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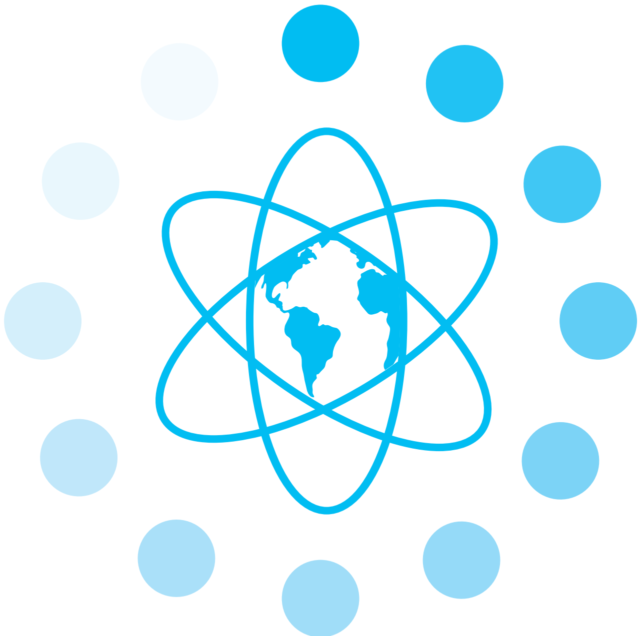

The global nuclear energy revival

Review Report 2024

Preface by the French Institute of International Relations (Ifri)

Preface

Nuclear energy key to securing resilience, decarbonization, and competitiveness

Marc-Antoine Eyl-Mazzega, ***Director of the Centre for Energy and Climate at the French Institute of International Relations (Ifri)***

Former ECB president Mario Draghi's European competitiveness report in September 2024 aptly lays out the significance of resilience and sovereignty in a rapidly changing world, industrial competitiveness in the face of global players, each with different climate ambitions and benefiting from cheap energy sources and, the necessity to continue decarbonization, particularly via electrification.

While these issues now rank highly on EU Member States' agendas, their willingness and ability to act varies greatly. Although decoupling from Russia is unanimously supported, the issues of security and industrial competitiveness are approached with more nuance vis-a-vis the United States, China, and the Gulf States, for example. Furthermore, decarbonization, resilience, and competitiveness are still often seen as objectives that are difficult to reconcile. However, one analytical viewpoint is gaining widespread traction, namely that the world has shifted direction away from free trade and free competition, once considered engines of growth and development. Nowadays, against a backdrop of heightened geo-economic confrontation, we see a rise in protectionism and economic-security related priorities, even to the point of instrumentalizing economic dependence.

The renewed interest in civil nuclear power provides a vector for this analytical convergence, and not just in Europe. Never have so many countries around the world been so keen to accelerate the development of nuclear energy, which is now being appreciated as an asset in the areas of energy, economic, and climate security. Arguably not before time. With interest rates starting to turn down, electricity prices moving higher, and the pressure to decarbonize growing alongside rising electricity production in tandem with renewable energies, we see both large nuclear reactors and promising small modular reactors attracting more and more interest across the globe.

The world needs to decarbonize faster and more intensively, while at the same time meet a rapidly growing demand for electricity, particularly outside the OECD, in India and China. Momentum is also burgeoning within several OECD countries, starting with the USA (albeit unevenly), and it will eventually extend to Europe, where industries are still struggling, but where electrification of end uses could progress rapidly.

A new era is opening for the civil nuclear energy industry, full of opportunities, yet also marked by growing tensions. While new reactors will not be operational before 2030, extending the lifespans of existing power plants and increasing their output levels are essential elements in closing out this decisive decade of global decarbonization.

These reactors, however, will be essential for finally phasing out the use of coal, complementing other low-carbon technologies, deepening electrification, and producing both heat and hydrogen.

> ***There is a growing interest across all continents in both large reactor plants and promising small modular reactors.***

Préface

China is speeding up reactor construction on its own soil, and it is high time for Western industries to make a return to responsible reliable series construction. The more we build, the more industry, and the climate will benefit, and the lower will be the costs. States and companies need to implement faster authorization processes, raise capital, and support the associated employment requirements (hundreds of thousands of jobs). The public debate on energy, hitherto dominated by ideological considerations and often ignoring external constraints, should refocus on efficiency, the resilience of the electric power system, and both supply and demand flexibility. System costs will necessarily be high, and the challenge will be how to distribute them over time and across the various stakeholders.

