2018, op. cit.

The Armenia Government stated that "it is impossible to shut down the nuclear power plant without launching an alternative facility—in our case another nuclear reactor."[1318]

Early June 2019, Armenia's reactor was shut down for substantial repair and upgrade. The outage is scheduled to last for 110 days. In March 2019, Prime Minister Nikol Pashinyan confirmed that there were no plans to close Medzamor and that "We will extend the lifecycle of the nuclear power station as long as possible, although it is clear that it cannot work forever."[1319]

For years, Armenia has been negotiating with Russia for the construction of a new 1000 MW unit and signed an intergovernmental agreement to that effect in August 2010. In March 2014, the energy minister admitted that it was having difficulty in attracting funds to start construction.[1320] Since then little progress appears to have been made with no clear choice on future technologies, with some proposing the construction of Small Modular Reactors (SMRs).[1321]

Some decisionmakers in the country started questioning the nuclear option, as in October 2017, then Justice Minister Davit Harutiunian stated: "Just imagine a possibility that it turns out tomorrow that modern technologies can generate the same amount of energy without a nuclear plant and that nuclear energy... is much more expensive for consumers. Which path should we opt for? Of course, modern technologies."[1322]

Russia

In 2018, nuclear energy contributed 17.9 percent to the country's electricity mix with a record production of 191.34 TWh. Rosatom is hoping to further increase production in the coming years, with output in 2019 expected to reach 214 TWh.[1323] Russia had shown a marked increase in its average load factor in recent years but slipped again in 2018 to 77.5 percent compared to 80 percent in 2017 and an average lifetime load factor of 66.6 percent.

The past 18 months have been mixed for the Russian nuclear industry. On the one hand there was the connection to the grid of the Rostov-4 reactor in February 2018—35 years after its construction was first started[1324]—and of the first unit at the Leningrad-II power station in March 2018. Fuel loading of a two-reactor floating nuclear power plant was completed in October 2018. Akademik Lomonosov is expected to be towed to its permanent location in

1318 - *Arka News Agency*, "Deputy Minister Says There Is Alternative to Shutting down Armenian Nuclear Power Plant", 11 April 2018.

1319 - *NEI*, "Armenian NPP to Close for Refurb", 21 March 2019, op. cit.

1320 - *BNE Intellinews*, "Armenia denies plans to abandon nuclear power plant project", 28 March 2014, see http://www.intellinews.com/armenia-denies-plans-to-abandon-nuclear-power-plant-project-500000301/?archive=bne, accessed 1 May 2018.

1321 - *Arka News Agency*, "Minister: Armenia not to give up the idea of building new nuclear power plant", 20 October 2017, see http://arka.am/en/news/technology/minister_armenia_not_to_give_up_the_idea_of_building_new_nuclear_power_plant/, accessed 1 May 2018.

1322 - Sargis Harutyunyan "Yerevan May Scrap Plans For New Nuclear Plant", *Azututyun.am*, 17 October 2017, see https://www.azatutyun.am/a/28799958.html, accessed 1 May 2018.

1323 - *NEI*, "Russia plant to boost nuclear power generation", 18 April 2017, see http://www.neimagazine.com/news/newsrussia-plans-to-boost-nuclear-power-generation-5789303/, accessed 25 April 2017.

1324 - See WNISR, "The construction Saga of Rostov Nuclear Reactors 3 and 4", 14 February 2018, see https://www.worldnuclearreport.org/The-Construction-Saga-of-Rostov-Reactors-3-and-4.html, accessed 14 August 2018.

the Chukotka region in the summer of 2019.[1325] Then in April 2019, the second unit at the Novovoronezh-II power plant was given regulatory approval and grid connection occurred in May, with commercial operation expected by the end of the year.[1326]

While the first unit at Leningrad-I station, a Chernobyl-type RBMK, was closed in December 2018, decommissioning of an 11 MW reactor at Bilibino—which had remained shut down since March 2018—was approved in early 2019. Consequently, as of July 2019, there are 36 reactors operating in the Russian Federation.

In addition to the small Akademik Lomonosov units, three large reactors remain under construction, Leningrad 2-2 as well as Kursk 2-1 and 2-2, whose construction started respectively in April 2010, in April 2018 and in April 2019.

The "floating reactors" (Akademik Lomonosov-1 and -2), are nominally 32 Mwe each. These were ordered in February 2009 and were expected to be delivered to the customer at the end of 2012.[1327] Critics of the project point out that the risk of accidents on a floating nuclear plant is greatly increased because they are even more susceptible to the elements, subject to threats of piracy, and if deployed widely would increase the risks of nuclear material proliferation.[1328]

Two VVER-1200 MW units were being built at the Leningrad nuclear power plant, at Sosnovy Bor, near St. Petersburg. At the time of ordering, the reactors were initially expected to start up in 2013 and 2016 respectively. Unit 1 was connected to the grid in March 2018,[1329] and reached commercial operation in October 2018.[1330] In August 2018, the turbine equipment was installed on Unit 2,[1331] with commercial operation expected in February 2022.[1332]

Construction started at the Baltic-1 unit, a 1109 MW VVER-491 reactor, in February 2012. However, construction was suspended in June 2013 for a variety of reasons, including recognition of the limited market for the electricity. Accordingly, WNISR pulled the project off the construction listing. Despite no indication that construction has restarted, the project remains "under construction" in International Atomic Energy Agency (IAEA) statistics.

In June 2016, the Russian regulator Rostechnadzor granted a construction license for Kursk 2-1. It was suggested in 2017 that 16.5 billion rubles (US$274 million) were allocated

1325 - *WNN*, "First reactor on Russia's floating plant starts up", 5 November 2018, see http://www.world-nuclear-news.org/Articles/First-reactor-on-Russia-s-floating-plant-starts-up, accessed 19 April 2019. In August 2019, the Akademik Lomonosov was reported to be towed to the port of Pevek on the Chukotka Peninsula in the east Arctic.

1326 - *WNN*, "Novovoronezh II-2 starts pilot operation", 4 June 2019, see http://world-nuclear-news.org/Articles/Novovoronezh-II-2-starts-pilot-operation, accessed 9 June 2019.

1327 - *NEI*, "KLT-40S nuclear barge project still afloat", 9 March 2010.

1328 - Martin Matishak, "Floating Nuclear Reactors Could Fall Prey to Terrorists, Experts Say", Nuclear Threat Initiative, 13 August 2010, see http://www.nti.org/gsn/article/floating-nuclear-reactors-could-fall-prey-to-terrorists-experts-say/, accessed 1 May 2018.

1329 - Rosatom, "Leningrad NPP: Unit 1 with VVER-1200 connected to the national grid", (Press Release), 12 March 2018, see http://www.rosatom.ru/en/press-centre/news/leningrad-npp-unit-1-with-vver-1200-connected-to-the-national-grid/, accessed 30 April 2018.

1330 - Rosatom, "Leningrad-II unit 1 enters final stage of commissioning", Press Release, 27 March 2018, see http://rosatom.ru/en/press-centre/news/leningrad-ii-unit-1-enters-final-stage-of-commissioning/, accessed 2 April 2018.

1331 - *WNN*, "Turbine equipment installed at Leningrad II-2", 7 August 2018, see http://www.world-nuclear-news.org/Articles/Turbine-equipment-installed-at-Leningrad-II-2, accessed 19 April 2019.

1332 - WNA, "Nuclear Power in Russia", May 2019, see http://www.world-nuclear.org/information-library/country-profiles/countries-o-s/russia-nuclear-power.aspx, accessed 9 June 2019.

for construction,[1333] with completion expected in 2022.[1334] At construction start in April 2018, completion was rescheduled to late 2023.[1335] Construction was launched at Kursk 2-2 a year later.[1336] This could be a particularly important project, as it would be the first of the latest Russian design, the VVER-TOI (VVER-V-510), which is said to be a 1200 MW, Generation-III+ design and destined for export.

In August 2016, a Government decree called for the construction of an additional 11 reactors by 2030, including two new fast breeder reactors, a VVER-600 at Kola and seven new VVER-TOI units at Kola, Smolensk, Nizhny Novgorod, Kostrom and Tatar.[1337] However, in early 2017 the CEO of Rosatom said that the government would end state support for the construction of new nuclear units in 2020 and therefore any new reactors would have to have to be financed primarily via commercial nuclear energy projects on the international market.[1338] Even before this date, the budget for construction of new reactors was expected to be in 2018, 2019 and 2020, a modest 15.7 billion rubles (US$250 million), 16.6 billion rubles (US$260 million) and 17.7 billion rubles (US$280 million) respectively,[1339] which may explain the lack of new construction in Russia beyond Kursk II.

Rosatom has reluctantly provisionally agreed to postpone by one year the launch of its next two VVERs, so that the wholesale market can more easily absorb another round of price increases. A previously agreed arrangement to encourage investment in power generation enables investors to earn a 10.5 percent return over a 20-year period. This can have a significant impact on the local electricity market. Following the completion of the 880 MW fast reactor in the Urals and a VVER-1200 in southern Russia, the wholesale price of electricity increased by 15–20 percent compared to the period prior to commissioning the two units. The Energy Consumers Association has estimated on average the electricity tariff would increase by 18 percent per year if the next four reactors under construction were completed by the end of the decade.[1340]

Russia has closed eight power generating reactors: Obninsk-1, Beloyarsk-1 and -2, Bilibino-1, Leningrad 1-1 and Novovoronezh 1-3. The average age of the Russian reactor fleet is now 29.1 years, with two thirds being 31 years or more, of which 8 over 40 (see **Figure 58**). Therefore, a key issue for the industry is how to manage its aging units.

1333 - Tatiana Kanunnikova, "Rosenergoatom invests $274m in building Kursk NPP this year", *Construction.RU*, 12 January 2017, see http://russianconstruction.com/news-1/26133-rosenergoatom-invests-274m-in-building-kursk-npp-this-year.html, accessed 1 May 2018.

1334 - *NIW*, "Briefs - Russia", 10 July 2017.

1335 - *NEI*, "Russia to start building Kursk-II in first half of 2018", 23 January 2018, see http://www.neimagazine.com/news/newsrussia-to-start-building-kursk-ii-in-first-half-of-2018-6033221/, accessed 1 May 2018.

1336 - Rosenergoatom, "The construction of unit 2 of Kursk NPP-2 has begun", Press Release, Atominfo.ru, 15 April 2019, see http://atominfo.ru/newsy/z0529.htm, accessed 19 April 2019.

