



# World Nuclear Performance Report 2020

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# Preface



Agneta Rising Director General World Nuclear Association

Electricity generated from the world's nuclear reactors increased for the seventh consecutive year in 2019, with electricity output reaching 2657 TWh. This was an increase of 95 TWh on the previous year, and the second highest ever output.

At the end of 2019 the capacity of the world's 442 operable reactors was 392 GWe, down from 397 GWe at the end of the previous year. Thirteen reactors shut down, of which four were in Japan and had not generated electricity since 2011; and three, in South Korea, Germany and Taiwan, were shut prematurely due to political phase-out policies.

Six reactors started up in 2019. Four large PWRs commenced operation, one in South Korea, one in Russia and two in China. In addition, two small reactors on the first purpose-built floating nuclear power plant, harboured at the town of Pevek in northeast Russia, started supplying electricity. New construction began on five reactors, two in China and one each in Iran, Russia and the UK.

Given the reduction in overall nuclear capacity, the increase in generation in 2019 is all the more remarkable. However, there is an urgent need for the pace of grid connections and new construction starts to increase in order to expand the essential contribution nuclear energy makes to global clean energy provision and reach the nuclear industry's *Harmony* goal.

The median construction time for reactors in 2019 was 117 months. As was the case in 2018, several of the reactors starting up in 2019 featured designs that were first-of-a-kind (FOAK). Construction times since 2015 have more typically been between five to six years. In August 2020 we saw the startup of Tianwan 5, after a construction period of 56 months, less than half the 2019 average; this is in part due to the benefits of experience gained through series construction. Even though the reactor is only the third of this specific design, it is a development of a design that was used for more than 20 different reactors. It is also partly the result of having an ongoing construction programme that helps build and retain skills among the workforce. Where new reactors have been successfully deployed there needs to be a commitment to repeating that deployment through series build, to take advantage of the learning gained. Barakah 1, which started up in August 2020, will be followed by three more reactors that will benefit from the experience gained in starting the first unit.

In 2020 the nuclear industry has been an essential part of the response to the coronavirus pandemic. Despite the challenges of working in COVID-safe conditions, nuclear operators have ensured reactors have been available to provide electricity and grid stability. Reactor operators have also had to respond to the marked reductions in demand that have been observed during the pandemic and have had to operate with more flexibility. For these reasons it is likely that next year's report will show a reduction in overall nuclear generation.

Looking forward, governments are considering at how to restart their economies and generate jobs, as well as how to meet their energy and environmental goals. Each new nuclear build project generates thousands of jobs and boosts the local economy, as well as contributes to our *Harmony* goal of a clean and reliable electricity mix.



### Nuclear industry performance indicators 2019 (change from 2018)

82.5% (+2.7%)

Global mean capacity factor

2657 TWh (+95 TWh)

Electricity generated in 2019

O (-3) New gridconnected reactors





# 117 months (+14 months)

Median construction period for new reactors grid connected in 2019

#### 1.1 Global highlights

Nuclear reactors generated a total 2657 TWh of electricity in 2019, up from 2563 TWh in 2018, and second only to the 2661 TWh generated in 2006. This is the seventh successive year that nuclear generation has risen, with output 311 TWh higher than in 2012.

Figure 1. Nuclear electricity production



Source: World Nuclear Association and IAEA Power Reactor Information Service (PRIS)

In 2019 reactors totalling 402.3 GWe were classed as operable, including those that either started up or shut down. This is fractionally higher than the 2018 figure of 402.0 GWe. The end of year capacity on 31 December 2019 was 392 GWe, down from 397 GWe in 2019.



Figure 2. Nuclear generation capacity operable (net)

In 2019, nuclear generation rose in Africa, Asia, South America and East Europe & Russia. It was fractionally down in North America, and 3 TWh lower in West & Central Europe. Recent trends continue, with particularly strong growth in Asia, which saw nuclear generation rise by 17%.



Global nuclear generation was 2657 TWh in 2019, up from 2563 TWh in 2018

Source: World Nuclear Association, IAEA PRIS

Figure 3. Regional generation

At the end of 2019 there were a total of 442 operable reactors, down seven from 2018. More than two-thirds of reactors in operation are now the PWR type.

Table 1. Operable nuclear power reactors at year-end 2019

	Africa	Asia	East Europe & Russia	North America	South America	West & Central Europe	Total
BWR		21 (-5)		34 (-1)		10 (-1)	65 (-7)
FNR			2				2
GCR						14	14
LWGR			13 (-1)				13 (-1)
PHWR		24 (-1)		19	3	2	48 (-1)
PWR	2	92 (+2)	38 (+3)	64 (-1)	2	102 (-2)	300 (+2)
Total	2	137 (-4)	53 (+2)	117 (-2)	5	128 (-3)	442 (-7)

#### 1.2 Operational performance

Capacity factors in this section are based on the performance of those reactors that generated electricity during each calendar year. For reactors that were grid connected or permanently shut down during a calendar year their capacity factor is calculated on the basis of their performance when operable.

In 2019 the global average capacity factor was 82.5%, up from 79.8% in 2018, maintaining the consistently high capacity factors seen over the last 20 years. In general, a high capacity factor is a good indication of excellent operational performance. However, there is an increasing trend in some countries for nuclear reactors to operate in a load-following mode, which will reduce the overall capacity factor. This is covered in one of this edition's case studies, which highlights the ability of nuclear reactors in France to adjust output to match varying demand and balance the output of intermittent renewables.



Figure 4. Global average capacity factor



Source: World Nuclear Association, IAEA PRIS

Capacity factors achieved in 2019 for different types of reactors are consistent with recent trends, with BWR reactors maintaining the highest capacity factor. More variation year-to-year is seen with FNR, AGR and LWGR reactors as the impact of a single reactor on the overall figure is greater due to the smaller number of reactors of those types.



AGR

LWGR

PHWR

PWR

Figure 5. Capacity factor by reactor type

FNR

BWR

0

Source: World Nuclear Association, IAEA PRIS

Capacity factors in the different geographical regions are also broadly consistent with those achieved over the preceding five years. Capacity factors in North America continue to exceed 90%.



There is no significant agerelated decline in nuclear reactor performance. Beyond 40 years of operation there is a slight increase in average capacity factor

Figure 6. Capacity factor by region



With 2019 seeing the first five reactors to reach 50 years of operation and the first licences granted for 80 years of operation, it is welcome to note that there is no significant age-related decline in nuclear reactor performance. The mean capacity factor for reactors over the last five years shows little variation with age after the initial start-up of the reactor. For reactors beyond 40 years of operation there is a slight increase in average capacity factor. There may be a selection effect, with those reactors performing best more likely to be selected for long-term operation.





The spread of capacity factors in 2019 is broadly similar to the average of the previous five years, with more than twothirds of reactors having a capacity factor greater than 80%. With load-following increasing in some countries, a greater spread of capacity factors may be seen in the future.



Figure 8. Percentage of units by capacity factor

Source: World Nuclear Association, IAEA PRIS

There was a substantial improvement in capacity factors achieved from the 1970s through to the 2000s. Since then, this high performance has been maintained. In the 1970s less than half of all reactors achieved a capacity factor greater than 70%, compared to 83% of reactors in 2019.



Figure 9. Long-term trends in capacity factors

#### 1.3 Permanent shutdowns

Thirteen reactors shut down in 2019. Of these, four were in Japan and had not generated electricity since 2011, and three reactors (in South Korea, Germany and Taiwan) were shut prematurely due to each country's phase-out policy.

	Location	Net capacity (MWe)	First grid connection	Permanent shutdown	Type of reactor
Bilibino 1	Russia	11	12 January 1974	14 January 2019	LWGR
Genkai 2	Japan	529	03 June 1980	09 April 2019	PWR
Pilgrim 1	USA	677	19 July 1972	31 May 2019	BWR
Chinshan 2	Taiwan	604	19 December 1978	16 July 2019	BWR
Three Mile Island 1	USA	819	19 June 1974	20 September 2019	PWR
Fukushima Daini 1	Japan	1067	31 July 1981	30 September 2019	BWR
Fukushima Daini 2	Japan	1067	23 June 1983	30 September 2019	BWR
Fukushima Daini 3	Japan	1067	14 December 1984	30 September 2019	BWR
Fukushima Daini 4	Japan	1067	17 December 1986	30 September 2019	BWR
Mühleberg	Switzerland	373	01 July 1971	20 December 2019	BWR
Wolsong 1	South Korea	661	31 December 1982	24 December 2019	PHWR
Philippsburg 2	Germany	1402	17 December 1984	31 December 2019	PWR
Ringhals 2	Sweden	852	17 August 1974	31 December 2019	PWR

Table 2. Shut down reactors in 2019

Source: World Nuclear Association, IAEA PRIS

#### 1.4 New construction

Five reactors started construction in 2019, two in China and one each in Iran, Russia and the UK. Hinkley Point C 2 began construction one year after unit 1. This plant is the first new nuclear construction in the UK for 30 years.

	Location	Net capacity (MWe)	Model	Reactor type	Construction start
Kursk II-2	Russia	1115	VVER-TOI	PWR (VVER)	15 April 2019
Zhangzhou 1	China	1126	Hualong One	PWR	16 October 2019
Bushehr 2	Iran	915	VVER-1000	PWR (VVER)	10 November 2019
Hinkley Point C 2	UK	1630	EPR	PWR	12 December 2019
Taipingling 1	China	1000	Hualong One	PWR	25 December 2019

Source: World Nuclear Association, IAEA PRIS

With six reactors being grid connected in 2019, this means the number of reactors under construction fell from 56 to 55. The overall capacity of reactors under construction rose slightly by 343 MWe to 57.5 GWe.

Table 4. Reactors under construction by region year-end 2019 (change since 2018)

	BWR	FNR	HTGR	PHWR	PWR	Total
Asia	4	2	1	4	26	37
East Europe & Russia					8 (-2)	8 (-2)
North America					2	2
South America					2	2
West & Central Europe					6 (+1)	6 (+1)
Total	4	2	1	4	44 (-1)	55 (-1)

Source: World Nuclear Association, IAEA PRIS

Table 5. Reactor grid connections in 2019

	Location	Net Capacity (MWe)	Reactor Type	Model	Construction Start	First Grid Connection
Yangjiang 6	China	1000	PWR	ACPR-1000	23 December 2013	29 June 2019
Taishan 2	China	1660	PWR	EPR	15 April 2010	23 June 2019
Shin Kori 4	South Korea	1418	PWR	APR-1400	19 August 2009	22 April 2019
Novovoronezh II-2	Russia	1101	PWR	VVER-1000/ V-392M	12 July 2009	01 May 2019
Akademik Lomonosov 1	Russia	32	PWR	KLT-40S	15 April 2007	19 December 2019
Akademik Lomonosov 2	Russia	32	PWR	KLT-40S	15 April 2007	19 December 2019

Source: World Nuclear Association, IAEA PRIS

Six reactors were connected to the grid in 2019. Four of these reactors were large-scale PWRs, two of which were in China, one in South Korea and one in Russia. In addition, the two reactors on the first purpose-built floating nuclear power plant, the *Akademik Lomonosov*, began supplying electricity in the town of Pevek, on the north east coast of Russia. The reactors also supply district heating to the community.

Figure 10. Construction times of new units grid connected in 2019



As was the case in 2018, the majority of reactors being grid-connected in 2019 were either first-of-a-kind (FOAK), or were units that had started construction soon after the initial FOAK plant.