If, as we hope, the decision is taken to keep energy intensive primary industries exposed to international competition, the only solution will be to subsidize their electricity supplies during the initial stages, to help them transform their industrial base and protect them against carbon leakage. These subsidies will have to be organized at European level and framed by strict conditions.

Nuclear industry in the West appears to be irreversibly extricating itself from Russia, while future cooperation with China's industry is bound to be limited. Competition is fierce within the Western bloc countries, in contrast with current conditions in the Sino-Russian bloc. China's industry is clearly mobilizing to meet its domestic needs, but it will also seek to expand internationally. As for the Russian industry, once its financial standing has been restored, it will have no choice but to seek growth beyond its borders. To save the planet, ideally, we should be constructing as rapidly and as extensively as possible. At the very minimum, the world needs common rules and a modus vivendi in civil nuclear power, based on the IAEA, where France is the European Union's most influential country in terms of nuclear issues. French commitment to strengthening the role of the IAEA, which has been weakened by the Ukrainian crisis, has been decisive. We need to continue with this effort, all the while remaining stringent on issues of safety and non-proliferation, as well as being vigilant to the risk of State-based geopolitical capture via civil nuclear contracts.

The revival of civil nuclear power is a strategic issue, as it affects energy and industrial security, as well as geopolitical influence, and it depends on a coordinated and determined approach. It is gratifying that Brussels is now taking greater account of these aspects, however over the next few years decisive action is required, and necessarily with great agility, because nuclear power is an industry with unique specificities.

Any strategy must be based on facts and a sound knowledge of markets, policies, and politics. The work presented below provides an indispensable understanding of a sector that is key to decarbonization and that is characterized by significant geopolitical effects. ■

It is high time for Western industries to make a return to responsible reliable series construction.

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Given the climate crisis, nuclear energy, an inherently long-term industry, is more crucial than ever

Valérie FAUDON, ***Executive Director of the French Nuclear Society (Sfen)***

In her speech in Brussels on 21 March 2024, European Commission President von der Leyen declared, "After the global energy crisis caused by Russia's invasion of Ukraine, many countries are giving a fresh look to the potential role that nuclear might play." The President identified three roles for nuclear power in Europe, namely, "To help reach our climate goals, ..., to safeguard our energy security," by reducing dependence on imported fossil fuels, and thirdly to ensure our competitiveness, with nuclear power reliably anchoring electricity prices.

This second edition of Sfen's global nuclear review shows the ongoing nature of the revival of nuclear power that started in 2022. At the end of 2023, more than 20 countries announced at December 2023 COP28 event in Dubai an ambition to triple global nuclear energy capacity by 2050. This declaration was followed week after week by a succession of announcements, from all over the world, about extending the operation lifespans of current nuclear fleets, new build projects, and the development of small modular reactors, based on either or both current and advanced technology (SMR/AMR). Some of these announcements present quite a departure from the industry's earlier trajectory back in 2010. One such example is US energy producer Constellation's re-start of the TMI1 reactor in the USA, which had been shut down for five years, and instead will now provide Microsoft's data center electricity needs. Two other examples are Italy and Switzerland, which, following referendum results that came out against the use of nuclear power are now looking to open a fresh debate on new nuclear builds.

Given the current climate crisis, nuclear power, an inherently long-term industry, is more crucial than ever. Firstly, because nuclear is currently the world's second largest source of low-carbon electricity generation, and in the very short-term can contribute via extending reactor lifespans (LTO), raising reactor power levels, and even restarting existing units. Secondly, because global demand for low-carbon energy will be even greater in 2030, 2040, 2050, and beyond, and particularly in sectors that are difficult to decarbonize.

This nuclear revival, which only started in 2022 still remains a hope for the future and many challenges lie ahead. First is the ability for series production to be successfully accomplished as part of planned industrial programs. China is currently demonstrating that this is possible and the West must regain the ability to manages these types of complex programs. Second is the imperative to secure financing. Climate Week in New York in September 2024 provided an excellent signal as fourteen financial institutions including Bank of America, Goldman Sachs, and BNP Paribas announced their backing for the development of the nuclear industry. The purpose of this report, a reference tool for Sfen, is to regularly observe and measure the progress made by governments and the nuclear industry during its revival. This document is updated annually, and Sfen, through its daily publications in the Revue Générale Nucléaire (RGN), is also interpreting the international news on a continuous basis throughout the year. While this report's first edition focused primarily on nuclear reactors, this second edition provides additional information on the nuclear fuel cycle and industrial value chains.