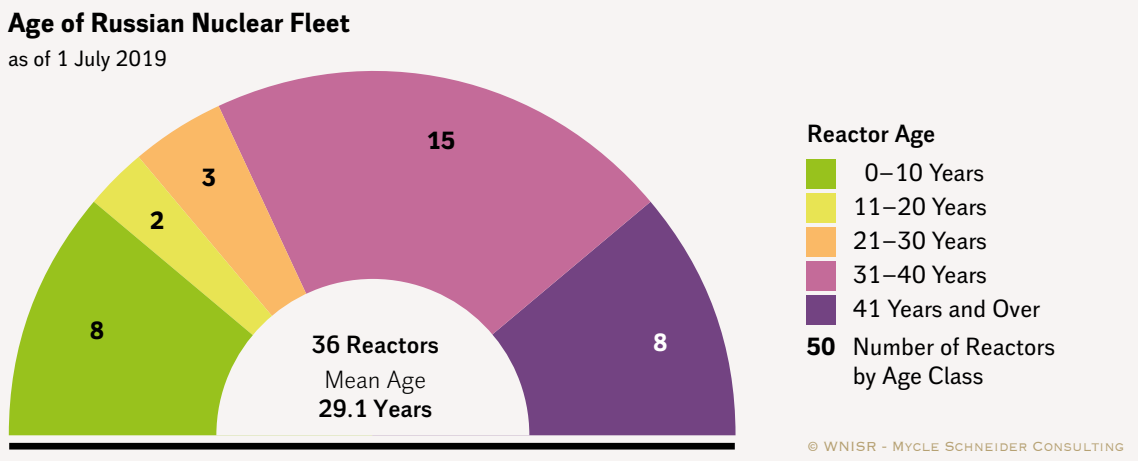
1337 - *WNN*, "Russia to build 11 new nuclear reactors by 2030", 10 August 2016, see http://www.world-nuclear-news.org/NP-Russia-to-build-11-new-nuclear-reactors-by-2030-10081602.html, accessed 1 May 2018.

1338 - WNA, "Nuclear Power in Russia", May 2019.

1339 - *NIW*, "Briefs—Russia", 22 September 2017.

1340 - Gary Peach, "Newbuild Rollout Impacts Large Energy Users", *NIW*, 2 March 2018.

Figure 58 | Age Distribution of the Russian Nuclear Fleet



Sources: WNISR, with IAEA-PRIS, 2019

There are mainly three classes of reactors in operation: the RBMK (a graphite-moderated reactor of the Chernobyl type), the VVER440, and the VVER1000. Designed for an operational lifetime of 30 years, both the RBMKs and VVER440s have been granted 15-year lifetime extensions to enable them to operate for 45 years, although there are plans to extend this in some cases to 60 years[1341], while the VVER1000s are expected to work for up to 50 years. Consequently, the closure of Leningrad 1-1 is potentially a significant event, as, after 46 years of operation, it would indicate that 60-year operational life is beyond the RMBKs, and could lead to the closure of 10 of the remaining 13 in this class in the next decade. According to the Norwegian NGO Bellona, life extensions have been granted without the necessary environmental impact assessments, which has both led to protests and made the life extensions "something of a legal grey area".[1342]

In December 2018, Rosatom's scientific-technical council adopted, but did not publish, a very long-term strategy (until 2100) that envisions the broad trajectory of Russia's nuclear industry development, with the continuation of the VVERs, but the foundation of the future program will be fast reactors with a closed fuel cycle. The strategy keeps open the debate on the type of fast reactor, with either lead- or sodium-cooled reactors still in the mix, depending on their practical performance.

Russia is an aggressive exporter of nuclear power, with, according to Rosatom, 36 separate projects including; Bangladesh (2 reactors at Rooppur); Belarus (2 reactors at Ostrovets); China (four reactors, two units at Tianwan, and two in the Liaoning province); Egypt (4 reactors at El Dabaa); Finland (1 reactor at Hanhikivi); Hungary (2 reactors at Paks); India (4 reactors at Kudankulam); Turkey (4 reactors at Akkuyu).[1343] But as of early 2019, there were only seven reactors actually under construction. According to environmental organization Ecodefense, actual investment in these projects totals US$36 billion— well short of the US$133 billion order

1341 - *NEI*, "Russia permanently closes Novovoronezh 3", 4 January 2017, see http://www.neimagazine.com/news/newsrussia-permanently-closes-novovoronezh-3-5709099/, accessed 1 May 2018.

1342 - Nils Bohmer, et.al., "Russian nuclear power–2017", Bellona, 30 May 2017, see http://network.bellona.org/content/uploads/sites/3/2017/05/2017-Russian-nuclear-power-NO-ISBN.pdf, accessed 1 May 2018.

1343 - Rosatom, "Projects", undated, see http://www.rosatom.ru/en/investors/projects/, accessed 9 June 2019.

book boasted by the industry.[1344] However, while many other projects are still to be officially launched and therefore may not come to fruition, the order book currently still makes Rosatom the world's largest exporter. Rosatom has identified a target of securing a portfolio of overseas orders for 10 years ahead in the amount of at least US$130 billion.[1345]

The relative success of Russia's export drive in a niche market of state-funded projects is not primarily due to the technology but to promised access to cheap financing that accompanies the deals. Therefore, the poor economic situation in Russia and the rise of national developers from China with equal access to capital are likely to undermine Rosatom's dominance of the very limited export opportunities.

Ukraine

Ukraine has 15 operating reactors, two of the VVER440 design and the rest VVER1000s. They provided 79.5 TWh or 53 percent of power generation in the country in 2018. Twelve out of the Ukraine's 15 reactors were completed in the late 1970s and 1980s and had an original design lifetime of thirty years. Ukraine has carried out a safety upgrade program for all of its 15 reactors, at an estimated cost of €1.45 billion (US$1.62 billion) in total, of which the European Bank for Reconstruction and Development (EBRD) and EURATOM will contribute €600 million between them (US$670 million). The nuclear operator has proposed to extend lifetimes of some of the reactors for another 20 years. The proposal was accepted and now constitutes a core element of the nuclear strategy approved by the government. The decision for lifetime extension has resulted in controversy around the EBRD and EURATOM loans, because these did not foresee any lifetime extension.

As of mid-2019, three nuclear reactors (two VVER 440s and one VVER 1000) at Rovno (also spelled Rivne) have been granted a lifetime extension of 20 years,[1346] two units at South Ukraine for 10 years, and four units at Zaporizhzhya power plant for 10 years.[1347] International firms, including Westinghouse[1348] and Toshiba,[1349] are to upgrade and extend the lifetimes of the Ukrainian reactors.

The International Atomic Energy Agency (IAEA) completed a Pre-SALTO (Safety Aspects of Long-Term Operation) peer review mission at the third unit at the South Ukraine plant in April 2018 and concluded that the "plant has made progress in the field of ageing management" but noted that it had only "initiated many activities to prepare for safe long term operation".

1344 - Vladimir Slivyak, "Dreams and realities of the Russian reactor export", *EcoDefense*, March 2019.

1345 - *TASS*, "Rosatom's foreign orders portfolio remains at $ 130-140 billion", *Atominfo.ru*, 18 April 2019, see http://atominfo.ru/newsy/z0536.htm, accessed 19 April 2019.

1346 - *NEI*, "Life extension for Ukraine's Rovno 3", 23 July 2018, see https://www.neimagazine.com/news/newslife-extension-for-ukraines-rovno-3-6258731/, accessed 19 April 2019.

1347 - *NEI*, "Life extension for Ukraine's Zaporozhye 4", 16 October 2018, see https://www.neimagazine.com/news/newslife-extension-for-ukraines-zaporozhye-4-6803714/, accessed 19 April 2019.

1348 - Gary Peach, "Ukraine", *NIW*, 15 September 2017.

1349 - *NEI*, "Ukraine plans nuclear expansion", 26 October 2017, see http://www.neimagazine.com/news/newsukraine-plans-nuclear-expansion-5957453/, accessed 1 May 2018.

The initial IAEA report also concluded: "The plant has developed a catalogue of operational defects in heat exchanging tubes in the steam generators".[1350]

The lifetime extension of Rivne-1 and -2 is part of an ongoing controversy within the Espoo Convention on transboundary Environmental Impact Assessment (EIA), which concluded that Ukraine was in non-compliance for not executing an EIA before its decision to prolong the lifetime of these VVER440 reactors beyond their original technical lifetime of 30 years.[1351] Environmental groups in Ukraine have called upon European institutions to stop the support for "risky" life extension programs.[1352] The intermediary session of the Meeting of the Parties to the Convention on Environmental Impact Assessment in a Transboundary Context (Espoo Convention) adopted a decision in February 2019 that "despite the positive steps taken, Ukraine remains in non-compliance with its obligations under the Convention" in regard to the Rivne life-extension projects.[1353] In April 2017, the Ukrainian Ministry of Environment had sent official notification to neighboring countries on the start of the EIA for the lifetime extension of South Ukraine and at Zaporizhzhya.[1354]

Two reactors, Khmelnitsky-3 and -4, are officially under construction, but WNISR pulled them from the list. Building work started in 1986 and 1987 but stopped in 1990. In February 2011, Russia and Ukraine signed an intergovernmental agreement to complete the reactors, and in 2012, the Ukrainian Parliament adopted legislation to create a framework to finance the project, with 80 percent of the funds to be coming from Russia. However, in September 2015, the Ukrainian Parliament voted to cancel the project, with Deputy Energy Minister Alexander Svetelik blaming Russia for "failing to fulfill the obligation under the deal", and saying that an "alternative partner" would be sought.[1355] In January 2017, the Russian Government confirmed that the 2011 agreement on the completion of the units had been cancelled.[1356]

Subsequently, Skoda JS has been appointed as the main supplier for the completion of the reactors and an EIA procedure has begun.[1357] As part of the Espoo Convention, in the spring of 2019, the Austrian Government sent documents on the potential environmental impact, with a

1350 - IAEA, "IAEA Concludes Long-Term Operational Safety Review at South Ukraine Nuclear Power Plant", 25 April 2018, see https://www.iaea.org/newscenter/pressreleases/iaea-concludes-long-term-operational-safety-review-at-south-ukraine-nuclear-power-plant, accessed 27 April 2018.

1351 - UNECE, "EIA/IC/CI/4 Ukraine", United Nations Economic Commission for Europe, Undated, see http://www.unece.org/environmental-policy/conventions/environmental-assessment/areas-of-work/review-of-compliance/committee-initiative/eiaicci4-ukraine.html, accessed 1 May 2018.

1352 - Iryna Holovko, "Time for Europe to stop Ukraine's nuclear energy sector", *Energy Post*, 18 May 2016, see http://energypost.eu/time-europe-stop-supporting-ukraines-risky-nuclear-power-sector/, accessed 1 May 2018.

1353 - UNECE, "Compliance by Ukraine with its obligations under the Convention in respect of the extension of the lifetime of the Rivne nuclear power plant", February 2019, see http://www.unece.org/index.php?id=50226, accessed 9 June 2019.

1354 - Resource and Analysis Center "Society and Environment", "Ukraine starts transboundary environmental impact assessment for nuclear power plants", 19 April 2017, see http://www.rac.org.ua/en/for-media/press-releases--comments/19042017-ukraine-starts-transboundary-environmental-impact-assessment-for-nuclear-power-plants, accessed 1 May 2018.

1355 - Ed Adamczyk, "Ukraine scraps nuclear reactor deal with Russia", *UPI*, 16 September 2015, see https://www.upi.com/Top_News/World-News/2015/09/16/Ukraine-scraps-nuclear-reactor-deal-with-Russia/9811442413199/, accessed 1 May 2018.

1356 - *NEI*, "Russia ends Khmelnitsky construction agreement with Ukraine", 13 January 2017, see http://www.neimagazine.com/news/newsrussia-ends-khmelnitsky-construction-agreement-with-ukraine-5718894/, accessed 1 May 2018.

1357 - Energoatom, "Notice for the Environmental Impact Assessment for Khmelnisky 3 and 4", 2017, see http://eia.menr.gov.ua/uploads/documents/332/reports/10f33f0f9340fb1cd06c16c7bcc24950.pdf, accessed 2 May 2018.

comment period, for Governments and citizens until early May 2019.[1358] Despite this initiation of the EIA processes, there seems little chance that construction will restart in the near term.