The Akademik Lomonosov's start date represents its first keel-laying ceremony. The project restarted with a second keellaying ceremony in 2009, when construction moved from Severodvinsk to Baltiysky Zavod.

Consequentially, the median construction time for reactors in 2019 is significantly above the average achieved over the last 20 years.

Not all new reactor designs have entailed such long construction times. Yangjiang 6, which was completed in 66 months, is the second ACPR-1000 unit to be built, after completion of its sister unit, Yanjiang 5, in 2018.



Figure 11. Median construction times for reactors since 1981

Source: World Nuclear Association, IAEA PRIS

Most reactors under construction today started construction in the last nine years. The small number that have taken longer are either pilot plants, FOAK reactors, or projects, where construction was suspended before being restarted more recently (such as Mochovce 3&4 in Slovakia).



Figure 12. Operational status of reactors with construction starts since 1985

Source: World Nuclear Association, IAEA PRIS

In 2019 five reactors were grid connected and 13 were permanently shut down. This is the joint second highest number of reactors shut down in a single year. However, for the majority of these reactors, 2019 was only the formal shutdown date, having ceased generation between 2011 and 2017.



Figure 13. Reactor first grid connection and shutdown 1954-2019

# 2 Case Studies

### Running a large nuclear fleet flexibly

French nuclear reactors (as of 1 July 2020)					
Number of reactors	56				
Total net capacity	61.3 MWe				
Output in 2019	382.4 TWh				
Share of generation in 2019	70.6%				

Nuclear reactors have supplied more than 70% of France's electricity for many years. Consequently, France has very low-carbon electricity, with carbon dioxide emissions of 49 g/kWh in 2018. However, with such a high proportion of nuclear generation, reactors in service in France have needed to have a considerable amount of built-in flexibility to accommodate seasonality and day/night variations in demand. Now this flexibility is being applied to the new challenge of accommodating a growing share of intermittent renewables.

Reactors in France are designed to be able to reduce output from 100% to 20% of rated capacity twice a day in under 30 minutes, depending on the type of reactor. They have a ramp up/down ability of 30-40 MW per minute. When combined as a fleet, up to 21 GW can be ramped up and down within 30 minutes, which is more than sufficient to meet the requirements of the French grid. The favourable economics of nuclear power in France means it is cost-effective to run them in this loadfollowing mode.

The complementarity of renewables and flexible nuclear is a pillar of the energy transition in France. However, with nuclear generation already supplying the majority of electricity, the nature of the transition for France is unlike most other nations. Instead of needing to switch from coal or gas, the challenge for France will be to accommodate a growing share of intermittent renewable energies without becoming more reliant on fossil fuels to provide backup and maintain electricity quality and the supply/demand balance. Nuclear, in addition to providing essential ancillary services to the system, such as inertia and frequency control, is an operational and proven source, unlike the as of yet untested at-scale technologies being developed, such as batteries, vehicle-to-grid, or demand side management.

While most reactors in operation worldwide have the potential to operate flexibly, innovation has allowed EDF to enhance its performance and develop technical skills. The design of French nuclear plants has evolved to include features not found in standard pressurized water reactors. These modifications have primarily involved using different types of control rod and changing their position in the core depending on power levels. The use of special 'grey rods', composed of materials that absorb fewer neutrons than standard ones, makes it possible to modulate chain reactions more precisely.

Safety studies have been extended to consider a wide power range. Dedicated specifications, validated by the French Nuclear Safety Authority, are applied to flexible operation. Control room operators receive specific training in this mode of operation on full-scope simulators that are exact physical replicas of control room equipment. Assistance tools have also been developed over the past 15 years.



Electric power output by Saint-Alban 2 nuclear power plant over one day in April 2016. Output was cut sharply twice, in the middle of the night and in the afternoon, with variations from 1,200 MW to 300 MW within half an hour. (Source: EDF)

Example of power variations over one day Saint-Alban 2 (1335 MWe)



### Interview

Stephane Feutry, Head of Nuclear Power Performance, EDF

# Is the ability to operate flexibly unique to reactors of the type operating in France?

Every nuclear reactor has a degree of flexibility. Reactors are usually operated in baseload because there is no need to be flexible. However, as around 75% of France's electricity is generated by nuclear power plants, EDF has used and increased this flexibility to operate its reactors flexibly to balance supply and demand.

Some modifications were implemented in the 1980s to enhance the ability of reactors to operate flexibly. Some control rods were modified to smooth the core power shape during output variation.

Most of the nuclear reactors in France can reduce their power twice a day, every day, going down to 20% of nominal power in half an hour. However, this theoretical capability is not always used. On average, a reactor performs 15 variations per year, but this figure is increasing because more and more renewable electricity is being injected into the grid.



Saint-Alban nuclear power plant (Image: EDF)

#### What impact does this have on reactor operation?

Of course, flexible operation is safe, without noticeable impact on nuclear equipment, and has no consequences on the environment. Control room operators are trained to monitor and operate their plant in flexible mode. There is not a lot of additional maintenance. One might think there would be impacts on the secondary circuits, but some EDF reactors have performed about 100 variations in a year, with almost no unplanned unavailability.

#### What impact is there on reactor economics?

EDF reactors produce less when spot prices are low, either because consumption is low or when there is a lot of wind or solar generation. The reactors can reach full power at sunset or during peak hours, when prices are higher. EDF reactors also provide frequency regulation. The fuel unused during this variation is still available. This allows EDF to choose the best period for the next refuelling outage. As consumption and prices are higher in winter, it is then possible to schedule an outage in April instead of in February for instance.

# What impact on operations arose as a result of COVID-19?

The COVID-19 pandemic has reduced French electricity consumption by about 15%. Generation was only provided by nuclear plants, hydropower, and other renewables. The flexibility of the EDF fleet was useful, and required. The number of load variations in April 2020 doubled compared to previous years. Operations teams on our sites are proud of having maintained nuclear generation under these conditions.

## What would be the impact of the planned increase in the share of renewable generation?

Even with more and more renewable generation, we think the capability of our reactors is sufficient. We do not need to reduce the output of individual reactors any lower than 20% or ramp down output any faster. However, we will need to make those variations simultaneously on more and more plants, which will require more accurate scheduling of maintenance or tests performed in baseload.



### Interview

Marc Ringeisen, Deputy Director, Centre Opérationnel Production Marchés, EDF

# What is involved in managing the different forms of generation and the variations in demand?

Load changes from hour to hour, from day to day, from season to season; we have to balance the generation and the load at each moment. And with growing renewable generation we have another variable to take into account. The flexibility of the nuclear plants are on the one hand very useful to be able to balance load and generation but also very useful to optimize the value of those power plants.

For example, if during summer we have very high solar generation at noon we will need to reduce nuclear power plant generation significantly, as solar generation is given priority. If the nuclear power plants were not able to reduce their generation for a few hours, the alternative would be to stop them. After stopping the plants it may take a day or more to restart them, and this would be very expensive.

The way we manage this is through the economics of the spot market. We arbitrage with spot market prices between all the different forms of generation. This arbitrage trading takes into account the variable costs of all types of power generation. This variable production cost is equal to zero or less for renewables, for CCGT it is equal to the cost of the fuel plus that of carbon dioxide emissions. For nuclear the variable cost is also the cost of the fuel, but this is very low compared to other thermal production. So in fact there is a very efficient integration from an economic point of view between flexible nuclear generation and renewables.

# Is the situation in France that only nuclear generation can be flexible or is this something that could be done with solar and wind too?

In France there is priority for solar and wind generation. The flexibility we have with a nuclear power plant is much higher than with renewable plant, except hydro.

# With the lower demand during the pandemic, have there been any particular challenges?

The period from March to June 2020 was very challenging for the markets and for balancing the system. The load was very low at a period of the year when there is quite high renewable production, from a lot of hydro and quite a lot of wind and solar. We had to tackle the difficulty that on some hours, some days – particularly the weekend – there was too much power in the system. What we could do was reduce nuclear generation significantly, so that even with very low gas prices we could balance the system almost without any CCGT, which was good from an economic point of view and also of course for avoiding carbon emissions. We decided to stop some nuclear power plants and keep the energy in the core for next winter, avoiding the need to refuel the plants during the challenging COVID-19 conditions.

In addition to the day-to-day flexibility, when you can change the load from maximum to 20%, sometimes twice a day, we also have another kind of flexibility, which is to manage the energy in the core and to decide on the best time for refuelling. This COVID period was very challenging for electricity systems and nuclear plants proved their capacity for flexibility during this period.

### Operating safely during the COVID-19 pandemic

Kansai Electric Power Company owns and operates three nuclear power plants at Mihama, Takahama and Ohi, all in Japan's Fukui prefecture.

After the March 2011 accident at Fukushima Daiichi, all reactors in Japan seeking restart have had to gain approval from the Japan Nuclear Regulation Authority (NRA). For Kansai, Takahama 3&4 were approved to restart in 2016 and Ohi 3&4 in 2018. The NRA has approved upgrade plans and given approval for the restart of Mihama 3 and Takahama 1&2. Completion of upgrade work is expected by 2021.

Nuclear reactors around the world have had a key role to play in many countries in ensuring that electricity supplies are maintained during the COVID-19 crisis. Reactor operators have taken steps to protect their workforce to allow their reactors to continue to operate.

In Japan, the emergency protocol for all prefectures was lifted on 25 May, with the number of new infections decreasing, although concern remained over the potential for a second wave of infection.

For this reason, Kansai has continued to take countermeasures at its facilities to prevent infection. These measures include checking workers' health every morning and ensuring the wearing of face masks and thorough cleaning of hands. Kansai is also limiting the number of entrances that bring workers in close proximity to each other and reducing the amount of close contact required in enclosed areas.

Reactor Name	Process	Capacity (MWe)	Grid Connection	Generation 2019 (TWh)	Status
Mihama 3	PWR	780	19 Feb 1976	0	Awaiting restart
Ohi 3	PWR	1127	7 June 1991	7.93	Operating
Ohi 4	PWR	1127	19 June 1992	8.08	Operating
Takahama 1	PWR	780	27 Mar 1974	0	Awaiting restart
Takahama 2	PWR	780	17 Jan 1975	0	Awaiting restart
Takahama 3	PWR	830	9 May 1984	7.65	Operating
Takahama 4	PWR	830	1 Nov 1984	5.46	Operating



Partitioned seating in a main control room (Image: Kansai Electric Power Company)



### Interview

Yoshinori Kondo, Assistant General Manager, Nuclear Power Division, Nuclear Power Generation Department Supervisor, Kansai Electric Power Company

#### What changes in nuclear plant operation have been introduced to ensure the safety of employees and the continuity of operation?

Our company is fully committed to maintaining safe and stable electricity supply as well as preventing the spread of COVID-19. At our nuclear power plants we are deploying several countermeasures against infection and transmission of the virus.

Specifically, we have introduced the following measures for all our employees and contractors working at the nuclear power plants:

- Using a checklist, staff must assess their health and physical condition at home, including checking their temperature.
- Face masks must be worn at the site, including the commute to and from work.
- We limit the number of people on the company's commuter buses.
- Body temperatures are checked using thermography at the entrances to the nuclear power plants.
- Seating in offices and canteens is spaced out, and partitions have been installed in offices to further reduce any transmission of the virus.