I wish to thank Gaïc Le Gros who headed up this project, as well as the embassy-based nuclear advisors who provided invaluable proofreading skills and suggestions. I also want to thank Marc-Antoine Eyl-Mazzega of the Institut français des relations internationals (Ifri- French Institute of International Relations) for kindly agreeing to write the preface for this report. Finally to our readers, we look forward to receiving your feedback as well as your suggestions for the 2025 edition. ■

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2024 in Review

I

2024 in Review

1 Highlights

1.1 Proactive announcements at a global level

In a first for a COP climate conference, COP28 in Dubai saw real ambitions emerge for nuclear power. The final agreement officially recognized the need to accelerate both zero and low-emissions technologies, including nuclear power. Some twenty heads of state, including France, the United States, and Japan, signed a declaration calling for a tripling of renewal energy capacity globally by 2050. According to the OECD's Nuclear Energy Agency (NEA), this trajectory would enable nuclear power to avoid nearly 90 Gt of CO2 between 2020 and 2050. Several countries subsequently confirmed this ambition at a domestic level, including India in March 2024 (tripling of capacity by 2047) and the USA in June 2024 (capacity to potentially reach 300 GW by 2050).[1,2] In September 2024, for the fourth year in a row, the IAEA raised its "plausible and technically feasible" regional projection scenarios, so they now range from a low capacity growth scenario of 40% right up to a high scenario of 250%.

Achieving these ambitious targets will require the pulling several levers including, the long-term operation of existing reactors, the construction of new large-scale reactors as well as small and medium-sized ones, and the building of advanced reactors capable of reducing emissions via vectors other than electricity, such as hydrogen and heat.

1.2 Europe's nuclear awakening

Heavily impacted by the gas crisis and the rise in wholesale electricity prices from the end of 2021, the European Union, which in recent years has focused almost exclusively on the development of renewables, has been gradually opening the door to nuclear power. In May 2023, fifteen European Union countries along with the United Kingdom, came together to form the Nuclear Alliance (a French initiative), and it set an ambitious target of developing a European nuclear fleet capable of generating 150 GW by 2050, compared with 100 GW today, which is the equivalent of "30 to 45 new large reactors and the development of small modular reactors (SMRs)," as well as extending existing fleet reactor lifespans.[3] Similarly, the European Commission's position on nuclear power has made several important advances. On 21 March 2024, at the Net Zero Nuclear Summit, the President of the European Commission President von de Leyen officially recognized that while countries did hold divergent views on nuclear power, nuclear technologies could play an important role, alongside renewables, in achieving the European Union's objectives in terms of fighting climate change, and in securing energy supplies and competitiveness. The NZIA's (Net-Zero Industry Act) climate-neutral technologies philosophy includes nuclear power as a strategic technology, and nuclear power has also been a factor in the reform of the electricity market. Lastly, in 2024 the European Commission launched its SMR Industrial Alliance with the goal of facilitating and accelerating "the development, demonstration, and deployment of the first SMR projects in Europe in the early 2030s."

1.3 Announcements to strengthen the fuel supply chain

The crisis following the invasion of Ukraine in 2022 revealed how a number of Western countries were dependent on Russia for their fuel supply chain requirements (uranium, conversion, enrichment, fuel assemblies). Although Russia accounts for only a small percentage of the world's uranium production, it holds a significant 40% market share in both uranium conversion and enrichment. In addition to its conversion and enrichment services, Russia also manufactures fuel assemblies for Russian-technology (VVER) power plants operating in Europe.

In May 2023 during the G7 summit in Japan, five countries, referred to as the Sapporo 5 (Canada, France, Japan, the United Kingdom, and the United States) made an announcement on the margins of that event to indicate their intention to invest in new domestic facilities aimed at establishing a "stable supply chain." In November 2023 at COP28, the Sapporo 5 confirmed a joint public-private investment of $4.2 billion over the succeeding three years, to strengthen their own domestic conversion and enrichment capacities. In Europe, Orano, while continuing to ramp-up its new Philippe Coste conversion plant, confirmed in late 2023 an investment injection to boost the capacity of its Georges Besse II enrichment plant at Tricastin (France) by 30%.