In August 2017, the Government adopted an energy strategy which aims to maintain nuclear power's current generation share of about 50 percent up to 2035, while halving the level of energy intensity of the economy and increasing the renewable share to 25 percent (excluding hydro with 13 percent).[1359]

Proposals are now being developed to introduce a direct connection from Khmelnitsky-2 to the European market. The Ukraine-EU Energy Bridge project, with an estimated cost of €243 million (US$290 million), could be carried out in the form of a public-private partnership between the Ukrainian state and an investor consortium consisting of Westinghouse Electric Sweden, Luxembourg-based Polenergia International, and EDF Trading. In January 2019, the Ministry of Energy announced a tender for the construction of power lines to Poland and substations, with bids received by mid-March 2019. Ukraine is already exporting electricity to Hungary, Romania and Slovakia through the Burshtyn "energy island" and to Poland and Moldova, while also importing electricity from Russia and Belarus. The Khmelnitsky project foresees electricity export in two ways: via the 750-kV transmission line to Rzeszów in Poland and the line to the Albertirsa substation in Hungary. Upgrading work on these lines will enable the addition of 1000 MWe of nuclear power to the existing export potential of Burshtyn Energy Island.[1360]

1358 - Austrian Ministry of Environment, "UVP KKW Khmelnitsky 3&4", Public Consultation Documents, 2019, see http://www.umweltbundesamt.at/umweltsituation/uvpsup/espooverfahren/espoo_ukraine/kkwkhmelnitsky34/, accessed 23 April 2019.

1359 - *NEI*, "Ukraine reveals new energy strategy", 28 August 2017, see http://www.neimagazine.com/news/newsukraine-reveals-new-energy-strategy-5910630/ accessed 1 May 2018.

1360 - *WNN*, "Energoatom awaits approval for energy bridge tender", 18 June 2019, see http://www.world-nuclear-news.org/NP-Energoatom-awaits-approval-for-energy-bridge-tender-18041801.html, accessed 9 June 2019.

ANNEX 2 – STATUS OF CHINESE NUCLEAR FLEET

Table 23 | Chinese Nuclear Reactors in Operation (as of 1 July 2019)

Reactor	Model	Net Capacity (MWe)	Construction Start	Grid Connection	Commercial Operation
Changjiang-1	CNP-600	601	25/04/2010	07/11/2015	25/12/2015
Changjiang-2	CNP-600	601	21/11/2010	20/06/2016	12/08/2016
Daya Bay-1	M310	944	07/08/1987	31/08/1993	01/02/1994
Daya Bay-2	M310	944	07/04/1988	07/02/1994	06/05/1994
Fangchenggang-1	CPR-1000	1 000	30/07/2010	25/10/2015	01/01/2016
Fangchenggang-2	CPR-1000	1 000	23/12/2010	15/07/2016	01/10/2016
Fangjiashan-1	CPR-1000	1 012	26/12/2008	04/11/2014	15/12/2014
Fangjiashan-2	CPR-1000	1 012	17/07/2009	12/01/2015	12/02/2015
Fuqing-1	CPR-1000	1 000	21/11/2008	20/08/2014	22/11/2014
Fuqing-2	CPR-1000	1 000	17/06/2009	06/08/2015	16/10/2015
Fuqing-3	CPR-1000	1 000	31/12/2010	07/09/2016	24/10/2016
Fuqing-4	CPR-1000	1 000	01/10/2012	29/07/2017	17/09/2017
Haiyang-1	AP-1000	1 170	24/09/2009	17/08/2018	22/10/2018
Haiyang-2	AP-1000	1 170	21/06/2010	13/10/2018	09/01/2019
Hongyanhe-1	CPR-1000	1 061	18/08/2007	01/02/2013	06/06/2013
Hongyanhe-2	CPR-1000	1 061	28/03/2008	23/11/2013	13/05/2014
Hongyanhe-3	CPR-1000	1 061	07/03/2009	23/03/2015	16/08/2015
Hongyanhe-4	CPR-1000	1 061	15/08/2009	01/04/2016	19/09/2016
Ling Ao-1	M310	950	15/05/1997	26/02/2002	28/05/2002
Ling Ao-2	M310	950	28/11/1997	15/12/2002	08/01/2003
Ling Ao-3	CPR-1000	1 007	15/12/2005	15/07/2010	15/09/2010
Ling Ao-4	CPR-1000	1007	15/06/2006	03/05/2011	07/08/2011
Ningde-1	CPR-1000	1 018	18/02/2008	28/12/2012	15/04/2009
Ningde-2	CPR-1000	1 018	12/11/2008	04/01/2014	04/05/2014
Ningde-3	CPR-1000	1 018	08/01/2010	21/03/2015	10/06/2015
Ningde-4	CPR-1000	1018	29/09/2010	29/03/2016	21/06/2016
Qinshan-1	CNP-300	298	20/03/1985	15/12/1991	01/04/1994
Qinshan 2-1	CNP-600	610	02/06/1996	06/02/2002	15/04/2002
Qinshan 2-2	CNP-600	610	01/04/1997	01/03/2004	03/05/2004
Qinshan 2-3	CNP-600	619	28/03/2006	01/08/2010	05/10/2010
Qinshan 2-4	CNP-600	619	28/01/2007	25/11/2011	30/12/2011
Qinshan 3-1	CANDU 6	677	08/06/1998	09/10/2002	31/12/2002
Qinshan 3-2	CANDU 6	677	25/09/1998	12/06/2003	24/07/2003
Sanmen-1	AP-1000	1 157	19/04/2009	30/06/2018	21/09/2018
Sanmen-2	AP-1000	1 157	15/12/2009	24/08/2018	05/11/2018

Reactor	Model	Net Capacity (MWe)	Construction Start	Grid Connection	Commercial Operation
Taishan-1	EPR-1750	1 660	28/10/2009	29/06/2018	13/12/2018
Taishan-2	EPR-1750	1 660	15/04/2010	28/06/2019	
Tianwan-1	VVER V-428	990	20/10/1999	12/05/2006	17/05/2007
Tianwan-2	VVER V-428	990	20/10/2000	14/05/2007	16/08/2007
Tianwan-3	VVER V-428M	1 045	22/12/2012	30/12/2017	14/02/2018
Tianwan-4	VVER V-428M	1 045	27/09/2013	27/10/2018	22/12/2018
Yangjiang-1	CPR-1000	1 000	16/12/2008	31/12/2013	25/03/2014
Yangjiang-2	CPR-1000	1 000	04/06/2009	10/03/2015	05/06/2015
Yangjiang-3	CPR-1000	1 000	15/11/2010	18/10/2015	01/01/2016
Yangjiang-4	CPR-1000	1 000	17/11/2012	08/01/2017	15/03/2017
Yangjiang-5	ACPR-1000	1 000	18/09/2013	23/05/2018	12/08/2018
Yangjiang-6	ACPR-1000	1 000	31/12/2013	29/06/2019	
Total Reactors in Operation: 47 Reactors / 45.5 GWe					

Sources: WNISR with IAEA-PRIS, 2019

Table 24 | Chinese Nuclear Reactors in LTO

Reactor	Model	Net Capacity (MWe)	Construction Start	Grid Connection	Commercial Operation
CEFR	BN-20	20	10/05/2000	21/07/2011	

Sources: WNISR with IAEA-PRIS, 2019

Note

The China Experimental Fast Reactor (CEFR) is not primarily a power generating reactor. However, as it was connected to the grid in 2011 at about 40 percent power and achieved full power for 72 hours starting 18 December 2014[1361], it is included in the WNISR. According to one source in China, the reactor has not been operating since December 2014, as it is lacking fuel. Other sources are also pointing to fuel issues.[1362] We have therefore decided to take it off the operational status and put it into Long-Term Outage (LTO) as of December 2014. In January 2017, an agreement entered into force, for Russian Rosatom's subsidiary TVEL fabricating fuel for CEFR in 2017 and 2018 for loading into the reactor in 2019.[1363]. In July 2019, Rosatom announced that TVEL had delivered "a batch of fuel" for the CEFR reactor. [1364]

1361 - See *Xinhua in China Securities Journal*, "China experimental fast reactor runs at full capacity", 19 December 2014, see http://www.cs.com.cn/english/ei/201412/t20141219_4595461.html, accessed 28 May 2018.

1362 - Marl Hibbs, "Rethinking China's Fast Reactor", *Arms Control Wonk*, 17 February 2017, see https://www.armscontrolwonk.com/archive/1202830/rethinking-chinas-fast-reactor/, accessed 28 May 2018.

1363 - *NEI*, "Russia to supply more fuel for China's fast reactor", 5 January 2017, see http://www.neimagazine.com/news/newsrussia-to-supply-more-fuel-for-chinas-fast-reactor-5709961, accessed 28 May 2018.

1364 - Rosatom, "TVEL Fuel Company of ROSATOM Supplied Fuel for China Experimental Fast Reactor", 9 July 2019, see https://www.rosatom.ru/en/press-centre/news/tvel-fuel-company-of-rosatom-supplied-fuel-for-china-experimental-fast-reactor-/, accessed 25 July 2019.

ANNEX 3 – STATUS OF JAPANESE NUCLEAR FLEET

Table 25 | Status of Japanese Nuclear Reactor Fleet (as of 1 July 2019)

Operator	Reactor	MW	Startup Year	Age Years	Shutdown		NRA Compliance[b]		Status
					Date[a] dd/mm/yy	Duration	Application dd/mm/yy	Approval dd/mm/yy	
CHUBU	Hamaoka-3 (BWR)	1 056	1987	32.4	29/11/10	8.6	16/06/15		LTO
	Hamaoka-4 (BWR)	1 092	1993	26.4	13/05/11	8.1	14/02/14[c]		LTO
	Hamaoka-5 (BWR)	1 325	2004	15.2	14/05/11	8.1			LTO
CHUGOKU	Shimane-2 (BWR)	789	1988	31.0	27/01/12	7.4	25/12/13		LTO
HEPCO	Tomari-1 (PWR)	550	1988	30.6	22/04/11	8.2	08/07/13		LTO
	Tomari-2 (PWR)	550	1990	28.8	26/08/11	7.8	08/07/13		LTO
	Tomari-3 (PWR)	866	2009	9.6	05/05/12	7.2	08/07/13		LTO
HOKURIKU	Shika-1 (BWR)	505	1993	26.5	01/03/11	8.3			LTO
	Shika-2 (BWR)	1 108	2005	14.0	11/03/11	8.3	12/08/14		LTO
JAPCO	Tokai-2 (BWR)	1 060	1978	41.3	21/05/11	8.1	20/05/14	18/10/18[d]	LTO
	Tsuruga-2 (PWR)	1 108	1986	33.0	07/05/11	8.1	05/11/15		LTO
KEPCO	Mihama-3 (PWR)	780	1976	43.4	14/05/11	8.1	17/03/15	26/10/16[e]	LTO
	Ohi-3 (PWR)	1 127	1991	28.1	02/09/13	(4.5)	08/07/13	01/09/17	Restarted 16/03/18
	Ohi-4 (PWR)	1 127	1992	27.0	15/09/13	(4.5)	08/07/13	01/09/17	Restarted 11/05/18
	Takahama-1 (PWR)	780	1974	45.3	10/01/11	8.5	17/03/15	10/06/16[f]	LTO
	Takahama-2 (PWR)	780	1975	44.4	25/11/11	7.6	17/03/15	10/06/16[f]	LTO
	Takahama-3 (PWR)	830	1984	35.1	20/02/12	(3.9)[e]	08/07/13	09/10/15	Restarted 9/06/17[g]
	Takahama-4 (PWR)	830	1984	34.7	21/07/11	(5.8)	08/07/13	09/10/15	Restarted 22/05/17
KYUSHU	Genkai-3 (PWR)	1 127	1993	26.0	11/12/10	(7.3)	12/07/13	14/09/17	Restarted 23/03/18
	Genkai-4 (PWR)	1 127	1996	22.6	25/12/11	(6.5)	12/07/13	14/09/17	Restarted 20/06/18
	Sendai-1 (PWR)	846	1983	35.8	10/05/11	(4.3)	08/07/13	27/05/15	Restarted 14/08/15
	Sendai-2 (PWR)	846	1985	34.2	01/09/11	(4.1)	08/07/13	27/05/15	Restarted 15/10/15
SHIKOKU	Ikata-3 (PWR)	846	1994	25.3	29/04/11	(5.3)	08/07/13	19/04/16	Restarted[h] 15/08/16