In particular, for workers who are essential to plant operation, we have introduced the following measures:

- A commuter bus exclusively for operators.
- Restrictions on entry and exit to the main control room.
- Obligatory wearing of a mask when entering and exiting.
- Thorough use of hand sanitizer.
- Installation of workplace partitions.

By implementing these infection prevention measures thoroughly, so far no COVID-19 infection has occurred in our nuclear power plants.

If a person were to become infected, or there were a suspicion of infection, we also have a system for dealing with such cases.

Should a worker be suspected of becoming infected, we would prohibit their entry to the site, as well as those who had recently been in close contact with that worker. We would disinfect the potentially affected offices and work areas.

If the case were to be confirmed, we would prohibit the infected person, and personnel suspected of coming into contact with that person, from entering the site. We would sanitize the offices or working area. If this would result in plant operation being difficult to continue, we would halt it.

Furthermore, we have prepared for the situation where we would be required to reduce the number of people onsite if a cluster of cases had been confirmed. We have listed all the essential duties and staff required for continued operation, as well as those staff that could be relocated from different sites, and the work that could be interrupted.

# What measures were taken regarding regular inspections and refuelling?

Across our nuclear power plants, four units are undergoing regular inspections. Even for these units, the above measures are implemented to prevent infection. We are working to identify workers suspected of being at risk of infection to prevent them from entering the plants.

We are analyzing and implementing countermeasures according to each site. For example, where workers would have needed to be in close proximity so they could carry out a short-distance conversation, they will now use mobile phones, walkie-talkies or megaphones.

As a further step, Ohi 3 was initially scheduled to carry out regular inspections from 8 May. However there were concerns expressed by the local community that this would involve many workers coming to Fukui prefecture, where the power plant is located, all at the same time. We therefore decided to postpone the start of regular inspections by two to three months to respect the concerns of the local people and our company's active commitment to prevent infection and fulfil our social mission. The regular inspections started from 20 July.

### Operation at Tianwan during and after COVID-19

#### Tianwan nuclear power plant

Number of reactors	5 operable, 1 under construction
Total net capacity	5.1 GWe operable, 1.0 GWe under construction
Output in 2019	30.6 TWh
Plant capacity factor in 2019	85.7%

The Tianwan nuclear power plant in Lianyun District, Lianyungang City, Jiangsu Province is owned and operated by Jiangsu Nuclear Power Corporation (JNPC), a subsidiary of China National Nuclear Corporation. The four units are all equipped with Russian VVER-1000 nuclear power units (model V-428 for units 1&2 and V-428M for units 3&4). Units 1&2 incorporate Finnish safety features and Siemens-Areva instrumentation and control (I&C) systems. Tianwan 3&4 are both the same version of the VVER-1000 reactor with Areva I&C systems.

The first phase of the project was started on October 20, 1999, and units 1 and 2 started commercial operation

in May and August 2007, respectively. The second phase project started in December 2012. Units 3&4 commenced commercial operation in February and December 2018. The units have performed well, with low individual and collective doses to workers, waste discharges far below national control standards, and the annual power generation and unit performance indicators steadily improving. To date, JNPC has generated over 30 TWh each year. The plant is a tax source enterprise in Jiangsu Province.

The emission reduction benefits of the first four units have been described as the equivalent to planting more than 70,000 hectares of green forest in the Yangtze River Delta region, creating good economic, social and environmental benefits.

In the third phase, 1118 MWe ACPR1000 reactors (developed from the French M310) were adopted for units 5&6. First concrete was in December 2015 and September 2016, respectively. Unit 5 was grid connected in August 2020, and commercial operation for both units is expected within their 60-month construction period, *i.e.* before the end of 2021.



Tianwan nuclear power plant units 1-6 (Image: JNPC)



### Interview

Cheng Kaixi, Deputy Director, Tianwan Nuclear Power Plant

#### Did the overall reduction in electricity demand have an impact on operations at the Tianwan plant?

Due to the COVID-19 prevention and control measures, the provincial power load remained low after the Spring Festival. During this period, units 1-4 of Tianwan nuclear power plant continued to participate in peak load adjustment and power reduction operation according to the dispatching requirements of the grid, and some units intervened during major holidays.

## Did Tianwan participate in national operations against COVID-19?

Tianwan nuclear power plant has taken measures in accordance with the national guidelines for COVID-19 response, including formulating emergency plans and conducting drills at the plant level, managing people entering from foreign regions at risk of COVID-19, organizing and reporting the preparation of pandemic prevention materials, and setting and maintaining the standby operation shift for the units.

# What measures were put in place to ensure continued operation of the plant and to protect employees?

A systematic response to the pandemic outbreak was put in place to ensure the safe operation of the units and the health of the staff. This included: setting up a special working group and joint coordination organization with the local government; identification and classification of personnel at risk of infection; plant employees health declaration; asking employees to wear masks; maintaining onsite disinfection and hand washing facilities; strengthening management of key personnel and areas; remote working and meetings; and development of plant epidemic prevention and management system.

#### Have things now returned to how they were before the start of the pandemic, or are there new measures in place?

As of mid-2020, the situation has essentially returned to the pre-pandemic situation, but some anti-pandemic measures are still being implemented on a long-term basis, such as regular meetings of special teams at power stations, identification of human infection risks, health declarations and disinfection of work areas.

#### After the epidemic, what are opinions towards Tianwan Nuclear Power Plant in Jiangsu Province? Has delivery of a continuous and reliable power supply strengthened support?

Nuclear power is a clean energy source. Jiangsu province ranks nuclear power as a second-level power generation priority, alongside hydropower, waste heat, pressure and gas generation, behind wind power, solar energy, biomass and other first-level power generation priorities. In 2019, Tianwan nuclear power plant accounted for about 6% of Jiangsu's total power generation. During 2020, as a result of the various measures to prevent and control the pandemic to ensure safe and stable production at the plant, Tianwan helped ensure the stability and safety of the power supply of Jiangsu power grid during the epidemic.

#### As China has been one of the first countries to begin recovering from the COVID-19 pandemic, do you have any advice for operators in other countries as they too emerge from the pandemic?

In order to better help international nuclear and power organizations to control the pandemic, Tianwan nuclear power plant has shared its experience and suggestions through translation and transmission of pandemic prevention and control plans via international video conferences. In March and April, Tianwan nuclear power plant was commissioned by the World Association of Nuclear Operators to draft the GL 2020-04 *Guideline for Members in Response to Pandemic Threat*. This guideline, consisting of nine parts, outlines the nuclear power plant's goals, strategies, organization, specific response actions, evaluation and improvement, and provided detailed information on good practices on pandemic prevention. The guideline was officially released in June 2020 for use by nuclear operators around the world.

### Commissioning of the first operational AP1000

Sanmen nuclear power plant is located in China's Zhejiang province and is operated by Sanmen Nuclear Power Company (SMNPC). The Sanmen site is planned to accommodate six units, built in three phases. The first two units (phase I) adopted Westinghouse's AP1000 passive pressurized water reactor technology.

Construction on Sanmen 1 began in April 2009. Unit 1 achieved grid connection in June 2018, with Sanmen 2 following in August that year.

Phase I of Sanmen nuclear power plant is the largest energy cooperation project between the USA and China and the first project supporting China's Generation III nuclear technology self-reliance programme. Being the

#### Sanmen nuclear power plant

Reactor Type	AP1000
Reactor Core Thermal Output	2 x 3400 MWt
Net capacity (electrical)	2 x 1157 Mwe
Design Lifetime	60 years

first operating AP1000, Sanmen 1 had a series of technical challenges from design to initial operation. These issues included the resolution of: large-scale modular construction; automatic depressurization system (ADS) stage 4 piping vibrations; reactor cavity temperature highs; and challenges associated with testing the passive safety system.



Sanmen 1&2 (Image: SMNPC)



### Interview

Fan Fuping, Vice-President, Sanmen Nuclear Power Company

#### Sanmen 1 has started operating and has achieved a high capacity factor from the outset. What steps taken during construction, commissioning and initial operation have contributed to this good performance?

Many factors contributed to the high operational performance of Sanmen 1 during the first fuel cycle. SMNPC has prioritized the cultivation of a healthy nuclear safety culture since the establishment of the company, and has promoted and standardized the use of human performance improvement tools.

We established a comprehensive quality assurance system for all stages of construction, installation, commissioning and operation. This process has greatly improved the reliability of the equipment, and laid the foundations for the plant to achieve good operational performance.

SMNPC took advantage of the full range of technical capabilities of its parent company, China National Nuclear Corporation (CNNC). During commissioning, startup, first cycle operation and first refuelling outage of the two units, CNNC provided strong all-round technical support.

When the commissioning of the Sanmen plant began, we incorporated production personnel into the commissioning teams, giving them experience of commissioning tasks such as systems and equipment testing, equipment maintenance and defect handling.

Based on the preliminary operational procedures provided by foreign suppliers, SMNPC performed operational validation and improvement through system and component testing and other means such as the use of simulators. Procedures were improved by correcting potential deficiencies, optimizing logic steps and eliminating human error traps. This allowed SMNPC to establish a full set of validated operational procedures for the plant operation and to ensure thorough risk control.

The implementation of onsite supervision enabled operational department management to focus on the site, coordinating the resolution of safety-related issues in a timely manner, correcting performance deviations during walk-downs and supervising the effective execution of risk control procedures.

#### The supply chain was split between locally made and imported equipment. Was this an additional difficulty to overcome? What was the role of Westinghouse during commissioning?

Yes, the diversity in equipment suppliers meant the coordination workload was increased, but it did not become a constraint on the construction or operation of the plant.

As the nuclear island design and equipment supplier of the AP1000 unit, Westinghouse is mainly responsible for test data evaluation, clarification of technical issues, abnormal conditions response, and design change support during the startup phase. Close cooperation between Westinghouse and SMNPC enabled both Sanmen units to be successfully put into operation.

# What has been the impact of the reactor coolant pump (RCP) fault with Sanmen 2?

After the failure of the RCP 2B in unit 2, SMNPC worked with Westinghouse, EMD Curtiss-Wright, and Chinese design institutes to carry out troubleshooting and cause analysis. With the joint efforts of all parties, the root cause of the fault was determined and the potential for a common cause fault was eliminated. The RCP was replaced and Sanmen 2 was synchronized to the grid on 28 November 2019 and has maintained safe and stable operation thereafter.

To ensure the reliable operation of the other three operating AP1000 units in China, comprehensive inspections were performed on the RCPs of those units during refuelling outages. The inspection results all indicated there to be no issues with those RCPs.

# Are you sharing lessons learned from the construction and commissioning of the AP1000s with the Vogtle project?

Since 2010, SMNPC has shared lessons learned with the Vogtle project in an open and transparent fashion. Many of our design improvements have been implemented at Vogtle 3&4 during construction. Staff from Vogtle have also participated in the commissioning and the first refuelling outage of Sanmen 1.

### Barakah: Transition from Construction Megaproject to Operational Nuclear Energy Plant

The Barakah nuclear plant, located on the Arabian Gulf coast of the United Arab Emirates (UAE), has four APR1400 pressurized water reactors (PWRs), and following the recent startup and grid connection of the first unit, Barakah is the first operating nuclear plant in the Arab World.

In 2009 the Emirates Nuclear Energy Corporation (ENEC) was formed. That same year, ENEC selected the Korea Electric Power Corporation (KEPCO) as the prime contractor for the project (and joint venture partner since 2016), and preparatory works were initiated for the Barakah plant. After obtaining the regulatory licences and approvals, construction of unit 1 started in July 2012, followed by unit 2 in 2013, unit 3 in 2014 and unit 4 in 2015.