In the United States, Congress passed a law in May 2024 banning enriched uranium imports from Russia from 2028, posting a strong signal to encourage domestic industry actors. In 2023, Converdyn restarted its Metropolis conversion plant. Additionally, $2.7 billion in federal funds will be invested, along with some $700 million from the Inflation Reduction Act, in the development of new enrichment capacities. In Europe, almost all VVER reactor operators have amassed fuel inventories and diversified supply by signing fuel manufacturing contracts with Westinghouse (U.S.) and Framatome (France).

2 Signs of recovery

2.1 Maintaining the nuclear base: from long-term reactor operation through to restarting reactors

2023 already stood out as a year in which significant decisions were made over long-term reactor operations. In some cases, states (Belgium, California) even reversed earlier decisions to close nuclear reactors, choosing instead to extend their operating lifespans. This is a strong trend that has continued into 2024, and we are even seeing discussions about restarting reactors that had previously been shut down.

In the United States, where the vast majority of reactors have already been licensed to operate for sixty years, a total of eight reactors, i.e., two more than in 2023, now have a license to operate for eighty years, and fifteen more have already applied for similar extensions. Furthermore, two reactors that had been shut down and therefore destined for dismantling, could soon be restarted: one in Michigan and one in Tennessee.

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In Europe, Finland has already extended the operating life of both of its Loviisa units out to seventy years. At the end of 2023, Belgium signed an agreement with Electrabel to extend the life of the Doel-4 and Tihange-3 nuclear reactors by ten years, alongside a €2 billion investment in the facilities and a guaranteed revenue stream (by way of a contract for difference (CFD)). In France, the government has called on EDF to draw up a performance plan aimed at raising production, in particular through power increases, to 400 TWh by 2035. In Germany, the official candidate of former Chancellor A Merkel's CDU party has announced that, should the CDU win the 2025 elections, he would consider restarting the nuclear power plants that shut down in 2022 and 2023.

2.2 Flurry of announcements about building high pressure reactors

According to the IAEA, in September 2024, 62 nuclear reactors were under construction worldwide, most of which are high pressure reactors. China alone accounts for more than a third of these, due to its domestic series construction program. After announcing the construction of ten new reactors in 2022, as well as another ten in 2023, China has again, since the start of 2024, announced a further fourteen reactors. In all, some fifty reactors are now either planned for, or under construction. With these programs, China is now in a position to demonstrate the effects of series production and is now aiming for construction times for the CAP1000 reactor of fifty-six months, i.e., under five years, with construction costs of less than $3 billion per reactor.[4]

Many Western countries have also been announcing major upcoming construction projects.

In Europe, several countries, including the Czech Republic, France, Hungary, Poland, and the U.K. have launched their own construction programs. Bulgaria, the Netherlands, Romania Sweden, Slovenia, and Slovakia have also announced nuclear projects. Canada, an early SMR adopter, is also planning a 4.8 GW expansion of the Bruce Power Generating Station in Ontario. Russia continues its policy of exporting to new country nuclear adopters, and provides reports on the progress of its projects, particularly in Turkey (four units) and Egypt (four units). South Korea has relaunched its project to build two APR1400 reactors, which received authorization in September 2024.

2.3 Ongoing momentum for SMR and AMR

At the beginning of 2024, the OECD's Nuclear Energy Agency (NEA) listed nearly 100 small modular reactor (SMR) concepts worldwide, and analyzed more than 50 of them in detail. These reactors notably feature ground-breaking innovations in terms of the economic model (factory production), the passive safety systems, and the usage opportunities. They enable new needs to be met, such as supplying remote areas, desalinating seawater, and producing heat or hydrogen for deep decarbonization (industrial processes). Lastly, so-called advanced technologies (AMR) use new fuels, enable materials to be managed differently, and reduce waste.

Several SMR/AMR plants are currently in operation (China, Japan, Russia). Others have begun construction, passed key licensing stages with safety authorities, and selected a demonstrator reactor site.