Operator	Reactor	MW	Startup Year	Age Years	Shutdown		NRA Compliance[b]		Status
					Date[a] dd/mm/yy	Duration	Application dd/mm/yy	Approval dd/mm/yy	
TEPCO	Kashiwazaki Kariwa-1 (BWR)	1 067	1985	34.4	06/08/11	7.9			LTO
	Kashiwazaki Kariwa-2 (BWR)	1 067	1990	29.4	19/02/07	12.4			LTO
	Kashiwazaki Kariwa-3 (BWR)	1 067	1992	26.6	16/07/07	12			LTO
	Kashiwazaki Kariwa-4 (BWR)	1 067	1993	25.5	16/07/07	12			LTO
	Kashiwazaki Kariwa-5 (BWR)	1 067	1989	29.8	25/01/12	7.4			LTO
	Kashiwazaki Kariwa-6 (BWR)	1 315	1996	23.4	26/03/12	7.3	27/9/13[i]	27/12/17	LTO
	Kashiwazaki Kariwa-7 (BWR)	1 315	1996	22.5	23/08/11	7.9	27/09/13	27/12/17	LTO
	Fukushima Daini-1 (BWR)	1 067	1981	29.6	11/03/11				Closed[j]
	Fukushima Daini-2 (BWR)	1 067	1983	27.7	11/03/11				Closed
	Fukushima Daini-3 (BWR)	1 067	1984	26.2	11/03/11				Closed
	Fukushima Daini-4 (BWR)	1 067	1986	24.2	11/03/11				Closed
TOHOKU	Higashi Dori-1 (BWR)	1 067	2005	13.8	06/02/11	8.4	20/06/14		LTO
	Onagawa-2 (BWR)	796	1994	25.5	06/11/10	8.6	27/12/13		LTO
	Onagawa-3 (BWR)	796	2001	18.1	11/03/11	8.3			LTO
Total: 37 Reactors / 35.9 GWe									

Sources: JAIF, NRA, compiled by WNISR, 2019

Notes

a – The shutdown dates are from JAIF, "Current Status of Nuclear Power Plants in Japan", Japan Atomic Industrial Forum, as of 6 June 2019, see https://www.jaif.or.jp/cms_admin/wp-content/uploads/2019/06/jp-npps-operation190606_en.pdf, accessed 2 July 2019.

b – The application and approval dates are from NRA, "Current circumstances regarding examinations for NPP adherence to new regulations", 15 May 2019. Gray dates refer to the first step (Permission for change in reactor-installation) or second step (Construction plan approval) of the procedure. All others indicate final agreement of the 3-step conformity review.

c – Application withdrawn and resubmitted on 26 January 2015.

d – Nuclear Regulatory Authority's (NRA) Approval for Basic Design (Step 2). In November 2018, NRA also approved lifetime extension to 60 years; see JAIF, "NRA Allows Tokai-2 to Be Operated for Sixty Years, a First for a BWR", 16 November 2018, see https://www.jaif.or.jp/en/nra-allows-tokai-2-to-be-operated-for-sixty-years-a-first-for-a-bwr/, accessed 28 April 2019.

e – Application for extension of operating period approved by NRA on 16 November 2016.

f – For both Takahama-1 and -2, the first two steps of the conformity review were achieved on 10 June 2016. The NRA also granted KEPCO approval of extension of operation for 20 years on 20 June 2016. For details, see NRA, "The NRA approved the extension of operation period of Takahama Power Station Units 1 and 2", 21 June 2016, see http://www.nsr.go.jp/data/000154256.pdf, accessed 14 July 2017.

g – Takahama-3 had operated briefly between 29 January and 10 March 2016, before it was shut down by court order. The "Shutdown Duration" is calculated until the first restart.

h – On 13 December 2017, the Hiroshima High Court ruled in favor of a citizen lawsuit and issued an injunction against operation of the Ikata-3 reactor, which remained in place until September 2018.

i – On 16 June 2017, TEPCO re-filed its application with the Nuclear Regulatory Authority (NRA) to confirm compliance with safety requirements for Kashiwazaki Kariwa-6 and -7. The NRA had requested resubmission in February 2017.

j – All 4 Fukushima Daini reactors are considered as closed by WNISR since March 2011. It is only in June 2018 that TEPCO announced that they would consider decommissioning the four reactors, and in July 2019 they confirmed the decision. As of 1 July 2019, these units were not considered "officially closed". Their age is calculated as of closure date. See TEPCO, "Fukushima Daini Nuclear Power Station to be Decommissioned", Press Release, 31 July 2019, see https://www7.tepco.co.jp/newsroom/press/archives/2019/hd_190731_01-e.html, accessed 2 August 2019.

ANNEX 4 – ABOUT THE AUTHORS

Mycle Schneider is an independent international analyst on energy and nuclear policy based in Paris. He is the Convening Lead Author and Publisher of the World Nuclear Industry Status Reports (WNISR). Mycle is a founding board member of the International Energy Advisory Council (IEAC) and serves as the Coordinator of the Seoul International Energy Advisory Council (SIEAC). He is a member of the International Panel on Fissile Materials (IPFM), based at Princeton University, U.S. He has provided information and consulting services, amongst others, to the Belgian Energy Minister, the French and German Environment Ministries, the U.S. Agency for International Development, the International Atomic Energy Agency, the European Commission, and the French Institute for Radiation Protection and Nuclear Safety. Schneider has given evidence and held briefings at national Parliaments in 15 countries and at the European Parliament. He has given lectures at over 20 universities and engineering schools around the globe. In 1997, along with Japan's Jinzaburo Takagi, he received the Right Livelihood Award, also known as the "Alternative Nobel Prize".

Antony Froggatt joined Chatham House in 2007 and is a Senior Research Fellow in the Energy, Environment and Resources Department. He studied energy and environmental policy at the University of Westminster and the Science Policy Research Unit at Sussex University and is currently an Associate Member of the Energy Policy Group at Exeter University. For over 20 years he has been involved in the publication of the World Nuclear Industry Status Report (WNISR). At Chatham House, he specializes on global electricity policy and the public understanding of climate change. He has worked as an independent consultant for two decades with environmental groups, academics and public bodies in Europe and Asia as well as a freelance journalist. His most recent research project is understanding the energy and climate policy implications of Brexit.

Julie Hazemann, based in Paris, France, is the Director of EnerWebWatch, an international documentation monitoring service, specializing in energy and climate issues, launched in 2004. As an information engineer and researcher, she has maintained, since 1992, a world nuclear reactor database and undertakes data-modelling and data-visualization work for the World Nuclear Industry Status Report (WNISR). Active in information and documentation project-management, she has a strong tropism for information structuration, dataviz and development of electronic information products. She also undertakes specialized translation and research activities for specific projects. She is a member of négaWatt (France) and develops EnerWebWatch in the framework of the Coopaname Coop.

Diana Ürge-Vorsatz Diana Ürge-Vorsatz is a Professor and former Director of the Center for Climate Change and Sustainable Energy Policy (3CSEP) at the Central European University (CEU) in Budapest. She is Vice-Chair of Working Group III of the Intergovernmental Panel on Climate Change (IPCC).

She conducted her Ph.D. studies at the University of California (Berkeley and Los Angeles), and has been a Fulbright Scholar. After four years in the USA, Diana Ürge-Vorsatz returned to Europe and has been devoting her research and teaching activities to the promotion of sustainable energy policy for the Central and Eastern European region. She has worked on and directed several international research projects for organizations including the European Commission, the Global Environment Facility, the United Nation's Environment Program, the World Energy Council and the World Bank. She has been regularly advising the Hungarian government on environmental, climate change and energy issues.

Dr. Ürge-Vorsatz has authored over 120 publications and has been serving on several advisory and governing bodies of organizations including U.K. Energy Research Centre, Renewable Energy and Energy Efficiency Partnership (REEEP), the European Council for an Energy Efficient Economy (ECEEE), among others. She serves on the United Nation's Special Expert Group on Climate Change. She has been acknowledged to share the Nobel Peace Prize of 2007 that was awarded to the IPCC and received the Hungarian Republic's Medium Cross Award.

Tadahiro Katsuta holds a PhD in plasma physics from Hiroshima University (1997). He is currently a Professor at Meiji University, Tokyo, Japan. During 2014–15 he was a Visiting Fellow in the Program on Science and Global Security (PSGS) at Princeton University, U.S. He is researching Japan's spent fuel management issues. He is also studying the Fukushima Daiichi nuclear power plant accident and following the new regulation standards with a focus on technical and political aspects. He has been appointed by Japan's Nuclear Regulation Authority (NRA) as a member of the study teams on the New Regulatory Requirements for Commercial Nuclear Power Reactors, for Nuclear Fuel Facilities, Research Reactors, and for Nuclear Waste Storage/Disposal Facilities. During 2008–09, he conducted research on multilateral nuclear fuel cycle systems as a Visiting Fellow at PSGS. During 2006–08, he carried out research at the University of Tokyo on separated plutonium issues linked to the Rokkasho reprocessing plant. During 1999–2005, he worked as a researcher at the Citizens' Nuclear Information Center (CNIC) in Tokyo.

M.V. Ramana is the Simons Chair in Disarmament, Global and Human Security with the Liu Institute for Global Issues at the School of Public Policy and Global Affairs, University of British Columbia, Vancouver, Canada. He received his Ph.D. in theoretical physics from Boston University. Ramana is the author of "The Power of Promise: Examining Nuclear Energy in India" (Penguin Books, 2012) and co-editor of "Prisoners of the Nuclear Dream" (Orient Longman, 2003). He is a member of the International Panel on Fissile Materials (IPFM) and the Canadian Pugwash Group. He is the recipient of a Guggenheim Fellowship and a Leo Szilard Award from the American Physical Society.

Amory B. Lovins is cofounder and Chief Scientist of Rocky Mountain Institute; energy advisor to governments (including the U.S. Department of Energy and Defense) and major firms (including 100+ utilities) in 70+ countries for 45+ years; author of 31 books and 640+ papers; an integrative designer of superefficient buildings, factories, and vehicles; and a student of nuclear issues for 55 years.