Construction of unit 1 was completed in March 2018. Shortly afterwards, Nawah Energy Company (Nawah), ENEC and KEPCO's joint venture subsidiary responsible for operating and maintaining the Barakah plant, completed a comprehensive operational readiness review.

Throughout 2018 and 2019, the Barakah plant was in a stage of transition, from a construction megaproject to an operational plant approaching the startup of its first unit.

This process culminated in early 2020 with the completion of all regulatory inspections by the Federal Authority for Nuclear Regulation (FANR) as well as voluntary reviews by the World Association of Nuclear Operators (WANO) and the International Atomic Energy Agency (IAEA)

FANR issued the operating licence for Barakah 1 on 17 February 2020 and fuel loading was completed on 3 March 2020.

Following a period of extensive testing, in the early hours of 31 July 2020, unit 1 started up, and just over two weeks later, it was synchronized to the UAE grid, commencing the distribution of the first megawatts of nuclear electricity to the UAE.

Once the unit becomes commercially operational, it will deliver baseload electricity for at least the next six decades.

Construction of units 3&4 is in the final stages, with unit 3 93% complete and unit 4 86% complete. The overall construction completion of the four units was 94% as of July 2020.



Barakah units 1-2 (Image: ENEC)



### Interview

Ali Al Hammadi, CEO, Nawah Energy Company

#### The UAE has gone from having no previous experience in nuclear technology to starting up its first reactor in a period of just over 10 years. What contributed to this rapid progress from an operations point of view?

The UAE Peaceful Nuclear Energy Program has indeed come a long way over the past decade and I am proud to have witnessed much of this growth first-hand.

The main factors that contributed to this operational success are the forward-looking vision and preparation for operations right from the start. The key focus area has been the development of a strong human capacity pipeline to ensure we have highly qualified and experienced nuclear professionals. The 'Energy Pioneers' capacity building programme launched in 2009 has ensured that we had the right expertise in place to operate and maintain the Barakah plant well in advance of operations.

As a result of a decade of consistent training and development, ENEC, Nawah and Barakah One Company now have a combined workforce of over 3000 employees with 60% being highly-skilled and qualified UAE nationals. Specifically to train our operations staff, we have some of the most modern and sophisticated facilities at Barakah, including full-scope APR1400 simulators where our reactor operators train in order to obtain and maintain their licences and qualifications.

# What has the UAE done to invest in developing local talent?

From the very beginning ENEC focused on developing talented UAE nationals to lead and ensure the long-term sustainability of the programme and at Nawah we have benefitted greatly from these efforts. Through the Energy Pioneers Program, which offers talented students the opportunity to study and train to become nuclear energy professionals, UAE nationals gain specialist expertise and practical experience to pursue a range of careers across the country's emerging nuclear energy industry. Over 500 students have benefitted from the programme to date, with many more in the pipeline. Our local talent development programmes have resulted in us having 30 UAE nationals as FANR-certified senior reactor operators and reactor operators, with many more in the pipeline. Also, of the 31-person team that completed the first fuel load at unit 1 in March 2020, 29 were qualified UAE nationals who spent years studying and training to acquire the necessary skills, knowledge and certification to complete the process flawlessly.

The Barakah plant will operate for at least 60 years and we are committed to continuing to build human capacity to ensure a sustainable local workforce throughout the life of the plant.

#### What is next for Barakah and the UAE?

With the successful startup and grid connection of unit 1, we will now focus on using the lessons learned for the remaining three units.

In July 2020, construction was completed on unit 2 and it was handed over to Nawah for completing the operational readiness requirements and all regulatory reviews. With unit 2, we will now go through the same rigorous inspection and review process as we did a year ago for unit 1. FANR will conduct a series of comprehensive inspections over several months to determine whether our policies, processes, procedures, people and plant (what we call the 'five Ps') meet regulatory requirements. We will also undergo two voluntary but crucial reviews by WANO - the Crew Performance Observation, which focuses on the readiness of our operations crews, and the Pre-Start Up Review (PSUR). These inspections and reviews ensure we meet national regulations and the highest international standards, and we look forward to receiving the operating licence from FANR and loading fuel into unit 2 subject to regulatory approvals.

Throughout, our focus remains on ensuring we deliver the four units of the Barakah plant, and generate clean, safe and reliable electricity for the UAE to the highest standards of safety and quality over the decades of operations ahead.

# 3 Country Pages

#### Argentina

Argentina has two nuclear power plants, the two-unit Atucha, 100 km northwest of Buenos Aries, and Embalse, about 100 km south of the city of Córdoba. All three reactors are pressurized heavy water reactors (PHWRs).

Atucha 1 was connected to the grid in 1974. It has a net capacity of 340 MWe. Atucha 2 began supplying electricity in 2014 and has a capacity of 693 MWe.

Embalse, which began operation in 1983, returned to service in May following a three-year upgrade and reconditioning programme that would allow it to operate for a further 30 years. This included increasing its net capacity by around 35 MWe. The modernization work included reactor retubing and replacing the steam generators.

In addition to providing electricity, the Embalse plant can now also produce Cobalt-60 to supply the internal market in medicinal and industrial applications, and for export.

An operating lifetime extension project at Atucha 1 was resumed in April 2020, having been suspended in 2019 due to contractor disputes. Work also resumed in April 2020 on the construction of the 25 MWe CAREM reactor, Argentina's first domestically-designed and developed nuclear power unit, which is also located at the Atucha site.

Discussions are continuing between Chinese and Argentinian authorities on the potential construction of a Chinese-designed HPR1000 reactor at the Atucha site.



Nuclear electricity production



Source: World Nuclear Association, IAEA PRIS

Average nuclear capacity factor



#### Armenia

The Metsamor nuclear power plant is located 30 km west of the Armenian capital of Yerevan. The site is also known as the Armenian Nuclear Power Plant (ANPP).

The plant currently has one operable VVER-440 model V-270 reactor, unit 2, which started up in 1980. Unit 1, also a VVER-440/V-270, started operation in 1976 and was shut down in 1989. Both units were taken offline in 1988 following a major earthquake earlier that year, although they both had continued to operate and had not sustained any damage.

Both units originally had a reference unit capacity of 408 MWe, which was reduced to 376 MWe in 1988.

The operating licence for unit 2 has been extended until 2021 subject to yearly safety demonstrations, with preparations under way for requesting an additional extension until 2026. Unit 2 is running on vibration-resistant fuel produced by TVEL's Elektrostal Machine-Building Plant.

Armenia also has a dry used fuel storage facility, a radioactive waste storage facility, and uses radioactive sources in medicine, industry and research.

In June 2019 an International Atomic Energy Agency (IAEA) team of experts reported that Armenia had made progress in strengthening its regulatory framework for nuclear and radiation safety but still faces challenges, including a shortage of qualified and experienced staff at its regulatory body. The chairman of the Armenian Nuclear Regulatory Authority (ANRA), Ashot Martirosyan, responded to the report, saying that measures were already under way to resolve the staffing issue.



Nuclear electricity production





#### **Belgium**

Belgium has four reactors at the Doel nuclear power plant, 15 km northwest of Antwerp, with a total capacity of 2922 MWe, and three at Tihange, 24 km west-southwest of Liège, with a total capacity of 3008 MWe.

Generation from nuclear power was up from 27.3 TWh in 2018 to 41.4 TWh. This increase is in part due to the return to service of Doel 1&2 and Tihange 2&3 in 2019. The Doel units were offline for repairs to cooling water pipelines, while the Tihange units had outages extended to allow for repairs to adjacent non-nuclear buildings.

Under current law all seven of Belgium's reactors are due to close before 2026. In July 2019 Belgian grid operator Elia concluded that the country would need more capacity than previously forecast to cope with its planned nuclear exit and is not yet ready for any scenario, including one where the phaseout of nuclear reactors is more gradual than currently envisaged.

Support from the Belgian public for keeping the country's nuclear power plants in operation beyond 2025 has been growing, rising from 30% in 2017 to 46% in 2019, with 37% wanting only to maintain nuclear power plants until 2025. 70% said they would agree to keep Belgian reactors in operation for longer in order to reduce carbon dioxide emissions.

In June 2020 Belgium's Federal Agency for Nuclear Control (FANC) announced it was in favour of a proposal for the disposal of high-level and/or long-lived radioactive waste in a geological repository. Unlike most other countries producing these wastes, Belgium has yet to take a position on their final disposal.



Nuclear electricity production









#### Brazil

Brazil has two reactors at Angra, 200 km west of Rio de Janeiro. The first unit, a Westinghouse-designed 609 MWe PWR, began operating in 1982, with the second unit, a Siemensdesigned 1275 MWe PWR, in 2000. With electricity generation of 15.22 TWh in 2019, the two units achieved their highest ever annual output.

In February 2020 Brazil and the USA signed agreements on extending the planned operational lifetime of Angra 1 to 60 years and increasing its generating capacity, as well as to cooperate on new nuclear technologies.

A used fuel dry storage facility is currently being constructed at the Angra plant and is set to be commissioned by the end of 2020.

Work on a third unit at Angra, planned to be a twin of unit 2, began in 1984 but was halted in 1986 before full construction began. The project was restarted, with first concrete in 2010, but was halted again in 2015.

In April 2019 the minister for mines and energy, Bento Alburquerque, said that the Brazilian government is "strongly committed" to resuming the Angra 3 project. The minister also said that Brazil would consider new nuclear power plants including Generation IV technology and small modular reactors (SMRs) to meet growing national electricity demand.

In June 2020 Brazil's Investment Partnership Programme (PPI) council approved a plan to complete Angra 3. The business model was devised by state development bank BNDES, and would require a private partner to share the financial burden.



Nuclear electricity production



Source: World Nuclear Association, IAEA PRIS



Source: World Nuclear Association, IAEA PRIS

#### **Bulgaria**

The Kozloduy nuclear power plant, 120km north of Sofia, has two operable VVER-1000 reactors – units 5&6 – supplying around one-third of the country's electricity. Four shut down VVER-440 units are also onsite.

In October 2019, unit 6 received authorization to operate for a further ten years, until 2029. Unit 5 had received a similar authorization in 2017. It is currently expected that both units will operate for 60 years.

Bulgaria has since 1980 been planning to construct a second nuclear power plant at Belene, also in the north of the country, 110km east of Kozloduy. In May 2019 the government advertised for a strategic investor to participate in the Belene project to build two large reactors but it said that neither funding guarantees nor long-term electricity sales contracts would be offered. The government plans to have a majority stake in the project, which it expects to be completed by 2030.

In August 2019, the energy minister reported that 13 applications for participation had been received, comprising seven to be a strategic advisor, four to be an electricity customer and/or minority shareholder, and two to be an equipment supplier. In December 2019, a shortlist of five companies was announced: CNNC, Rosatom and Korea Hydro & Nuclear Power, as well as Framatome and General Electric for equipment contracts.

In April 2020 parts already delivered to the Belene site were purchased by operators of the Kozloduy plant. These parts will help to increase the operational capacity of the Kozloduy reactors by 4%.



Nuclear electricity production







Source: World Nuclear Association, IAEA PRIS

#### Canada

Nineteen reactors operate in southeast Canada, 18 of which are in Ontario and one in New Brunswick. All reactors are Candu PHWR models with capacities ranging from 515 to 881 MWe. Nuclear supplies around 60% of the electricity in Ontario in a mix of predominantly low-carbon generation.