While Russia and China may have led the way, albeit without having deployed series construction, the United States

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More and more experiments occurring to establish how nuclear energy can contribute to decarbonization beyond electricity

and Europe are also making progress. At the end of 2023, and marking a first in fifty years, the United States certified a 4th-generation reactor, the Kairos Power's Hermes demonstration reactor. Construction began in July 2024 at the Oak Ridge site in Tennessee. The United States is generally home to the largest number of new nuclear reactor designers, although France is also engaged in this wave of innovation with twelve new concepts under development alongside support from the France 2030 investment plan. According to the IAEA, SMR/AMRs could account for between 6% and 24% of global nuclear capacity, or almost 140 GW, by 2050. It's in Big Tech that SMR/AMR could even find its first series effects. Google has teamed up with Kairos Power to deploy a fleet of 500 MW small reactors by 2035. For its part, Amazon is also thinking big, and aims to deploy and develop 5 GW of nuclear energy in the USA by 2039 via investment in the X-energy Reactor Company.

2.4 Nuclear power – multiple uses

While electricity is an essential vector for decarbonizing the economy, other vectors, such as heat and low-carbon hydrogen, will be needed to replace fossil fuels in industry, construction, and transport. Several experiments are underway across the globe to enable nuclear power to contribute to decarbonizing beyond the field of electricity.

Cogeneration, i.e. the simultaneous production of low-carbon steam or heat and electricity, is already a tried-and-tested solution for supplying urban heat networks. According to the IAEA, 43 nuclear reactors worldwide are currently supplying urban heating networks, most of which are in Eastern Europe and Russia. In the heart of Europe, the Beznau power plant in Switzerland has been supplying heat to 20,000 people since 1983.[5] China is now stepping up a gear, and at the end of 2020 launched a large-scale low-carbon heat supply service in the coastal city of Haiyang, using AP1000 reactors. The project is to accommodate a 23km extension pipeline that will serve one million inhabitants and will eliminate 1.65 Mt of annual CO_2 emissions by replacing the current suite of coal-fired boilers.

New advanced nuclear technologies aim to produce heat at the high temperatures (> 500°C) needed to decarbonize a number of industrial processes. U.S. chemical company Dow Chemical has announced an agreement with X-energy to build four Xe-100 high-temperature reactor demonstrators, the first of which will be located at its Seadrift industrial site in Texas.[6] In July 2024, China also announced a new project at Xuwei (Jiangsu province) that seeks to couple Hualong pressurized water reactors with a high-temperature gas-cooled reactor, in order to supply 32.5 Mt per year of industrial steam through cogeneration.

Nuclear power can contribute to the goals of low-carbon hydrogen production by powering electrolyzers at low and high temperatures, on site or via the electricity transmission grid. In March 2023 the Nine Mile Point (Constellation) nuclear power plant in New York State, became the first plant in the United States to begin producing low-carbon hydrogen as part of a federal program using an on-site low-temperature electrolyzer.[7] Xcel Energy is working on a project using high-temperature electrolysis at the Prairie Island nuclear power plant in Minnesota.

The use of nuclear energy to desalinate water is also a tried and tested technology. The Madras nuclear power plant in India houses a desalination plant producing 6.3 million liters of fresh water daily.[8] Based on hybrid thermal and osmotic technology, the plant uses seawater and heat generated by the power plant. Last but certainly not least, we must not forget other developing uses such as space technologies, notably for the establishment of lunar and Martian bases.

2.5 New pathways to meet the financing challenge

Nuclear project financing is integral to the industry's key recovery path. In recent months, several models have taken shape. The Czech Republic, for example, has received approval from the European Commission (EC) to provide a zero-interest state loan covering 98% of the investment costs of the Dukovany reactors, a 40-year revenue guarantee, and a contingency protection mechanism. In the U.K. and in Poland, funds are allocated directly to support projects. The U.K. has provided £5.5 billion for the two Sizewell C EPRs, while Poland is seeking EC approval for the provision of $14.5 billion for its first nuclear power plant (Lubiatowo-Kopalino).