He has received the Blue Planet, Volvo, Zayed, Onassis, Nissan, Shingo, and Mitchell Prizes, the MacArthur and Ashoka Fellowships, the Happold, Benjamin Franklin, and Spencer Hutchens Medals, 12 honorary doctorates, and the Heinz, Lindbergh, Right Livelihood ("alternative Nobel"), National Design, and World Technology Awards. In 2016, the President of Germany awarded him the Officer's Cross of the Order of Merit (*Bundesverdienstkreuz 1. Klasse*).

A Harvard and Oxford dropout, former Oxford don, honorary U.S. architect, and Swedish engineering academician, he has taught at ten universities, most recently Stanford's Engineering School and the Naval Postgraduate School (but only on topics he's never formally studied, so as to retain beginner's mind). He served in 2011–18 on the U.S. National Petroleum Council. *Time* has named him one of the world's 100 most influential people, and *Foreign Policy*, one of the 100 top global thinkers. His latest books include *Natural Capitalism* (1999), *Small Is Profitable* (2002), *Winning the Oil Endgame* (2004), *The Essential Amory Lovins* (2011), and *Reinventing Fire* (2011).

His main recent efforts include supporting RMI's collaborative synthesis, for China's National Development and Reform Commission, of an ambitious efficiency-and-renewables trajectory that informed the 13th Five Year Plan; helping the Government of India design transformational mobility; and exploring how to make integrative design the new normal, so investments to energy efficiency can yield expanding rather than diminishing returns.

Christian von Hirschhausen is Professor of Economics at the Workgroup for Economic and Infrastructure Policy (WIP) at Berlin University of Technology (TU Berlin), and Research Director at DIW Berlin (German Institute for Economic Research). He obtained a PhD in Industrial Economics from the Ecole Nationale Supérieure des Mines de Paris, and was previously Chair of Energy Economics and Public Sector Management University of Technology (TU Dresden). Von Hirschhausen focuses on the regulation and financing of infrastructure sectors, mainly energy, and is a regular advisor to industry and policymakers, amongst them the World Bank, the European Commission, European Investment Bank, and several German Ministries. Von Hirschhausen also focusses on energy technologies, and is one of the coordinators of a research project on nuclear energy in Germany, Europe, and abroad, including the first independent monitoring of the decommissioning process of German nuclear power plants.

Ben Wealer is a Research Associate at the Workgroup for Economic and Infrastructure Policy (WIP) at Berlin University of Technology (TU Berlin), and guest researcher at DIW Berlin (German Institute for Economic Research). He holds an MSc in Industrial Engineering in the discipline of energy and resource management from TU Berlin. His field of research is nuclear power economics with a focus on organizational models for decommissioning of nuclear power plants and radioactive waste management, economics of nuclear power plant new-build, and the dual-use issues of nuclear power. Wealer is a long-term member of a research project on nuclear energy in Germany, Europe, and abroad run jointly by TU Berlin and DIW Berlin and he is a co-author of the first German independent decommissioning monitoring survey.

Agnès Stienne is an artist, cartographer, and independent graphic designer. She has contributed for over a decade to the French journal *Le Monde Diplomatique*, and the Visioncarto.net website dedicated to cartographical experimentation. She has created numerous "narrative cartographics" to illustrate a wide range of complex subjects and issues, including international treatises on armed conflicts, and the damages of wars. She currently leads a research project focusing on agricultural practices, "land grabbing" and other fundamental agriculture and food issues. The results of her research are featured on the Visioncarto.net website, as "geo-poetic" briefs, in which she uses aquarelle-paint to translate her findings into maps and data-visualizations. More recently her work was exhibited at the University Library of Valenciennes in Octobre 2018, and Montmorillon's Cartography Festival in May 2019. She contributed to the CIRAD-FAO Report "Agri-food Systems at risk: new trends and challenges" published in April 2019.

ANNEX 5 – ABBREVIATIONS

3/11	East Japan Great Earthquake, Fukushima Nuclear Accident
ABB	*Asea Brown Boveri* — Swiss-Swedish Electric Power Corporation
ABWR	Advanced Boiling Water Reactor
ADR	Alternative Dispute Resolution Center (Japan)
AEC	Atomic Energy Commission (U.S.) **or** Atomic Energy Council (Taiwan)
AECL	Atomic Energy of Canada Limited (Canada)
AEPS	Alternative Energy Portfolio Standards
AFP	*Agence France Presse* — French Press Agency
AGEB	*Arbeitsgruppe Energiebilanzen* — Working Group on Energy Balances of the German Institute for Economic Research (DIW)
AGR	Advanced Gas-cooled Reactor
AHWR	Advanced Heavy Water Reactor
ALPS	Advanced Liquid Processing System
ANAV	*Asociación Nuclear Ascó Vandellós II* — Nuclear Power Utility Ascó Vandellós II (Spain)
AR5	5th Assessment Report on Climate Change, of the Intergovernmental Panel on Climate Change
ARENH	*Accès Régulé à l'Énergie Nucléaire Historique* — Regulated Access to Historic Nuclear Energy
ASBL	Atomic Safety Licensing Board (U.S.)
ASN	*Autorité de Sûreté Nucléaire* — Nuclear Safety Authority (France)
ATMEA	Areva–MHI joint reactor design
B&W	Babcock & Wilcox
BAEC	Bangladesh Atomic Energy Commission
BNDES	Brazilian National Development Bank
BNEF	Bloomberg New Energy Finance
BP	BP plc / Beyond Petroleum
BPE	Basic Plan for long-term Electricity supply and demand (South Korea)
BREST	Reactor Design
BWR	Boiling Water Reactor
CANDU	*CANadian Deuterium Uranium* — Canadian Reactor Design
CAREM	*Central Argentina de Elementos Modulares* — Spanish Small Modular Reactor
CCC	Committee on Climate Change (U.K.)
CCS	Carbon Capture and Storage
CCSE	*La Cassa conguaglio per il settore elettrico* — Public Equalization Fund for the Electricity Sector—now CSEA (Italy)
CEA	*Commissariat à l'Énergie Atomique et aux Énergies Alternatives* — Alternative Energies and Atomic Energy Commission (France) **or** Central Electric Authority (India)
CEFR	China Experimental Fast Reactor
CEO	Chief Executive Officer
CEU	Central European University (Hungary)
ČEZ	*České Energetické Závody* — Public Power Utility (Czech Republic)

CfD	Contract for Difference
CGDD	*Commissariat général au développement durable* — General Commission for Sustainable Development (France)
CGN	China General Nuclear Corporation
CLP	Containment Liner Plate
CNEA	*Comision Nacional de Energia Atómica* — National Atomic Energy Commission (Argentina)
CNIC	Citizens' Nuclear Information Center (Japan)
CNNC	China National Nuclear Corporation
CNSC	Canadian Nuclear Safety Commission
CO_2	Carbon Dioxide
Cs-134/-137	Caesium-134 or -137
CSEA	*Cassa per i Servizi Energetici e Ambientali* — Public Fund for Energy & Environmental Services—formerly CCSE (Italy)
CSN	*Consejo de Seguridad Nuclear* — Nuclear Safety Council (Spain)
CVTR	Carolinas-Virginia Tube Reactor (U.S.)
CWIP	Construction? Works in Progress
DAE	Department of Atomic Energy (India)
DBE	Design Basis Earthquake
DCRM	Dynamic Control rod Reactivity Measurement
DECC	Department of Energy & Climate Change (U.K.)
DIW	*Deutsches Institut für Wirtschaftsforschung* — German Institute for Economic Research (Germany)
DOE	Department of Energy (U.S.) **or** Department of Energy (South-Africa)
DPP	Democratic Progressive Party (Taiwan)
EBITDA	Earnings Before Interest, Taxes, Depreciation, and Amortization
EBRD	European Bank for Reconstruction and Development
ECEEE	European Council for an Energy Efficient Economy
ECJ	European Court of Justice (EU)
EDF	*Éléctricité de France* — French Power Utility
EGAT	Electricity Generating Authority of Thailand
EIA	Energy Information Administration (U.S. Department of Energy) **or** Environmental Impact Assessment
ENEC	Emirates Nuclear Energy Corporation (UAE)
ENEL	*Ente Nazionale per l'Energia elettrica* — National Electric Power Corporation (Italy)
ENSI	*Eidgenössischen Nuklearsicherheitsinspektorat* — Federal Nuclear Safety Inspectorate (Switzerland)
ENSREG	European Nuclear Safety Regulators Group
ENTSO-E	European Network of Transmission System Operators for Electricity
EPH	*Energeticky a Prumyslovy Holding* — Energy and Industry Holding — privately-held Czech-Slovak company
EPR	European Pressurized water Reactors
EPSA	Electric Power Supply Association
EPZ	*Elektriciteits Produktiemaatschappij Zuid-Nederland* — Electricity Production Company South-Netherlands

ERI	Energy Research Institute (NDRC)
EU	European Union
EÜAS	*Elektrik Üretim A.Ş.* — Electricity Generation Company (Turkey)
EVN	Electricity of Vietnam
FANC	Federal Agency for Nuclear Control (Belgium)
FAO	Financial Accountability Office of Ontario (Canada)
FBI	Federal Bureau of Investigation (U.S.)
FBR	Fast Breeder Reactor
FEPC	Federation of Electric Power Companies (Japan)
FERC	Federal Energy Regulatory Commission (U.S.)
FL3	Flamanville-3
FTP	Federal Target Program (Russia)
FY	Financial Year
GCNEP	Global Centre for Nuclear Energy Partnership
GCR	Gas-Cooled Reactor
GDA	Generic Design Assessment
GDF	*Gaz De France* — French Power Utility (now known as Engie)
GDOS	General Directorate for the Environment (Poland)
Gen III	Generation III reactor
GP ESPN	*Groupe Permanent d'Experts pour les équipements sous Pression Nucléaires* — Advisory Committee for nuclear pressure equipment of the French Nuclear Safety Authority
HB6	House Bill 6 (U.S.)
HFT	Hot Functional Testing
HPC	Hinkley Point C
HTR	High Temperature Reactor
HWLWR	Heavy Water-Moderated Light Water-Cooled Reactor
IAEA	International Atomic Energy Agency
ICBC	Industrial and Commercial Bank of China
ICC	International Chamber of Commerce
IEA	International Energy Agency (OECD)
IEAC	International Energy Advisory Council
IEEFA	Institute for Energy Economics and Financial Analysis
IIDSF	Ignalina International Decommissioning Support Fund
IMF	International Monetary Fund
INIR	Integrated Nuclear Infrastructure Review
INPP	Ignalina Nuclear Power Plant
INRAG	International Nuclear Risk Assessment Group
IPCC	Intergovernmental Panel on Climate Change
IPFM	International Panel on Fissile Materials
IRENA	International Renewable Energy Agency
IRID	International Research Institute for Nuclear Decommissioning
IRP	Integrated Resource Plan