Units 3-8 at the Bruce site are being refurbished, extending their operation to 2064. Units 1&2 have already been refurbished and Bruce 6 was taken offline in January 2020. All units will be refurbished by 2033.

In June 2020 Darlington 2 was reconnected to the grid after a three-year refurbishment. The three other units will also be refurbished, with the entire project scheduled for completion by 2026.

The provinces of New Brunswick, Ontario and Saskatchewan agreed in December 2019 to collaborate on SMRs.

Canadian Nuclear Laboratories (CNL) aims to provide a global hub for SMR research and technology and plans to have a demonstration SMR built on site by 2026. Kairos Power, Moltex Canada, Terrestrial Energy Inc and UltraSafe Nuclear Corporation (USNC) were selected by CNL as the first recipients of support earlier this year.

GE Hitachi Nuclear Energy, NuScale Power and X Energy made submittals to the Canadian Nuclear Safety Commission in 2020 for the prelicensing vendor design review of their SMR designs.

New Brunswick is supporting the siting of ARC Nuclear Canada's ARC-100 SMR at the Point Lepreau nuclear power plant site. The ARC-100 completed its Phase 1 pre-licensing vendor design review in October 2019.



Nuclear electricity production







Source: World Nuclear Association, IAEA PRIS

#### China, mainland

Mainland China has 48 operable reactors primarily at sites along its southeast coastline. Nuclear generation has grown substantially over the last 20 years, rising from 16 TWh in 2000 to 330 TWh in 2019.

According to the National Development and Reform Commission, China aims to have 200 GWe of nuclear generating capacity in place by 2035, out of a total generating capacity of 2600 GWe.

Two reactors were connected to the grid in 2019, Taishan 2, the second EPR reactor to start operation, and Yangjiang 6, an ACPR-1000. In August 2020, Tianwan 5 was connected to the grid.

Two reactors started construction, Zhangzhou 2 and Taipingling 1. Both reactors will be based on the Hualong One design.

China's first commercial nuclear heating project began operating at the Haiyang nuclear power plant in Shandong province in November 2019. The plant's two AP1000 units initially provided heating to 700,000 m2 of housing. The system extracts steam from the secondary circuit of the units, which is then fed through an onsite multi-stage heat exchanger.

Hot testing was completed in early 2020 at the Fuqing 5 reactor in Fujian province, one of the first four Hualong One units under construction in China.

Progress was also made in March 2020 with testing of the reactor pressure vessel, steam generator and hot gas duct of the second of the twin reactors of China's demonstration high-temperature gas-cooled reactor plant (HTR-PM) at the Shidaowan site in Weihai city, in Shandong province.



Nuclear electricity production







Source: World Nuclear Association, IAEA PRIS

#### Taiwan, China

Taiwan is served by two reactors at Kuosheng, 25 km northeast of Taipei, and two reactors at Maanshan, at the southern end of the island, 9km south of Hengchun airport. These provide around 15% of the island's electricity generation

In February 2019 it was announced that Taiwan would proceed with its plan to phase out the use of nuclear energy, despite citizens voting against the policy in a referendum. Generation has already ceased at the two units at Chinshan.

The Democratic Progressive Party (DPP) was elected in 2016 with a manifesto that included a nuclear phase-out policy. Shortly after taking office, the government passed an amendment to the Electricity Act, passing policy into law.

However, in a referendum held in 2018, voters chose to abolish that amendment. The Ministry of Economic Affairs said the amendment was officially removed from the Electricity Industry Act on 2 December. However, the decommissioning of the Chinshan units would continue as planned and, the operating licences of the Kuosheng and Maanshan units would not be extended

The plan to decommission the Chinshan plant includes the construction of a dry storage facility for used fuel. Construction of this facility was completed in 2013. However, the New Taipei City municipal government has yet to issue a permit for its use.

State-owned Taiwan Power Company (Taipower) has ruled out the possibility of completing the Lungmen project, which consists of two partially constructed ABWRs.



Nuclear electricity production







#### **Czech Republic**

The Czech Republic has six operable reactors; two units are at Temelin, 100 km south of Prague and four units at Dukovany, 34 km west of Brno.

The government's long-term energy strategy, adopted in 2015, forecasts the need to increase the share of nuclear power in the country's electricity mix to 50-55% by 2050. Czech utility ČEZ has said it expects to operate the four Dukovany units until 2045 and 2047, and the two Temelín units until 2060 and 2062.

ČEZ has applied to the State Office for Nuclear Safety (SUJB) to construct two new reactors at its Dukovany nuclear power plant. Four VVER-440 units are currently in operation at the site, in Vysočina Region. The application is for two pressurized water reactors (PWRs), each with a generating capacity of up to 1200 MWe.

Five companies are understood to have shown interest in building new nuclear units in the Czech Republic. Under the current schedule, the reactor vendor is to be selected by the end of 2022 and a construction licence issued by 2029, with commissioning expected in 2036.

In May 2020 the Czech prime minister announced that the government would Ioan 70% of the cost of building a single 1200 MWe unit, with ČEZ funding the remaining 30%. In October 2019 Deputy Prime Minister and Minister of Industry and Trade Karel Havlíček had said that the Czech Republic would need to build not only one new unit at Dukovany, but also more reactors at Temelín if it were to avoid becoming dependent on electricity imports from 2030.



Nuclear electricity production



Source: World Nuclear Association, IAEA PRIS



Source: World Nuclear Association, IAEA PRIS

#### Finland

Finland has two nuclear power plants, Loviisa, 80km east of Helsinki, with two VVER reactors, and Olkiluoto, 225 km northwest of the capital, with two BWR reactors. A fifth reactor, the Olkiluoto 3 EPR, is nearing completion and a sixth unit (a VVER) is planned for Hanhikivi, in the Pyhäjoki municipality.

Operating reactor performance in 2019 in Finland was strong, with Olkiluoto 1 setting a plant production record of 7.54 TWh.

During 2019 operator Teollisuuden Voima Oyj (TVO) took action to address a pressuriser surge line vibration that was encountered during testing at Olkiluoto 3, ahead of the startup of the reactor. TVO was granted an operating licence in March 2019 and in April 2020 TVO applied for permission to load fuel. The loading of fuel into the core had been delayed until June 2020 because of slow progress of the system tests and shortcomings in spare part deliveries. The June target was delayed further due to measures put in place to prevent the spread of COVID-19.

Preparations are continuing on the Hanhikivi 1 project, with a construction licence expected in 2021. Fennovoima has essentially completed preparatory construction work of the infrastructure in the project area on the Hanhikivi headland. In order to comply with social distancing requirements during the coronavirus pandemic Finland's regulator, STUK, carried out a scheduled inspection of RAOS Project Oy, the general supplier for Hanhikivi-1 NPP, via videoconference.



Nuclear electricity production





Average nuclear capacity factor





#### France

France has 56 operable reactors at a variety of coastal and inland sites throughout the country. Nuclear generation has supplied around 75% of the country's electricity for 30 years, following a major expansion of nuclear capacity in the 1970s and '80s.

With a high share of supply, demand for nuclear electricity in France has been significantly affected during the COVID-19 pandemic.

In February 2020, unit 1 at Fessenheim was closed, after 42 years of operation. The closure of unit 2 followed in June.

The closure of Fessenheim was imposed as part of the current energy policy. In November 2018, a draft of the country's new energy plan postponed by ten years plans to reduce the nuclear share in the mix to 50% from the original target of 2025 to 2035. This would require 14 of the country's nuclear reactors to shut down by then, up to six of those by 2030. However, the plan also states that the option to build new nuclear reactors remains.

In October 2019 the environment and economy ministers asked EDF to study the potential for building three pairs of EPR2 reactors at three existing nuclear sites in France. A decision whether to build such capacity has been delayed until 2022.

An EPR has been under construction at Flamanville since 2007. In October 2019 it was concluded that repairs to the reactor's main secondary system penetration welds would be needed and that this would further delay loading of fuel into the reactor until the end of 2022.



Nuclear electricity production







Source: World Nuclear Association, IAEA PRIS

#### Germany

Nuclear capacity in Germany has fallen from 20.5 GWe in 2010 to 8.1 GWe as part of Germany's policy of closing all nuclear reactors by the end of 2022.

The most recent reactor to be closed was Philippsburg 2, in December 2019. In contrast, a much slower exit from coal could see coal power plants remain as part of the generation mix until 2038.

A study released in January 2020 by the University of California at Santa Barbara, the University of California at Berkeley, and Carnegie Mellon University found that Germany's phaseout of nuclear power may have led to 1100 additional deaths each year. Those deaths are attributable to continued generation from coal-fired power replacing shuttered nuclear power plants in Germany, driving around a 12% increase in local air pollution. That rise in pollution alone. the authors concluded, bears a price tag of US\$8.7 billion per year, more than 70% of the phaseout's annual costs of US\$12.2 billion.

While no new nuclear fission capacity is planned, Germany is developing the world's largest stellarator-type fusion device – the Wendelstein 7-X. The pilot plant will not be used to produce energy but should demonstrate whether stellarators have the potential to be used as power plants.

In October 2019 Siemens signed a contract with Rosatom and Framatome to supply the instrumentation and control systems to Hanhikivi 1, planned to be constructed in Finland. Under the contract Framatome would supply the safety automation systems for the proposed VVER.



Nuclear electricity production



Source: World Nuclear Association, IAEA PRIS





Source: World Nuclear Association, IAEA PRIS

#### Hungary

Four VVER-440 reactors operate at the Paks nuclear power plant, 100km south of Budapest, with a combined capacity of 1902 MWe. The four reactors generate around half of the electricity produced in Hungary, but supply around a third of the electricity demand, as Hungary relies on imports for around a third of its electricity requirements.

Plans are well advanced for the construction of two new VVER-1200 reactors at Paks. These units are known both as units 5&6 and Paks II. In October Rusatom Automated Control Systems (RASU) and the Franco-German consortium Framatome-Siemens signed an agreement to manufacture, deliver and commission automated process control systems for the new units.

In April 2020, János Süli, Minister without Portfolio responsible for the planned two new reactors at Paks emphasised the role of the Paks plant in ensuring Hungarian electricity supplies during the COVID-19 pandemic. The minister said that the plant was "of strategic importance in these difficult times" noting that the Hungarian plant always has enough fuel for two years, as required by law, which could be stored in a small space and can be obtained from multiple sources when needed. This, the minister said, was much more secure than importing either electricity or natural gas.

Regarding the proposed new nuclear units at Paks, Minister János Süli said that they were a major investment that could be a lifeline for many Hungarian businesses recovering from the pandemic and a livelihood for many Hungarian people, with the project employing 8000-10,000 people at its peak.



Nuclear electricity production



Source: World Nuclear Association, IAEA PRIS



Source: World Nuclear Association, IAEA PRIS

#### India

India has 22 operable reactors in seven locations, both inland and coastal, with seven more reactors under construction. Nuclear generation currently supplies around 2-3% of India's electricity demand.

The majority of reactors are indigenously designed pressurized heavy water reactors (PHWRs), although two Russian-designed VVERs are in operation, with two further VVERs under construction.

As is the case with other countries with PHWRs, India has started the process of refurbishing its reactors to allow for extended operation. Unit 1 at Kakrapar restarted in May 2019, three months ahead of schedule, after replacement of coolant channels, feeder tubes and other upgrades.