In the United States, Microsoft has signed a twenty-year power purchase agreement with Constellation Energy in connection with restarting the Unit 1 reactor at Three Mile Island (Tennessee), which was shuttered in 2019. This clean electricity is intended to power Microsoft data centers. Although the financial details are unknown, they have enabled the electric utility to invest around $2 billion in the unit. In Michigan, Holtec, which had acquired the Palisades reactor originally for dismantling (closed in 2022), will instead benefit from a $1.5 billion federal loan along with a power purchase agreement with the local authorities, with a view to restarting the unit at the end of 2025.

Banks and institutional investors, noted for their reluctance in committing to such projects, say they are now ready to get involved, effectively normalizing nuclear energy in the world of low-carbon investment. On the margins of the Climate Week 2024 event in New York, fourteen financial institutions, including Goldman Sachs and BNP Paribas, pledged to support the development of new nuclear power with the aim of tripling installed capacity worldwide (as set out at the December 2023 COP28). The OECD's Nuclear Energy Agency member countries are calling for greater cooperation from multilateral financial institutions. The Development Bank of Latin America granted a loan for the extension of the operating lifespan of the Embalse reactor, albeit this dates back to 2013. The EIB's new director Nadia Calviño is keen to redirect the institution's policy direction. ■

Finance for nuclear projects is an essential element in the nuclear relaunch. Recent months have seen the development of several funding models.

Geographical Focus

II

Europe

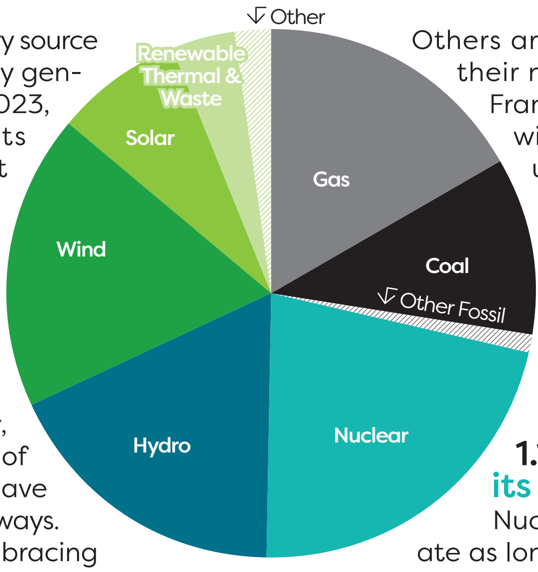
1 European nuclear revival continues to advance

OVERVIEW **Europe's nuclear revival is characterized as much by a widespread adoption of long-term reactor operation (LTO) as by an increase in new reactor unit projects. This is truly significant in so far as post-Fukushima; several countries had been skeptical about the future for nuclear but are now becoming nuclear adopters. In terms of the fuel industry this revival is translating into greater production capacity to meet rising global demand in light of the sanctions imposed on Russia following its invasion of Ukraine in February 2022.**

Nuclear energy is a primary source of low-carbon electricity generation in Europe. In 2023, nuclear reactor plants across fifteen different countries produced 22% of the continent's electricity. This asset is a legacy of the period between the 1970s and 1990s.[9] Since then new reactor projects have been few and far between. Instead, reactor closures have been commonplace, especially in Germany, which has closed the equivalent of 20 GW, and other countries that have been navigating phasing out pathways.

Today, Europe is once more embracing nuclear power, as it faces the challenges of energy transition and supply. In March 2024, European Commission President von der Leyen notes, "After the global energy crisis caused by Russia's invasion of Ukraine, many countries are giving a fresh look to the potential role that nuclear might play."

Nuclear power's return to favor can most clearly be seen by the widespread adoption of long-term reactor operation (LTO) beyond 40 years, even in countries with traditionally anti-nuclear governments. Furthermore, some countries with anti-nuclear legislation are seriously considering providing pathways for building fresh capacity (Italy, Switzerland...).