IRSN	Institut de Radioprotection et de Sûreté Nucléaire — Institute for Radiation Protection and Nuclear Safety (France)
ISO-NE	Independent System Operator-New England (U.S.)
JAEA	Japan Atomic Energy Agency
JAIF	Japan Atomic Industrial Forum, Inc.
JAPC	Japan Atomic Power Company
JAVYS	*Jadrová A VYradovacia Spoločnost'* — State-Owned Nuclear Power And Decommissioning Company (Slovakia)
JESS	*Jadrová energetická spoločnosť Slovenska* — Nuclear Power Company (Slovakia)
JPY	Japanese Yen
JSW	Japan Steel Works
KA-CARE	King Abdullah City for Atomic and Renewable Energy (Saudi Arabia)
KAERI	Korean Atomic Energy Research Institute (South Korea)
KANUPP	Karachi Nuclear Power Plant
KEPCO	Korean Electric Power Corporation (South Korea) **or** Kansai Electric Power Company (Japan)
KGHM	*Kombinat Górniczo-Hutniczy Miedzi* — Copper Mining and Smelting Industrial Complex (Poland)
KHNP	Korea Hydro & Nuclear Power Company (South Korea)
KKW	*Kernkraftwerk* — Nuclear Power Station (in German)
KLT-40S	Floating Reactor Design (Russia)
LBNL	Lawrence Berkeley National Laboraty
LCOE	Levelized Cost of Energy
LDP	Liberal Democratic Party (Japan)
LKP	Liberty Korea Party (South Korea)
LMP	Locational Marginal Price
LTE	Long-Term Enclosure or "Safe Storage"
LTO	Long-Term Outage
LTS	Long-Term Shutdown
LWGR	Light-Water Gas-Cooled Reactor
LWR	Light-Water Reactor
MEAG	Municipal Electric Authority of Georgia (U.S.)
METI	Ministry of Economy, Trade and Industry (Japan)
MHI	Mitsubishi Heavy Industries Ltd.
MHLW	Ministry of Health, Labor and Welfare (Japan)
MIT	Massachusetts Institute of Technology (U.S.)
MME	Ministry of Mines and Energy (Brazil)
MoE	Ministry of the Environment (Japan)
MOEA	Ministry of Economic Affairs (Taiwan)
MoFa	Ministry of Foreign Affairs (Lithuania)
MOTIE	Ministry of Trade, Industry and Energy (South Korea)
MoU	Memorandum of Understanding
MOX	uranium-plutonium Mixed Oxide fuel

NAO	National Audit Office (U.K.)
NDA	National Decommissioning Authority (U.K.)
NDC	Nationally Determined Contributions
NDRC	National Development and Reform Commission (China)
NEA	National Energy Administration (China)
	or Nuclear Energy Agency (OECD)
NEB	National Energy Board (Canada)
NEI	Nuclear Engineering International
	or Nuclear Energy Institute
NEK	*Nuklearna Elektrarna Krško* — Krško Nuclear Power Plant (Slovenia)
NGO	Non-Governmental Organization
NIW	Nuclear Intelligence Weekly (Publication)
NJBPU	New Jersey Board of Public Utilities (U.S.)
NJZ	*Nová Jadrová Zdroj* — Bohunice new-build Project (Slovakia)
NPCIL	Nuclear Power Corporation of India Ltd.
NPS	Nuclear Power Station
	or National Policy Statement (U.K.)
NPT	Non-Proliferation Treaty
NRA	Nuclear Regulatory Authority (Japan)
NRC	Nuclear Regulatory Commission (U.S. or Japan)
NRCan	Natural Resources Canada
NRDC	Natural Resources Defense Council
NSSC	Nuclear Safety and Security Commission (South Korea)
NW	Nucleonics Week (Publication)
NYPSC	New York Public Service Commission (U.S.)
OECD	Organisation for Economic Co-operation and Development
OKG	*Oskarshamns Kraftgrupp AB* — Oskarshamn Power Corporation (Sweden)
OL3	Olkiluoto-3 Project (Finland)
ONR	Office for Nuclear Regulation (U.K.)
OPC	Oglethorpe Power Corporation (U.S.)
OPPD	Omaha Public Power District (U.S.)
OPS	Oglethorpe Power Corporation (U.S.)
PAEC	Pakistan Atomic Energy Commission (Pakistan)
PCV	Primary Containment Vessel
PFBR	Prototype Fast Breeder Reactor
PG&E	Pacific Gas and Electric Company (U.S.)
PGE	Polska Grupa Energetyczna — State-owned Public Power Company (Poland)
PHWR	Pressurized High Water Reactor
PIEC	Integrated Energy and Climate Plan
PJM	Pennsylvania New Jersey Maryland Interconnection LLC (U.S.)
PLEX	Plant Life Extension
POSRV	pilot-operated safety relief valve

PPA	Power Purchase Agreement
PPE	Multi Annual Energy Plan (France)
PRIS	Power Reactor Information System
PSC	Public Service Commission (U.S.)
PSEG	Public Service Enterprise Group (U.S.)
PSGS	Program on Science and Global Security, Princeton University (U.S.)
PSOE	Partido Socialista Obrero Español — Spanish Socialist Worker's Party
PWR	Pressurized Water Reactor
PZEM	*Provinciale Zeeuwse Energie Maatschappij N.V.* — Energy Company of the Zeeland Province (Netherlands)
R&D	Research & Design **or** Research & Development
RAB	Regulated Asset Base
RBMK	Graphite-Moderated Boiling Water Reactor—Chernobyl Type
RCS	Reactor Coolant System
REEEP	Renewable Energy and Energy Efficiency Partnership
REN21	Renewable Energy Policy Network for the 21st Century
RPM	Reliability Pricing Model
RPV	Reactor Pressure Vessel
RTE	*Réseau de Transport d'Électricité* — Transmission System Operator (France)
RTO	Regional Transmission Organization
RVI	Reactor Vessel Internals
RWE	*Rheinisch-Westfälisches Elektrizitätswerk AG* — RWE AG — Rhine-Westphalia Power Utility (Germany)
S&P	Standard & Poor's
SAFCEI	Southern African Faith Communities Environment Institute
SALTO	Safety Aspects of Long-Term Operation
SCE	Southern California Edison (U.S.)
SCG&E	South Carolina Electric & Gas (U.S.)
SDG&E	San Diego Gas & Electric (U.S.)
SE	*Slovenské Elektrárne* — State Utility (Slovakia)
SEC	Securities and Exchange Commission (U.S.)
SELC	Southern Environmental Law Center (U.S.)
SFOE	Swiss Federal Office of Energy
SGHWR	Steam Generating Heavy Water Reactor
SIEAC	Seoul International Energy Advisory Council
SMART	System-Integrated Modular Advanced Reactor
SMR	Small Modular Reactor
SNN	*Societatea Nationala Nuclearelectrica* — National Nuclear Power Company (Romania)
SNPTC	Chinese State Nuclear Power Technology Corporation
Sogin	*Società Gestione Impianti Nucleari SpA* — State-owned company responsible for decommissioning & radioactive waste management (Italy)
SPIC	State Power Investment Corporation
SRO	Senior Reactor Operator

SSM	*Strålsäkerhetsmyndigheten* — Swedish Radiation Safety Authority
STUK	*Säteilyturvakeskus* — Radiation and Nuclear Safety Authority (Finland)
TEPCO	Tokyo Electric Power Company (Japan)
THORP	Thermal Oxide Reprocessing Plant
TMI	Three Mile Island Nuclear Power Plant (U.S.)
TU-Berlin	Berlin University of Technology
TVA	Tennessee Valley Authority
TVO	*Teollisuuden Voima's* — Nuclear Power Company (Finland)
U.K.	United Kingdom
U.S.	United States
U.S.DOE	U.S. Department of Energy
U.S.EIA	U.S. Energy Information Administration
UAE	United Arab Emirates
UAMPS	Utah Associated Municipal Power Systems (U.S.)
UCS	Union of Concerned Scientists
UNECE	UN Economic Commission for Europe
UNEP	United Nations Environment Program
UNGG	Uranium Naturel Graphite Gaz
UNSCEAR	United Nations Scientific Committee on the Effects of Atomic Radiation
UzAtom	Agency for Nuclear Energy (Uzbekistan)
VAT	Value-Added Tax
VD3 or VD4	3rd or 4th Decennial Safety Review (France)
VVER	*Vodo-Vodianoï Energuetitcheski Reaktor* — Russian Pressurized Water Reactor Design
WACC	Weighted Average Cost of Capital
WIP	Workgroup at the Workgroup for Economic and Infrastructure Policy
WNA	World Nuclear Association
WNISR	World Nuclear Industry Status Report
WNN	World Nuclear News
WTO	World Trade Organization
ZEC	Zero Emission Credits **or** Zero Emission Certificates (U.S.)
ZEN	Zero Emission Nuclear

Electrical and Other Units

kW	kilowatt (unit of installed electric power capacity)
kWh	kilowatt-hour (unit of electricity production or consumption)
MW	megawatt (10^6 watts)
MWe	megawatt electric (as distinguished from megawatt thermal, MWt)
GW	gigawatt (10^9 watts)
GWe	gigawatt electric
TWh	terawatt hour (10^{12} watt-hours)
J	joule (unit of energy in the international system of Units)
EJ	exajoule, or 10^{18} joules
MTOE	Million Tons of Oil Equivalent
Bq	Becquerel
Bq/cm3	Becquerel per cubic centimeter
Bq/m2	Becquerel per square meter
Gy	gray (derived unit of ionizing radiation dose—defined as the absorption of one joule of radiation energy per kilogram of matter)
Gy/h	gray per hour
mSv	millisievert
mSv/h	millisievert per hour
Sv	Sievert
Sv/h	Sievert per hour
Sv/y	Sievert per year

ANNEX 6 - STATUS OF NUCLEAR POWER IN THE WORLD

Table 26 | Status of Nuclear Power in the World (as of 1 July 2019)

Country	Nuclear Fleet					Power	Energy
	Operating		LTO	Mean Age[a]	Under Construction	Share of Electricity[b]	Share of Commercial Primary Energy[c]
	Units	Capacity (MW)	Units	Years	Units		
Argentina	3	1 633		28.8	1	4.7% (=)	1.8% (=)
Armenia	1	375		39.5		25.6% (-)	
Bangladesh	-	-		-	2		
Belarus	-	-		-	2		
Belgium	7	5 918		39.3		39% (-)	10.4% (-)
Brazil	2	1 884		28.1		2.7% (=)	1.2% (=)
Bulgaria	2	1 966		29.8		34.7% (=)	19.7% (=)
Canada	18	12 676	1	36.4/36		14.9% (=)	6.6 (=)
China	47	45 498	1	7.15	10	4.2% (=)	2% (=)
Czech Republic	6	3 932		28		34.5% (+)	16.1% (=)
Finland	4	2 784		40.3	1	32.4% (=)	17.8% (=)
France	58	63 130		34.4	1	71.7% (=)	38.5% (=)
Germany	7	9 515		32.8		11.7% (=)	5.3% (=)
Hungary	4	1 902		34.0		50.6% (=)	15% (=)
India	21	6 165		22.3	7	3.1% (=)	1.1% (=)
Iran	1	915		7.8		2.1% (=)	0.6% (=)
Japan	9	8 706	24	28.4/29.9	1	6.2% (+)	2.4% (+)
Mexico	2	1 552		27.4		5.3% (=)	1.6% (=)
Netherlands	1	482		46,0		3% (=)	0.9% (=)
Pakistan	5	1 318		15.9	2	6.8% (=)	2.6% (=)
Romania	2	1 300		17.5		17.2% (=)	7.7% (=)
Russia	36	28 355		29.1	5	17.9% (=)	6.4% (=)
Slovakia	4	1 814		27.3	2	55% (=)	20.6 (=)
Slovenia	1	688		37.7		35.9% (-)	18.6%(-)
South Africa	2	1 860		34.6		4.7% (-)	2.1% (=)
South Korea	23	22 153	1	20.1/19.9	4	23.7% (-)	10% (-)
Spain	7	7 121		34.4		20.4% (=)	8.9% (=)
Sweden	8	8 631		38.9		40.3% (=)	29% (+)
Switzerland	5	3 333		44.2		37.7% (+)	20.9% (+)
Taiwan	4	3 844	1	37/36.1		11.4% (+)	5.3% (-)
Turkey	-	-		-	1		
UAE	-	-		-	4		
UK	15	8 923		35.4	1	17.7% (-)	7.7% (=)
Ukraine	15	13 107		30.4		53% (-)	22.7% (=)
USA	97	98 658		38.9	2	19.3% (=)	8.4% (=)
EU	126	118 106		34.4	5	25.2% (=)[c]	11.1% (=)
World	417	370 138	28	29.9/30.1	46	10.2% (=)[c]	4.4% (=)