India has plans to increase its nuclear generation substantially. In January 2019 the Department of Atomic Energy (DAE) announced that India plans to build 21 new nuclear power reactors – including 10 PHWRs – with a combined generating capacity of 15,700 MWe by 2031. In October 2019 DAE chairman Kamlesh Vyas said that 17 nuclear power reactors are planned in addition to those already under construction.

India's Parliamentary Standing Committee on Science & Technology, Environment, Forests and Climate Change recommended in March 2020 that India should aim to at least double the present proportion of electricity generated by nuclear power plants by 2030. The committee said that, for the time being, India should adopt "home-grown" 700 MWe heavy water reactors for its nuclear expansion programme.



Nuclear electricity production



Source: World Nuclear Association, IAEA PRIS



Source: World Nuclear Association, IAEA PRIS

#### Iran

A single VVER/V-446 reactor operates at the Bushehr site, 185 km west of the city of Shiraz.

Construction on Bushehr's second reactor, an updated VVER-1000, commenced in November 2019. The reactor is expected to start up in 2024, with a third unit due to start up two years later.

Since 2015, nuclear activities in Iran had been carried out under the Joint Comprehensive Plan of Action (JCPOA) agreed by Iran, China, France, Germany, Russia, the UK and the USA. Under its terms, Iran agreed to limit its uranium enrichment activities, eliminate its stockpile of medium-enriched uranium and limit its stockpile of low-enriched uranium over the subsequent 15 years. However, in 2018 the USA withdrew from the agreement and imposed sanctions on Iran.

In May 2019 France, Germany, and the UK issued a joint statement reaffirming their commitment to the JCPOA. In June 2020 the European Union plus France, Germany and the UK said they "deeply regretted" the USA's decision to end three sanction waivers covering JCPOA projects.

In July 2019, the IAEA's latest verification and monitoring report stated that Iran has been enriching uranium at its Fuel Enrichment Plant at Natanz above the 3.67% U-235 limit stipulated in the JCPOA. The European signatories to the Iran nuclear deal did not see this as significant and did not intend to trigger the agreement's dispute mechanism.



Nuclear electricity production







#### Japan

Up until 2011, Japan was generating some 30% of electricity from its reactors and this was expected to increase to at least 40% by 2017. The plan is now for at least 20% of Japan's electricity demand to be met by nuclear generation by 2030.

Following the March 2011 tsunami and subsequent accident at the Fukushima Daiichi plant, all reactors in Japan have had to get regulatory approval to restart. The first reactors to restart, Sendai 1&2, did so in 2015, and a further seven have restarted since then. Currently, 18 reactors are in the process of restart approval and a further eight are yet to apply.

Construction has also been delayed on two ABWRs, Shimane 3 and Ohma 1, which were respectively 94% and 38% complete at the time of the tsunami.

In some cases, extensive upgrades at existing reactors are required to comply with the new regulations. The Japanese Nuclear Regulatory Authority has approved the proposed upgrade for the restart of Onagawa 2, however, the work is not due to be completed until March 2023.

Reactors that have restarted are also required to construct bunkered backup control centres within five years of regulatory approval to restart. Because these facilities were not completed at Sendai within the five-year limit, the plant's two reactors were taken offline in March and May 2020 and they will remain offline until the work is completed. Several other reactors are expected to be taken offline due to construction delays of back-up centres.



Nuclear electricity production



Source: World Nuclear Association, IAEA PRIS

Average nuclear capacity factor



#### **Mexico**

Mexico has two operable nuclear reactors located on the east coast of the country, 285km east of the capital, Mexico City. Laguna Verde 1 began commercial operations in 1990 and unit 2 in 1995

In July 2020 the Mexico energy ministry gave final approval for a 30-year extension of the operating licence for the first unit at Laguan Verde. This would allow the reactor to operate until 2050.

The plant's operator, the Federal Electricity Commission (CFE), had requested the extension beyond unit 1's current 30-year licence from Mexico's National Commission for Nuclear Safety and Safeguards five years previously, and was required to complete a series of upgrades, inspections and tests prior to approval of the licence extension.

An application for a similar extension for unit 2 has been filed and is under review.

In 2019 Laguna Verde underwent a 10-day SALTO (Safety Aspects of Long Term Operation) peer review mission, requested by state-owned utility CFE, which operates the twounit plant. A team of experts from the IAEA focused on aspects essential to the safe long term operation (LTO) of the two boiling water reactors.



Nuclear electricity production



Source: World Nuclear Association, IAEA PRIS



Source: World Nuclear Association, IAEA PRIS

#### Netherlands

A single 485 MWe PWR at Borssele has been in operation since 1973. Located 70 km southwest of Rotterdam, the reactor generates around 3% of the Netherlands' electricity and is expected to operate until 2033.

Around ten years ago there were a number of proposals to build new units at Borssele, and the then government stated that it would "be open to issuing permits for new nuclear power plants." However, these proposals did not make significant progress and there are currently no plans for new nuclear build in the Netherlands.

New irradiation experiments on the behaviour of nuclear fuel have recently started in the High Flux Reactor at Petten. The Nuclear Research and Consultancy Group (NRG) says that, by using a new measurement technique, data collected during the experiments could be used to develop new fuels and to optimise the efficiency of existing ones.

The same facility is also providing materials testing services for Terrestrial Energy's Integral Molten Salt Reactor (IMSR) design.

The Petten facility has continued to operate during the COVID-19 pandemic in order to continue the production of Mo-99, a vital isotope for medical applications.



Nuclear electricity production



Source: World Nuclear Association, IAEA PRIS



Source: World Nuclear Association, IAEA PRIS

#### Pakistan

There are two nuclear power plant sites in Pakistan. Chashma, 200 km southwest of Islamabad, hosts four 300 MWe units and Karachi, 22 km west of Karachi, hosts a single 90 MWe PHWR.

The four units at Chashma are CNP-300 models, based on the Qinshan 1 reactor in China. The first reactor came online in 2000 and the fourth unit was grid connected in 2017. With the startup of these reactors the overall capacity factor for Pakistan's reactors has risen to be on a par with global levels.

Two Hualong One reactors are under construction at Karachi, with startup expected in 2021 and 2022.

Installation of the reactor internals of Karachi 2 was completed in January 2019, with installation at unit 3 completed in April 2020.

Cold testing began at Karachi 2 in November 2019 and was completed in the following month. The tests involved checking more than 7200 welds and 800 mechanical connection points. The concreting of the outer dome of the double-layer containment building at unit 2 was completed on 10 April this year.

In light of its inability to buy uranium on the open market, PAEC says that Pakistan has agreed with CNNC to provide lifetime fuel supply for the reactors, specified as 60 years.

Pakistan aims for a significant expansion of nuclear power over the coming decades in order to meet its growing energy demand. A fouryear technical cooperation project with the IAEA was launched in 2018 in order to streamline workflows, reduce delays and costs, enhance cooperation and harmonise safety and waste management approaches.



Nuclear electricity production



Average nuclear capacity factor



Source: World Nuclear Association, IAEA PRIS

#### Romania

Two CANDU-6 PHWRs operate at the Cernavodă nuclear power plant, which is directly adjacent to the town of Cernavodă and 50km west of the city of Constanța. In addition to electricity, the plant also provides district heating to Cernavodă town.

Originally planned as a five-unit plant, work on the later units was suspended to focus on completion of unit 1, and later unit 2.

In July 2020 the government announced it would create a committee headed by the energy minister tasked with completing units 3&4, cancelling a May 2019 agreement between Romania and China. A tender for a new feasibility study on completing the units was launched a few days later.

The refurbishment of unit 1 is planned to start in 2026, 30 years after it began operation. In the interim, Candu Energy has been contracted to carry out engineering analyses and assessments on unit 1 to extend the effective full power hours of operation by 35,000 hours (beyond the design estimate) to enable the unit to operate until 2026.

In March 2019 SNN signed a memorandum of understanding (MoU) with NuScale Power to evaluate the potential for a NuScale SMR in Romania. In October 2019 SNN also signed an MoU with the Fostering ALFRED Construction (Falcon) consortium for cooperation on the of the Advanced Lead Fast Reactor European Demonstrator (ALFRED)

The USA and Romania signed an MoU to cooperate on civil nuclear energy in September 2019 during the United Nations Climate Action Summit in New York.



Nuclear electricity production







Source: World Nuclear Association, IAEA PRIS

#### **Russia**

There are 38 operable reactors in Russia, with the majority in the west of the country. Three small reactors are in operation at Bilibino, on the northeast Arctic coast, which are being replaced by a new floating power plant moored at the nearby town of Pevek.

Russia has brought an additional nine reactors online over the last ten years, increasing its overall nuclear capacity by 25%. There are four reactors currently under construction, although construction has been suspended on one unit in Kaliningrad, with the reactor vessel intended for the plant transferred to the Ostrovets project in Belarus.

In April 2020 Russian nuclear regulator Rostekhnadzor extended the operating licence of the Beloyarsk BN-600 fast reactor by five years to 2025. The operator. Rosenergoatom. intends to apply for an operating licence extension until 2040.

In December 2019 Siberian Chemical Combine (SCC) contracted Titan-2 to construct the BREST-OD-300 lead-cooled fast neutron reactor facility at its site in Seversk. BREST-OD-300 is part of Rosatom's Proryv, or Breakthrough, project to enable a closed nuclear fuel cycle.

In addition to domestic nuclear generation, Russia is expanding into construction overseas, with Russiandesigned plants under construction in Belarus, Bangladesh, India, Iran, Slovakia, Turkey and Ukraine, as well as another site being prepared in Egypt.



Nuclear electricity production





Source: World Nuclear Association, IAEA PRIS

#### Slovakia

Two VVER-440 reactors are in operation at Mochovce, 100 km east of Bratislava. Construction on two more reactors originally started in 1987, before being halted in 1992.

Construction restarted on units 3&4 in 2009 and unit 3 is due to start up in 2020. As of the end of May 2020 the third Mochovce unit was 99.7% complete, and the fourth at 87.3%.

Mochovce 3 completed hot testing in April 2019, and at the time the owner SE said the unit could be ready for fuel loading in the summer of 2019. The draft permit of the Nuclear Regulatory Authority for fuel loading was issued in 2020, to date fuel loading has not started.

The Ministry of the Economy has said that the third unit must be put into operation as soon as possible and without further cost increases. The Slovak state owns 34% of SE.

SE expects the two new reactors, with a combined capacity of 942 MWe, to produce about 7 TWh per year, which would cover about 13% of Slovakia's electricity demand.

In December 2019 a Pre-Operational Safety Review Team (Pre-OSART) concluded an 18-day mission to assess operational safety at Mochovce 3. The 17-member team concluded that Slovenské Elektrárne had shown a commitment to safety, but also identified areas for further enhancements.

TVEL has signed a contract with SE for the supply of nuclear fuel for 2022-2026 with the possibility of extension to 2030.



Nuclear electricity production



Average nuclear capacity factor



Source: World Nuclear Association, IAEA PRIS

#### Slovenia

Slovenia's only nuclear power plant at Krško, 80 km east of Ljubljana, is a two-loop Westinghouse pressurized water reactor with a net capacity of 688 MWe.

The plant's operating company Nuklearna elektrarna Krško (NEK), is jointly owned by Slovenian stateowned company Gen-Energija and Croatian state-owned company Hrvatska elektroprivreda (HEP). The plant generates around 36% of the electricity produced in Slovenia and supplies more than one-quarter of Slovenia's and 15% of Croatia's electricity demand.