1• European Electricity mix 2023

- **Gas**: 17%
- **Coal**: 11%
- **Other Fossil**: 1%
- **Nuclear**: 22%
- **Hydro**: 18%
- **Wind**: 18%
- **Solar**: 7%
- **Renewable Thermal** & Waste: 4%
- **Other** (incl. Geothermal): 2%

Source: RTE 2023 Electricity report, incl. U.K. excl. Switzerland

Others are gearing up for a renewal of their nuclear fleet (Czech Republic, France, Sweden, United Kingdom), with some even building their first units (Poland). The Nuclear Alliance estimates that nuclear power could supply up to 150 GW of capacity by engaging LTO, building some 30 to 45 high-power reactors, and developing small modular reactors.[10,11]

1.1 Europe safeguarding its nuclear fleet

Nuclear reactors continue to operate as long as the necessary safety considerations are met, even in countries that are not particularly nuclear friendly. One example is Belgium, where recent ruling energy ministers have been 'anti-nuclear' power, and also Spain, which is targeting the definitive shutdown of its seven reactors by 2035. Switzerland is also nuclear ambivalent and has legislation banning new construction. In fact, the Swiss are operating the world's longest running reactor, Beznau-1, commissioned back in 1969.

Notable among those countries supporting nuclear is Finland, which has announced the long-term operation (LTO) of two reactors at Loviisa until 2050, i.e., for a period of seventy years, and France,

Europe

The trend in 2023 continues apace with new reactor projects continuing to flourish

which, via the 2014 'grand carénage' (Great Refit) program, is also readying for reactor operation beyond fifty years. Maintaining Europe's nuclear fleet illustrates political recognition of its use in terms of the climate and of energy supply and is the first sign of the nuclear energy revival.

1.2 Greater prospects for new reactors

The trend described in 2023 is gaining traction. The number of new reactor projects continues to multiply, with progress being made in Bulgaria, the Czech Republic, Finland, France, Hungary, the Netherlands, Poland, Romania, Slovakia, Slovenia, Sweden, and the U.K.. Four programs stand out in particular for their scope.

In France, six EPR2s are to be built, and an option for eight additional units is also under examination. Preparatory work, such as roadworks, has already begun on the first site at Penly (see p. 19).

In August 2024, the U.K. announced £5.5 billion in funding to accelerate the duplication and construction of both Hinkley Point C EPRs at the Sizewell C site in the east of the U.K.. Also noteworthy is the UK government's announcement in March 2024 of its purchase of the Hitachi-owned Wylfa site with a view to accommodating high-power units. The pre-July 2024 14-year ruling Conservative government had set an ambitious target of achieving 24 GW of nuclear capacity by 2050, compared with 5.8 GW currently, in a country with a declining nuclear fleet (primarily AGRs) that technologically cannot operate for as long as pressurized water reactor lifespans. Since winning the general election in July 2024, the new ruling Labour government does not appear to be casting doubt over the future of these projects.