Source: WNISR2019, IAEA-PRIS, BP, 2019

a - Including reactors in Long-Term Outage (LTO)/Excluding reactors in LTO (when different)

b - From IAEA-PRIS, "Nuclear Share of Electricity Generation in 2018", as of 1 July 2019

c - From BP, "Statistical Review of World Energy", 2019

ANNEX 7 - NUCLEAR REACTORS IN THE WORLD "UNDER CONSTRUCTION"

Table 27 | Nuclear Reactors in the World "Under Construction" (as of 1 July 2019)

Country	Units	Capacity MW net	Model	Construction Start (dd/mm/yyyy)	Expected Grid Connection	Delayed
Argentina	**1**	**25**				
Carem25		25	CAREM (PWR)	08/02/2014	2021[1]	yes
Bangladesh	2	2 160				
Rooppur-1		1 080	VVER-1200	30/11/2017	2023[2] (commercial operation)	
Rooppur-2		1 080	VVER-1200	14/07/2018	2024[3] (commercial operation)	
Belarus	**2**	**2 218**				
Belarusian-1		1 109	VVER V-491	06/11/2013	Q4 2019[4]	yes
Belarusian-2		1 109	VVER V-491	03/06/2014	7/2020[5]	?
China	**10**	**8 800**				
CFR-600		600	FBR	29/12/2017	2023[6]	
Fangchenggang-3		1 000	HPR-1000	24/12/2015	2021[7]	
Fangchenggang-4		1 000	HPR-1000	23/12/2016	2022[8]	
Fuqing-5		1 000	HPR-1000	07/05/2015	6/2020 (completion)[9]	yes
Fuqing-6		1 000	HPR-1000	22/12/2015	2021[10]	?
Hongyanhe-5		1 000	ACPR-1000	29/03/2015	2020[11]	
Hongyanhe-6		1 000	ACPR-1000	24/07/2015	2021[12]	
Shidao Bay-1		200	HTR-PM	01/12/2012	2020[13]	yes
Tianwan-5		1 000	CNP-1000	27/12/2015	12/2020[14] (commercial operation)	
Tianwan-6		1 000	CPR-1000	07/09/2016	10/2021[15] (commercial operation)	
Finland	**1**	**1 600**				
Olkiluoto-3		1 600	EPR	12/08/2005	4/2020[16]	yes
France	**1**	**1 600**				
Flamanville-3		1 600	EPR	03/12/2007	2022[17]	yes
India	**7**	**4 824**				
Kakrapar-3		630	PHWR-700	22/11/2010	12/2019[18] (commercial operation)	yes
Kakrapar-4		630	PHWR-700	22/11/2010	12/2020[19] (commercial operation)	yes
Kudankulam-3		917	VVER V-412	29/06/2017	3/2023[20] (commercial operation)	
Kudankulam-4		917	VVER V-412	23/10/2017	11/2023[21] (commercial operation)	
PFBR		470	FBR	23/10/2004	10/2021[22]	yes

Country	Units	Capacity MW net	Model	Construction Start (dd/mm/yyyy)	Expected Grid Connection	Delayed
Rajasthan-7		630	PHWR	18/07/2011	12/2020[23] (commercial operation)	yes
Rajasthan-8		630	PHWR	30/09/2011	12/2021[24] (commercial operation)	yes
Japan	**1**	**1 325**				
Shimane-3		1 325	ABWR	12/10/2007	?[25]	yes
Pakistan	**2**	**2 028**				
Kanupp-2		1 014	ACP-1000	20/08/2015	2020[26] (expected operation)	
Kanupp-3		1 014	ACP-1000	31/05/2016	2021[27] (expected operation)	
Russia	**5**	**3 379**				
Akademic Lomonosov-1		32	KLT-40S 'Floating'	15/04/2007	2019[28]	yes
Akademic Lomonosov-2		32	KLT-40S 'Floating'	15/04/2007	2019[29]	yes
Kursk 2-1		1 115	VVER V-510	29/04/2018	2022	
Kursk 2-2		1 115	VVER V-510	15/04/2019	2023[30]	
Leningrad 2-2		1 085	VVER V-491	15/04/2010	2022[31] (commissioning)	yes
Slovakia	**2**	**880**				
Mochovce-3		440	VVER V-213	01/01/1985	2020[32]	yes
Mochovce-4		440	VVER V-213	01/01/1985	2021[33]	yes
South Korea	**4**	**5 360**				
Shin-Hanul-1		1 340	APR-1400	10/07/2012	11/2019[34] (commercial operation)	yes
Shin-Hanul-2		1 340	APR-1400	19/06/2013	7/2020[35] (commercial operation)	yes
Shin-Kori-5		1 340	APR-1400	03/04/2017	3/2023[36] (commercial operation)	yes
Shin-Kori-6		1 340	APR-1400	20/09/2018	6/2024[37]	
Turkey	**1**	**1 114**				
Akkuyu-1		1 114	VVER V-491	03/04/2018	2024[38]	yes
UAE	**4**	**5 380**				
Barakah-1		1 345	APR-1400	19/07/2012	2020[39]	yes
Barakah-2		1 345	APR-1400	30/05/2013	2021[40]	yes
Barakah-3		1 345	APR-1400	24/09/2014	2022[41]	yes
Barakah-4		1 345	APR-1400	30/07/2015	2023[42]	yes
UK	**1**	**1 630**				
Hinkley Point C-1	1	1 630	EPR-1750	11/12/2018[43]	2025[44]	
USA	**2**	**2 234**				
Vogtle-3		1 117	AP-1000	12/03/2013	11/2021[45]	yes
Vogtle-4		1 117	AP-1000	19/11/2013	11/2022[46]	yes
World	**46**	**44 557**		**1985–2019**	**2019–2025**	**27–29**

Notes

1 - Delayed several times. Carem is now expected to be in operation in late 2021 or 2022, a further delay of at least one year since WNISR2018. See WNA, "Nuclear Power in Argentina", June 2019, see http://www.world-nuclear.org/information-library/country-profiles/countries-a-f/argentina.aspx, accessed 16 June 2019; and Matías Alonso, "CAREM: Reactor en alta tensión", *Agencia TSS*, 21 February 2019 (in Spanish), see http://www.unsam.edu.ar/tss/carem-reactor-en-alta-tension/, accessed 16 May 2019.

2 - Rosatom, "First concrete poured at the constructed Rooppur NPP site (Bangladesh)", Press Release, 30 November 2017, see http://rosatom.ru/en/press-centre/news/first-concrete-poured-at-the-constructed-rooppur-npp-site-bangladesh/, accessed 30 November 2017.

3 - Rosatom, "Main construction of the 2nd Unit of Rooppur NPP begins with the 'First Concrete' ceremony", Press Release, 14 July 2018, see http://rosatom.ru/en/press-centre/news/main-construction-of-the-2nd-unit-of-rooppur-npp-begins-with-the-first-concrete-ceremony/, accessed 15 July 2018.

4 - Delayed. Grid connection is expected in last quarter 2019. No delay since WNISR2018. See *BelTA*, "Belarusian nuclear power plant specialists issued nuclear energy permits", *Belarus News*, 20 May 2019, see https://eng.belta.by/society/view/belarusian-nuclear-power-plant-specialists-issued-nuclear-energy-permits-121157-2019, accessed 21 May 2019.

5 - *BelTta*, "Belarusian nuclear power plant to give electricity to national power grid in Q4 2019", *Belarus News*, 28 March 2018, see http://eng.belta.by/economics/view/belarusian-nuclear-power-plant-to-give-electricity-to-national-power-grid-in-q1-2019-110418-2018, accessed 24 April 2018.

6 - CFR-600 is not listed as under construction by PRIS. Concrete pouring is reported to have taken place in December 2017; commercial operation was then expected 2023. See *WNN*, "China begins building pilot fast reactor", 29 December 2017, see http://www.world-nuclear-news.org/NN-China-begins-building-pilot-fast-reactor-2912174.html, accessed 30 December 2017.

7 - No information concerning expected startup date in CGN's announcement of construction start. CGN's Annual Reports for 2016 to 2018 refer to 2022 as "Expected Date of Commencement of Operation" for both units. CGN, "Annual Report 2018", 2019, see http://www3.hkexnews.hk/listedco/listconews/sehk/2019/0408/LTN20190408772.pdf, accessed 9 April 2019. Sources in China suggest that because the two units are the first HPR-1000 to be constructed, grid connection appears impossible before 2020–21 for Unit 3 and 2021–22 for Unit 4, although CGN has pledged to do its utmost to connect its first domestic Generation III reactor to the grid in 2021, at the earliest in November 2021. WNISR2019 advances the date from 2022 to 2021.

8 - See previous note.

9 - CNNC Chairman quoted by *Reuters* in March 2016, said that hopes are that construction of the first Hualong (Fuqing5) will be completed by June 2020. See *Reuters*, "China's debut Westinghouse reactor delayed until June 2017", 9 March 2016, see http://www.reuters.com/article/us-china-parliament-nuclear-idUSKCN0WB09F, accessed 24 June 2016. No change since WNISR2016, already delayed from original startup date of 2019. Other sources (World Nuclear Association, *Nuclear Engineering International*) keep 2019 as completion date.

10 - Probably delayed. 2020 was the completion date announced at construction start. See *WNN*, "First concrete for sixth Fuqing unit", 22 December 2015, see http://www.world-nuclear-news.org/NN-First-concrete-for-sixth-Fuqing-unit-2212154.html, accessed 26 June 2016. Other sources in China point to dome hosting only implemented in March 2018 and installation of the pressure vessel in January 2019. The earliest expected grid connection would be June 2021.

11 - At construction start of Hongyanhe-5, it was announced that Honghyane-5 & -6 would be completed by 2021. Operation of Hongyanhe5 was later reported to be expected in November 2019, change introduced in WNISR2017.
See *NEI*, "Dome installed at China's Hongyanhe5", 17 April 2017, see http://www.neimagazine.com/news/newsdome-installed-at-chinas-hongyanhe-5-5787690, accessed 6 August 2017. As CGN's annual reports refer to second semester 2020 as "Expected Date of Commencement of Operation", WNISR2018 reinstated 2020.