As with many plants across the world, the Krško plant has modified working practices as a result of the COVID-19 pandemic, for example limiting work to essential activities such as shift control of plant operation, urgent surveillance of safety equipment. urgent maintenance works, analytical chemistry of cooling media, radiological control onsite and offsite and plant security.

In addition, all the construction sites and onsite projects at Krško were temporarily closed; working from home and home-based on-call time was introduced for every support function of the plant; access to the plant and the services were only allowed when necessary for plant safety and operation.



Nuclear electricity production





#### South Africa

Koeberg nuclear power plant's two reactors lie around 30km north of Cape Town. The reactors have been in operation since the mid-1980s. The plant's electricity output in 2019 was the fifth-highest achieved in the plant's 35-year operating history.

During the height of the COVID-19 pandemic, South African electricity usage dropped by between 7.5-9 GW. In response, the plant operator made use of the significant reduction in electricity demand to increase the scope of planned maintenance work, including taking unit 2 at Koeberg offline from 3 to 30 April.

In October 2019 it was announced in the update to the country's Integrated Resource Plan (IRP), that the operation of Koeberg would be extended by 20 years to 2044. The government would immediately start a nuclear new build programme to add 2500 MW of generating capacity. The programme would be "implemented at an affordable pace and modular scale (as opposed to a fleet approach) and taking into account technological developments in the nuclear space."

The report noted that "small nuclear units will be a much more manageable investment when compared to a fleet approach" and that the development of such plants elsewhere in the world was therefore particularly interesting for South Africa.

In May 2020 the Department of Mineral Resources and Energy (DMRE) announced it would begin work on a roadmap for the procurement of 2500 MWe of new nuclear capacity. It will consider "all options" including SMR projects led by private companies and consortia.



Nuclear electricity production







Source: World Nuclear Association, IAEA PRIS

#### South Korea

There are 24 reactors operating in South Korea, with six on the west coast of the country at Hanbit, and 18 across three sites on the east coast, at Hanul, Wolsong/Shin Wolsong) and Kori/Shin Kori.

The most recent connection to the grid was Shin Kori 4 on 22 April 2019. Shin Kori 5&6 are under construction and are expected to start operation by 2024. Construction is also taking place on units 1&2 at Shin Hanul, which are expected to be in operation by 2021.

These units are coming online despite a government policy that came into force in 2018 to phase out nuclear power over a period of 40 years. The plan assumes that power demand will grow at an average of 1% a year to 2034 and that there would be 17 operable reactors by then. Construction on Shin Kori 5&6 was paused for three months pending a decision on the units' completion and in October 2017 a government-appointed committee voted 59.5% in favour of continuing construction.

The South Korean nuclear industry continues to pursue cooperation opportunities and business outside of South Korea. In January 2020, a revised pre-project engineering contract was signed by South Korea's Ministry of Science and ICT and Saudi Arabia's King Abdullah City for Atomic and Renewable Energy to establish a joint entity for the construction and commercialisation of the Koreandesigned 330 MWt SMART reactor (System-integrated Modular Advanced Reactor) in Saudi Arabia.



Nuclear electricity production







Source: World Nuclear Association, IAEA PRIS

#### Spain

Seven nuclear reactors generate around 20% of Spain's electricity. These reactors all started operations in the 1980s.

Until 2011 it was planned that operation of Spain's reactors would draw to a close in the 2020s as operating lifetimes would be limited to 40 years. That restriction has since been removed and the reactors currently in operation are now expected to close over the next 15 years, with Trillo 1 the last to close in 2035. In May 2020, the Spanish Nuclear Safety Council granted permission for Almaraz 1&2 to operate until 2027 and 2028, respectively.

Progress has been made recently in the decommissioning of two of Spain's three older, shutdown reactors. In late October 2019, work to dismantle the dome of the containment building of the José Cabrera nuclear power plant began. The plant — also known as Zorita — is the first to be decommissioned in Spain. It is estimated that about 104,000 tonnes of materials will be managed throughout the duration of the dismantling project. Only around 4% of them will be classified as radioactive waste.

In May 2020, an application was submitted to the Ministry for Ecological Transition and Demographic Challenge (MITECO) for the transfer of ownership of the Garoña nuclear power plant and the first phase of its dismantling. The single-unit plant was shut down in mid-December 2012. The authorisation could be issued in 2022, from which time the first phase of the plant's dismantling could begin. In this phase, expected to last three years, the main activities will be loading of used fuel into containers and its transfer to the on-site interim storage facility.



Nuclear electricity production







Source: World Nuclear Association, IAEA PRIS

#### Sweden

There are seven reactors operating in three locations in Sweden, Ringhals, 50 km south of Gothenburg, Oskarshamn, 22 km northeast of the city of the same name and Forsmark, 120 km north of Stockholm.

At the end of 2019 Ringhals 2 was shut down after 44 years of operation during which it supplied 215 TWh of electricity. Ringhals 1 went offline from March 2020 for a maintenance outage and remained offline due to low electricity demand but returned to service in June to provide grid stability.

In January 2020 the Swedish Parliament narrowly rejected by a one vote majority a proposal from the Sweden Democrats party to reverse the planned closure of Ringhals 1& 2.

Public opinion has been shifting in favour of nuclear energy in Sweden. A survey by Novus and published by Analysgruppen in November 2019 showed that 78% of people surveyed in Sweden strongly supported nuclear energy — up from 71% in 2017. In contrast, only 11% of those polled were opposed to nuclear power. 43% were open to the construction of new nuclear power plants.

In June 2019 the Swedish Radiation Safety Authority (SSM) approved Forsmark 1&2 to operate for a further ten years, until 2028, following a periodic safety review. This will extend their operations well beyond their initial 40-year planned operation.

Swedish engineering consultancy company Sweco will prepare the detailed design of the planned used nuclear fuel repository at Forsmark.



Nuclear electricity production



Source: World Nuclear Association, IAEA PRIS



Source: World Nuclear Association, IAEA PRIS

#### Switzerland

Switzerland has two reactors at Beznau, 30 km southwest of Zurich, one reactor at Gösgen, 40 km west of Zurich and one at Leibstadt, 35 northwest of Zurich.

A fifth reactor at Mühleberg ended generation in December 2019 after 47 years in operation, having supplied 125 TWh of electricity.

Switzerland voted in a referendum in May 2017 to approve a revision to the country's energy policy that promotes the use of renewable energy sources and energy conservation. The revised Federal Energy Act also prohibits the construction of new nuclear power plants. In October 2018, the International Energy Agency (IEA) said Switzerland's phased withdrawal from nuclear power presents challenges for maintaining its electricity security.

In April 2019, Framatome was awarded a contract by Kernkraftwerk Gösgen-Däniken (KKG) to modernise the reactor protection system at Gösgen. The scope of the contract at Gösgen includes modernisation of the entire RPS using Framatome's TELEPERM XS digital instrumentation and control (I&C) platform. Installation and commissioning of the new RPS are scheduled to be carried out during the plant's planned 2022 outage.

In November 2019, Swiss nuclear power plant operators criticised a reform of regulations for decommissioning and waste disposal funds, which they said would disproportionately increase their costs and thus reduce their ability to invest in the country's energy sector.



Nuclear electricity production



Source: World Nuclear Association, IAEA PRIS







#### Ukraine

Ukraine has 15 reactors operating from four sites, at Rovno and Khmelnitski in the west of the country, and South Ukraine and Zaporozhye in the south. Together they supply around half of Ukraine's electricity needs.

While 2019 performance was in line with that of recent years, the high share of nuclear generation in the Ukrainian electricity mix has meant that operator Energoatom has reduced output, rescheduled outages and temporarily withdrawn from service some reactors during the period of reduced electricity demand caused by the COVID-19 pandemic.

In June 2019, Holtec International, Ukraine's Energoatom and the country's State Scientific and Technology Centre (SSTC) formally entered into a partnership to advance the US company's SMR-160 SMR for deployment in Ukraine.

In August Energoatom and Cameco signed a memorandum of cooperation and understanding as part of the Ukrainian nuclear power plant operator's strategy to diversify its nuclear fuel supply. In December the core of unit 5 at the Zaporozhe nuclear power plant was fully loaded with WER-1000 fuel produced by Westinghouse for the first time.

During a working trip in March 2019 to the South Ukraine Energy Complex, where the South Ukraine nuclear power plant is located, Ukrainian president Petro Poroshenko noted that nuclear energy reduces Ukraine's dependence on natural gas. The Complex is the only enterprise in Ukraine where nuclear, hydro- and pumped-storage facilities are used in an integrated manner.



Nuclear electricity production



Source: World Nuclear Association, IAEA PRIS



Source: World Nuclear Association, IAEA PRIS

#### **United Kingdom**

The UK has 15 reactors at seven sites, 14 of which are advanced gas-cooled reactors (AGRs), with one PWR at Sizewell. Around half of the AGRs are scheduled to shut down by 2025, with the remaining ones closing by 2030.

Production at the UK's reactors was lower in 2019 than in previous years due to a number of extended outages, including at two reactors at Hunterston, which were undergoing investigation of cracking in the reactors' graphite moderators. This cracking is a well-known characteristic of the UK's AGR design and requires monitoring and regulatory approval for continued operation.

Output at the UK's one operating PWR, Sizewell B, was reduced during the summer of 2020 following agreement with the National Grid because of the lower demand for electricity during the COVID-19 pandemic.

Two EPR reactors are under construction at Hinkley Point. In addition, plans are being developed for construction of two EPRs at Sizewell, and two HPR1000 units at Bradwell, the site of a shutdown Magnox plant.

Work has been suspended since January 2019 on proposals to construct new reactors at Wylfa, in north Wales. In June 2020 a group of companies, trade unions and individuals proposed the construction of the Moorside Clean Energy Hub in Cumbria, which would include EPRs as well as SMRs and advanced modular reactors (AMRs).

![](_page_56_Figure_6.jpeg)

Nuclear electricity production

![](_page_56_Figure_8.jpeg)

![](_page_56_Figure_10.jpeg)

![](_page_56_Figure_11.jpeg)

Source: World Nuclear Association, IAEA PRIS

#### United States of America

The USA has 95 operable reactors with a combined capacity of 97.2 GWe, the largest nuclear fleet of any single country. Two AP1000 reactors are under construction at the Vogtle power plant in the state of Georgia.

The Vogtle reactors will be the only ones to enter service following 17 licence applications made since mid-2007 to build 26 new nuclear reactors. Some states have liberalized wholesale electricity markets, which makes the financing of capital-intensive power projects difficult, and coupled with lower gas prices since 2009, have put the economic viability of some existing reactors and proposed projects in doubt. In April 2020 Indian Point 2 was shut down four years ahead of the expiry of its operating licence.

The USA is examining the potential for SMRs and advanced nuclear reactors.

In July 2020 the US International Development Finance Corporation (DFC) lifted its legacy prohibition on funding nuclear energy projects overseas. The DFC said the update recognised the "vast" energy needs of developing countries as well as the potential of new and advanced technologies such as SMRs and micro-reactors.

The potential for existing reactors to make a significant contribution to meeting the USA's energy needs many decades into the future was highlighted by the decision of the US Nuclear Regulatory Commission to approve a 20-year subsequent licence extension for Turkey Point 3&4, authorising the reactors to operate for up to 80 years. In May 2020, a subsequent licence extension was granted to Peach Bottom 2&3.