12 - At construction start of Honghyane-5, *WNN* wrote "the company aims to have Honghyane-5 & -6 in operation by 2021." Later, as it announced construction start of Hongyanhe6, *WNN* used 8/2020 as startup date.
CGN's annual report for 2018 still refers to 2021 as "Expected Date of Commencement of Operation". WNISR2018 reinstated 2021 as a target, however sources in China indicated that grid connection could be achieved in 2020.

13 - Further delay of one year since WNISR2018. According to sources in China, problems with the manufacturing of the steam generators for ShidaoBay will make it difficult to finish construction in 2019; startup is therefore likely to be postponed until 2020 at the earliest.

14 - WNISR, "China: Grid Connection for Fuqing-3 and Construction Start on Tianwan-6", 9 September 2016, see https://www.worldnuclearreport.org/China-Grid-Connection-for-Fuqing-3-and-Construction-Start-on-Tianwan-6.html, accessed 22 August 2019.

15 - Ibidem.

16 - Delayed several times from its original planned commissioning in 2009. According to new schedule provided in July 2019, grid connection is now expected in April 2020, and regular electricity generation in July 2020. A further delay of about one year compared to WNISR2018. TVO, "OL3 EPR's regular electricity generation starts in July 2020", Press Release, 13 June 2018, see https://www.tvo.fi/news/2124, accessed 17 July 2019.

17 - Delayed several times from its original planned startup date of 2012. In July 2019, EDF announced that following the decision of the French Nuclear Safety Authority (ASN) concerning the penetration welds (see France Focus) it was studying three different scenarios concerning "the impacts on schedule and costs in the coming months", and would comunicate on the matter, adding that "at this stage, commissioning cannot be expected before end of 2022". See EDF, "2019 half-year results—Stable EBITDA—Confirmation of 2019 targets and 2019–2020 ambitions", Press Release, 26 July 2019, see https://www.edf.fr/sites/default/files/contrib/groupe-edf/

espaces-dedies/espace-finance-en/financial-information/publications/financial-results/h1-2019/20190726-h1-2019-cp-en.pdf, accessed 26 July 2019.

18 - Delayed several times. See NPCIL, "Status of Project under Construction—Kakrapar Atomic Power Project", Undated, see https://www.npcil.nic.in/content/301_1_KakraparAtomicPowerProject.aspx, last accessed 19 July 2019.

19 - Ibidem.

20 - No indication of delay. See NPCIL, "Status of Project under Construction—Kudankulam Atomic Power Project", Undated, see https://www.npcil.nic.in/content/831_1_KudankulamNuclearPowerProject.aspx, accessed 25 June 2019.

21 - NPCIL, "Status of Project under Construction—Kudankulam Atomic Power Project", op. cit. In 2018, ASE quoted 2024 as "guarantee operation date". See Atomstroyexport, "Kudankulam NPP (India)", Undated, see http://www.atomstroyexport.ru/wps/wcm/connect/ase/eng/about/NPP+Projects/Current/Kudankulam_india/, accessed 9 May 2018.

22 - Further delayed. Criticality is now announced for 2020 with commissioning in October 2021. A further delay of 3 years compared to WNISR2018. See Ministry of Statistics and Programme Implementation, "Flash Report on Central Sector Projects (Rs. 150 crore and above) March 2019", Government of India, 2019, see http://www.cspm.gov.in/english/flr/Fr_mar_Report_2019.pdf, accessed 20 June 2019.

23 - Delayed. According to NPCIL, the original scheduled dates for Commercial Operation for Rajasthan-7 & -8 were June and December 2016, respectively. As of June 2019, they are expected to be December 2020 and December 2021. See NPCIL, "Status of Project under Construction—Rajasthan Atomic Power Project", Undated, see https://www.npcil.nic.in/content/300_1_RajasthanAtomicPowerProject.aspx, accessed 24 June 2019.

24 - Delayed. See previous note.

25 - Construction status unclear. Chugoku "took the first step" toward Shimane-3 startup by asking prefectural and local governments for their consent on applying to the Nuclear Regulation Authority (NRA) for safety screening; see The *Asahi Shimbun*, "Process begins at Shimane nuclear plant to operate new reactor", 22 May 2018, see http://www.asahi.com/ajw/articles/AJ201805220043.html, accessed 22 May 2018. Still no clear date for startup.

26 - No information on possible delay. Expected start of operation, according to PNRA, "PNRA Annual Report 2018", 2019, see https://www.pnra.org/upload/pnrarpt/PNRA%20Report%202018.pdf, accessed 15 May 2019.

27 - Ibidem.

28 - Rsatom, "Floating nuclear power plant The Akademik Lomonosov has received an operating license", 28 June 2019, see https://www.rosatom.ru/en/press-centre/news/floating-nuclear-power-plant-the-akademik-lomonosov-has-received-an-operating-license-/, accessed 20 July 2019.

29 - Ibidem.

30 - WNA, "Nuclear Power in Russia", April 2019, see http://www.world-nuclear.org/information-library/country-profiles/countries-o-s/russia-nuclear-power9aspx, accessed 23 April 2019.

31 - Delayed several times. In 2018, TASS agency reported that Russia was ready to postpone 'Commissioning of two Nuclear Plants'. Commissioning of Leningrad 22, then planned for February 2020, would be postponed by two years. See *NucNet*, "Russia Ready To Postpone Commissioning Of Two Nuclear Plants, Says Official Agency", 5 February 2018, see https://www.nucnet.org/all-the-news/2018/02/05/russia-ready-to-postpone-commissioning-of-two-nuclear-plants-says-official-agency, accessed 7 February 2018. However, the reactor might be commissioned in 2021. See Judith Perera, "What's next for Leningrad?", *NEI*, 2 May 2019, see https://www.neimagazine.com/features/featurewhats-next-for-leningrad-7183813/, accessed 1 July 2019.

32 - Delayed several times. Construction was suspended between March 1993 and June 2009. In the Framework of the Strategic Plan, approved by the extraordinary General Assembly of Slovenské Elektrárne, a.s. (SE) on 28 March 2017, operation of Mochovce3 was expected by the end of 2018. In May 2019, CEO of SE Branislav Strycek announced that startup would be delayed again to March 2020, an optimistic variant being November 2019. See TASR, "B. Strýček: Tretí blok elektrárne Mochovce spustíme najskôr v novembri", *TERAZ.sk*, 6 May 2019 (in Slovak), see http://www.teraz.sk/ekonomika/strycek-treti-blok-elektrarne-mocho/393763-clanok.html, accessed 20 July 2019. A delay of at least one year compared to WNISR2018.

33 - Delayed several times. Construction was suspended between March 1993 and June 2009. In the Framework of the Strategic Plan, approved by the extraordinary General Assembly of Slovenské Elektrárne, a.s. (SE) on 28 March 2017, operation of Mochovce4 was expected by the end of 2019. It is now expected in 2021. A delay of over a year compared to WNISR2018.

34 - Delayed several times. In January 2019, KHNP's webpage dedicated to ShinHanul1 announced a change in Commercial Operation (November 2019), with fuel loading to take place in June 2019, which did not happen as of 1 July 2019. A delay of one year compared to WNISR2018. KHNP, "Nuclear Power Construction—ShinHanul #1,2", 1 January 2019, see http://cms.khnp.co.kr/eng/content/547/main.do?mnCd=EN03020303, accessed 17 June 2019.

35 - Delayed several times. In January 2019, KHNP's webpage dedicated to Shin-Hanul-2 announced a change in Commercial Operation (July 2020) a delay of around 10 months compared to WNISR2018. See previous note.

36 - Further delayed. Construction officially started in April 2017, suspended in July to resume in October of the same year. Commercial operation at construction start was October 2021, it is now expected in March 2023, almost 1.5 year of delay. KHNP, "Nuclear Power Construction—Shin-Kori #5,6", various dates, see http://cms.khnp.co.kr/eng/content/548/main.do?mnCd=EN03020304, last accessed 10 August 2019.

37 - KHNP, "Nuclear Power Construction—Shin-Kori #5,6", Various dates, see http://cms.khnp.co.kr/eng/content/548/main.do?mnCd=EN03020304, last accessed 10 August 2019

38 - Delayed. In March 2019, the project management announced that it had finished the concreting of the basemat for the nuclear island and that it was now expected that Akkuyu-1 would be physically completed in 2023, with generation coming at a later date. Phil Chaffee, "New Build, Revised 2023 Milestone for Akkuyu", NIW, 29 March 2019.

39 - Delayed several times. In May 2017, startup of Barakah-1 was first postponed to 2018. In May 2018, the reviewed forecast of its operator, Nawah, after it had "completed a comprehensive operational readiness review to generate an updated schedule for the start-up", is that "the loading of nuclear fuel assemblies required to commence nuclear operations at Barakah Unit 1 will occur between the end of 2019 and early 2020". See Nawah, "Next phase of preparations for Barakah Unit 1 Nuclear Operations starts", 28 May 2018, Press Release, see https://www.nawah.ae/media/press-news/2018/05/26/Next-phase-of-preparations-for-Barakah, accessed 26 July 2019. In July 2019, FANR announced that "Unit 1 construction is complete and the unit is currently undergoing commissioning and testing, prior to receipt of the Operating License from FANR, which is currently in the final stages of reviewing the Operating License application for the Unit, in preparation for the loading of the first nuclear assemblies". See FANR, "FANR Certifies ENEC's First group of UAE National Nuclear Reactor Operators", 8 July 2019, see https://www.fanr.gov.ae/en/media-centre/news?g=0b7fd437-2044-4346-90ef-76d8eaeb5c59, accessed 8 July 2019.

40 - Delayed. No new date for Barakah-2 in updated schedule (see previous note). WNA uses 2021, a three year delay compared to original schedule. See WNA, "Nuclear Power in the United Arab Emirates", April 2019, see http://www.world-nuclear.org/information-library/country-profiles/countries-t-z/united-arab-emirates.aspx, accessed 17 April 2019.

41 - Delayed. No new date for Barakah-3 in updated schedule. WNA uses 2022, a three year delay compared to original schedule. (See previous notes).

42 - Delayed. No new date for Barakah-4 in updated schedule. WNA uses 2023, a three year delay compared to original schedule. (See previous notes).

43 - See WNISR, "The Oddly Discreet Construction Start of Hinkley Point C", 29 December 2018, see https://www.worldnuclearreport.org/The-Oddly-Discreet-Construction-Start-of-Hinkley-Point-C.html, accessed 24 August 2019.

44 - EDF, "Clarifications on Hinkley Point C project", 3 July 2017, see https://www.edf.fr/en/the-edf-group/dedicated-sections/journalists/all-press-releases/clarifications-on-hinkley-point-c-project, accessed 7 May 2018.

45 - Delayed. Georgia Power is expressing confidence that it can meet target dates of November 2021 and November 2022 for Unit 3 and 4 respectively announced in 2018. Georgia Power, "Georgia Power's Vogtle Unit 3 achieves Initial Energization", Press Release, 7 May 2019, see https://southerncompany.mediaroom.com/2019-05-07-Georgia-Powers-Vogtle-Unit-3-achieves-Initial-Energization, accessed 20 July 2019. No change since WNISR2018.

46 - Delayed. No change since WNISR2018. (See previous note).