![](_page_57_Figure_6.jpeg)

![](_page_57_Figure_7.jpeg)

![](_page_57_Figure_8.jpeg)

![](_page_57_Figure_9.jpeg)

![](_page_57_Figure_10.jpeg)

![](_page_57_Figure_11.jpeg)

Source: World Nuclear Association, IAEA PRIS

#### Emerging Nuclear Countries

#### Bangladesh

Two 1080 MWe reactors are under construction at Rooppur, approximately 160 km northwest of Dhaka. Construction began in November 2017 (unit 1) and July 2018 (unit 2) on the VVER-1200/V-523 reactors, which are based on the V-392M reactors at Novovoronezh II. The two units are due to be grid connected in 2023 and 2024, respectively.

Bangladesh, which has a population of 160 million, plans to produce 9% of its electricity from nuclear power and reduce its dependence on fossil fuels by the middle of the 2020s.

The pouring of concrete for the foundation of the turbine building at unit 2 was completed in August 2019, following on from the unit 1 turbine hall foundation earlier in the year. In July 2020 Atommash, part of the engineering division of Russian nuclear corporation Rosatom, completed hydraulic tests on the reactor pressure vessel of unit 1.

Rosatom's fuel manufacturing business TVEL will supply fuel for the Rooppur plant for its entire operating life.

#### **Belarus**

Two 1110 MWe VVER-1200/V-491 reactors are under construction about 8 km northeast Astroverts of and 120 km northwest of Minsk. The two reactors, known as Ostrovets or Belarusian units 1&2, started construction in 2013 and 2017, respectively.

Hydraulic tests at unit 1 were completed in September 2019 and hot tests were carried out between December 2019 and April 2020. The first fuel load for unit 1 was delivered in May 2020. Startup of the reactor is expected in 2020, with unit 2 following in 2021.

#### Turkey

Construction is continuing on the Akkuyu nuclear plant on Turkey's southern coast, 120 km southwest of Mersin. The Akkuyu plant will comprise four 1114 MWe VVER-1200/V-509 reactors, based on the V-392M reactors at Novovoronezh II. When all four reactors are operational the plant is expected to meet about 10% of Turkey's electricity needs.

Construction of the basemat of unit 1 started in April 2018 and was completed in March 2019 and involved the casting of 17,000 cubic meters of self-compacting concrete. The core catcher for unit 1 has been installed and hydraulic tests on the reactor pressure vessel for that unit were completed in July 2020.

A construction license for unit 2 was issued in September 2019, and concreting of the foundation slabs is approaching completion. The construction area is being prepared for unit 3. Turkey aims to bring unit 1 online in 2023, with the other three units following by 2025.

#### **United Arab Emirates**

Grid connection of Barakah 1 was achieved on 19 August 2020, marking the transition to operable status for unit 1.

Three further APR1400 reactor are under construction at Barakah, which is in the Emirate of Abu Dhabi, located 50 km east of Al Sila, in the Al Dhafrah Region.

Construction of unit 2 was completed in July 2020, at which point unit 3 was 92% complete on and unit 4 was 85% complete. Once the four reactors are online, the facility will provide around 25% of the country's electricity and avoid the release of up to 21 million tonnes of carbon emissions.

# 4 Director General's Concluding Remarks

While this report details the performance of nuclear reactors globally in 2019, over the last few months our focus has been on the impacts of the COVID-19 pandemic.

Throughout the pandemic, operators have worked with great commitment to ensure that their reactors have continued to provide electricity and support grid stability. Staff working at reactors have had to adapt to working in COVID-safe conditions whilst ensuring continuity.

With the dramatic drop in electricity demand seen in some regions, reactors have had to demonstrate greater flexibility in operation. While many renewable generators have been cushioned from the impacts of the pandemic by obligations to purchase their electricity, nuclear operators have had to vary the output of their plants to support both intermittent generation and changes in demand.

It is not just the simple production of electricity that nuclear generators have provided. The inertia provided by the rotating mass of large turbine generators, such as those used in nuclear power plants, is essential. Without this inertia, which cannot be provided by most renewables, grid systems can experience rapid drops in frequency, resulting in power cuts.

In Sweden, Ringhals 1 was brought back into service earlier than planned at the request of the national electricity transmission system operator. The reactor was needed online to secure the voltage stability and short-circuit power required to handle the operating situation in southern Sweden during the summer. The fact that Ringhals 1 is due to shut down at the end of 2020, and therefore will not be available to provide this vital service next summer, demonstrates the paucity of thinking in continuing with the unnecessary closure of some reactors.

# Nuclear's place in the post-pandemic recovery

At the time of writing, the pandemic is still affecting many parts of the world. Its impact has not been limited to its tragic health effects. Around the world, economies have contracted sharply and many people have lost their jobs. A key question for governments now is how to restart their economies safely to generate new employment opportunities.

Major public infrastructure investment is the cornerstone of many governments' strategies for recovery. The scale of planned stimulus packages provides a unique opportunity to build a more sustainable world, with societies emerging stronger, cleaner and more resilient.

Nuclear energy should play a central role in these recovery efforts. Supporting existing nuclear generation and promoting new nuclear build will boost economic growth in the short-term and underpin the development of a low-carbon, resilient and cost-effective electricity infrastructure. Nuclear projects attract valuable inward investment, driving sustained long-term local and national economic growth.

Investments into nuclear projects stimulate the economy well beyond the nuclear industry and deliver widespread economic growth. Studies in the USA and Europe have shown that every euro or dollar spent on the nuclear industry results in four times that investment in the broader economy. And, when evaluated on an equitable basis, nuclear energy remains a very competitive option for new generation. Investment in nuclear energy research, development and deployment will stimulate job creation in new sectors, and broaden the application of nuclear technologies. Small modular reactors and advanced reactor technologies have the potential to decarbonize other sectors through, for example, the provision of carbon-free heat for use in both residential and industrial applications.

Around the world there are more than 100 planned reactors with approval, funding or commitment in place. With the right support, these reactors would play a crucial role in the postpandemic recovery, and each and every one will create considerable societal benefits – but to ensure these are realised governments must put mechanisms in place to value nuclear energy's unique attributes.

Further opportunities exist in the form of ensuring the long-term operation of existing nuclear reactors. Securing continued generation from the approximately 290 reactors which have been operating for more than 30 years, and which have the potential to generate for decades to come, is the cheapest way to generate low-carbon electricity.

#### Creating jobs and boosting local economies

Investing in nuclear energy is a very good way to create a large number of jobs for local and regional economies, as well as strengthening national construction and technology capabilities.

For example, 25,000 employment opportunities will be created by the Hinkley Point C project in the UK, including over 1,000 apprenticeships during the construction phase, and 900 permanent jobs onsite during more than 60 years of operation. About 64% of the construction contracts are being delivered by UK companies, and the project is contributing some £1.5 billion to the local economy during construction, when operating it is expected to contribute £40 million every year.

Upgrading existing reactors also provides major employment benefits. The Bruce nuclear power plant in Canada is undergoing refurbishment of its six reactors. This will sustain 22,000 jobs, as well as providing lowcost, reliable, carbon-free electricity until 2064.

# A time for action and ambition

The global nuclear industry is ready to work with policy-makers to set a greater ambition for meeting climate goals and to create the jobs needed for sustainable economic growth.

We cannot afford to allow a minority of countries promoting their ill-judged anti-nuclear dogma to dictate and restrict multilateral action on energy and the environment. The failure to include nuclear energy in the European Commission's sustainable finance taxonomy from the very start, thereby potentially hampering the financing of new nuclear projects. runs counter to its "do no significant harm" principle – constraining nuclear energy will mean more pollution and higher carbon emissions, as well as less reliable supply and higher prices for consumers.

We need to have greater ambition to build a more sustainable and equitable future for everyone around the world. While the pandemic has been the focus for governments in 2020, the essential challenge of our time remains to ensure that no one is forced to live without reliable and affordable energy, whilst also protecting the planet for future generations.

We are ready to meet the *Harmony* goal of 1000 GWe of new nuclear capacity before 2050, which would ensure that at least 25% of global electricity would be generated by nuclear reactors, as part of a low-carbon energy mix.

World Nuclear Association therefore calls on policy-makers to consider nuclear in energy transition plans, and enact policies to ensure that the socio-economic, environmental and public health benefits of nuclear technology are extended to as many people as possible.

# 5 Status Update to 21 August 2020

![](_page_61_Figure_1.jpeg)

#### **Construction starts**

	Capacity (net)	Location	First concrete
Akkuyu 2	1114 MWe	Turkey	8 April 2020

#### Grid connections

	Capacity (net)	Location	Grid connection
Tianwan 5	1000 MWe	China	8 August 2020
Barakah 1	1345 MWe	United Arab Emirates	19 August 2020

#### Permanent shutdowns

	Capacity (net)	Location	Shutdown
Fessenheim 1	880 MWe	France	22 Feb 2020
Indian Point 2	998 MWe	United States	30 April 2020
Fessenheim 2	880 MWe	France	29 June 2020

# Abbreviations

AGR	Advanced gas-cooled reactor
BWR	Boiling water reactor
CCGT	Combined cycle gas turbines
FNR	Fast neutron reactor
FOAK	First of a kind
g	gram
GCR	Gas-cooled reactor
GWe	Gigawatt (one billion watts of electric power)
HTGR	High temperature gas-cooled reactor
IAEA	International Atomic Energy Agency
kWh	kilowatt hour (one thousand watt hours of electricity)
LTO	Long-term operation
LWGR	Light water-cooled graphite-moderated reactor
MoU	Memorandum of understanding
MOX	Mixed uranium and plutonium oxide
MWe	Megawatt (one million watts of electric power)
PHWR	Pressurized heavy water reactor
PRIS	Power Reactor Information System database (IAEA)
PWR	Pressurized water reactor
SMR	Small modular reactor
TWh	Terawatt hour (one trillion watt hours of electricity)
VVER	Vodo-Vodyanoi Energetichesky Reaktor (a PWR)

# **Geographical Categories**

#### Africa

South Africa, Egypt

#### Asia

Armenia, Bangladesh, China mainland and Taiwan, India, Iran, Japan, Kazakhstan, Pakistan, South Korea, Turkey, United Arab Emirates

East Europe & Russia Belarus, Russia, Ukraine

North America Canada, Mexico, USA

South America Argentina, Brazil

#### West & Central Europe

Belgium, Bulgaria, Czech Republic, Finland, France, Germany, Hungary, Italy, Lithuania, Netherlands, Poland, Romania, Slovakia, Slovenia, Spain, Sweden, Switzerland, UK

# Further Reading

World Nuclear Association Information Library https://world-nuclear.org/information-library.aspx

World Nuclear Association Reactor Database https://world-nuclear.org/information-library/facts-and-figures/reactor-database. aspx

The Nuclear Fuel Report: Global Scenarios for Demand and Supply Availability 2019-2040 (published September 2019) https://world-nuclear.org/shop.aspx

The World Nuclear Supply Chain: Outlook 2035 https://world-nuclear.org/shop.aspx

World Nuclear News https://world-nuclear-news.org

The Harmony programme https://world-nuclear.org/harmony

International Atomic Energy Agency Power Reactor Information System https://www.iaea.org/PRIS/home.aspx

World Nuclear Association is the industry organization that represents the global nuclear industry. Its mission is to promote a wider understanding of nuclear energy among key international influencers by producing authoritative information, developing common industry positions, and contributing to the energy debate, as well as to pave the way for expanding nuclear business.

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