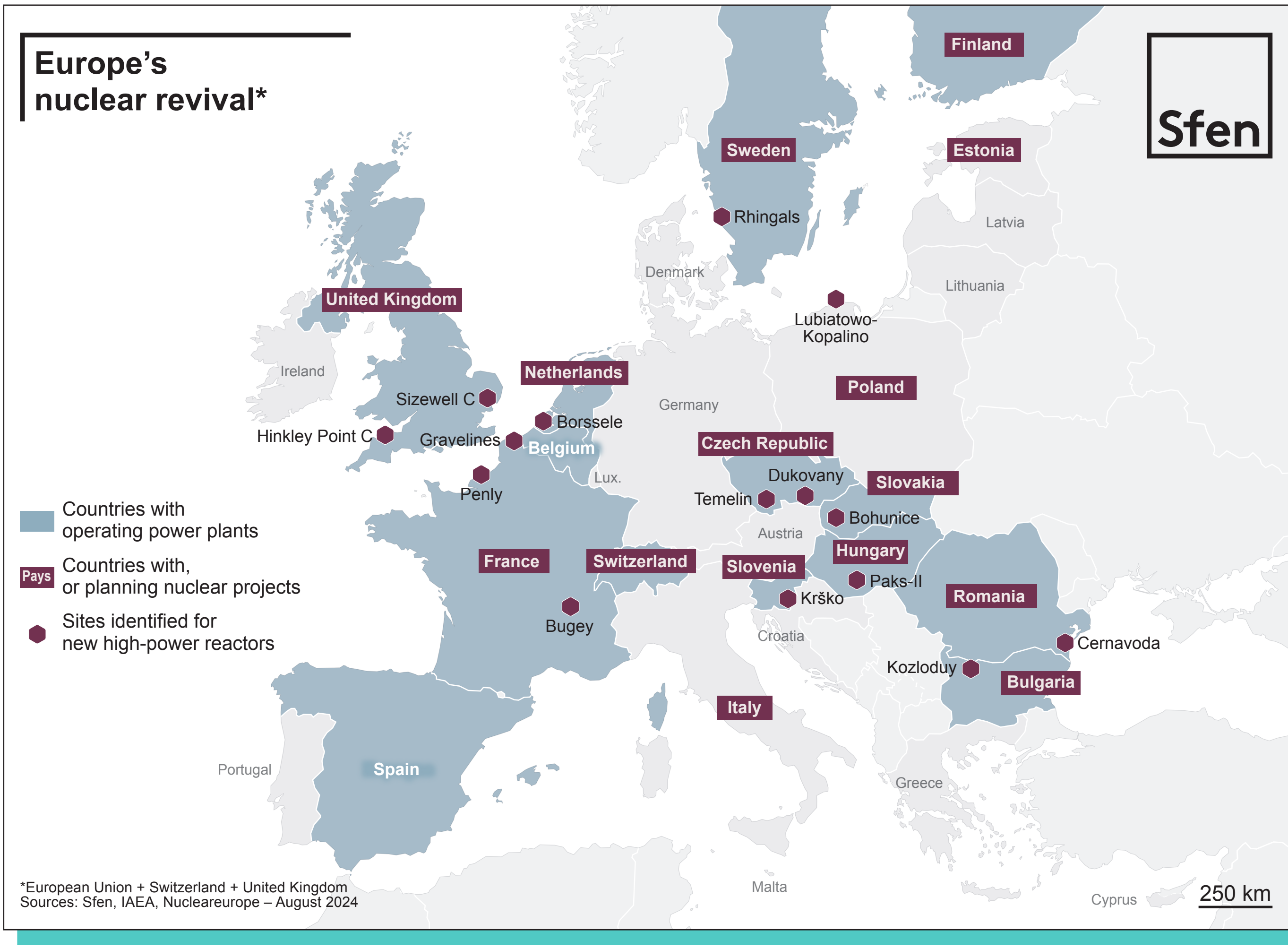
For Poland, the challenge lies with building its first reactors as part of a program comprising between 6 GW and 9 GW of nuclear power. It sidestepped the competitive process and instead in October 2022 selected U.S. nuclear company Westinghouse for the first three units. In September 2024, the government announced funding of around €14 billion for the project, which will need European Commission authorization.

At the end of 2023, Sweden unveiled a roadmap including the construction of the equivalent of two high pressure nuclear reactors by 2035, making a total of around ten small and large reactors by 2045. While this is not an exhaustive list, we also note that in the summer of 2024 the Czech Republic entered into exclusive negotiations with Korea's KHNP for

WHO IS BUILDING the reactor vessels and steam generators?

Europe can mobilize significant manufacturing capacity to produce large components by way of several industrial companies including ENSA (Spain), Framatome (France), Vitkovice Machinery Group (Czech Republic), Ansaldo Energia (Italy), and Mangiarotti (Italy). These manufacturers in turn rely on major forging companies in France (Framatome, Le Creusot), Italy (Forgiatura A. Vienna, Societa delle Fucine), the Czech Republic (Pilsen Steel, Vitkovice Heavy Machinery), and the U.K. (Sheffield Forgemasters).

Europe



the construction of between two and four units with a signature expected in March 2025. At the end of 2022, the Netherlands announced its intention to build two units as early as 2028. In addition to these projects, there are plans for small modular reactors (SMRs) and advanced modular reactors (AMRs), (Estonia, Finland, France, Italy, Poland, U.K.,...), although it is too soon to say which will be realized. U.S., Korean, and French manufacturers are all competing in these markets.

1.3 Fuel cycle: capacity increases

The geopolitical disruptions following Russia's invasion of Ukraine have raised several questions about supply security vis-a-vis fossil and non-fossil fuels, and nuclear materials.

The 2023 EURATOM Supply Agency (ESA) report indicates that Europe imported its natural uranium needs from four major producing countries (Canada 33%, Russia 23%, Kazakhstan 21%, Niger 14%).[12] France stands out from its European contemporaries in so far as it houses facilities covering the entire nuclear cycle. Orano is the leading converter (29%) serving operators, ahead of Rosatom (26.5%), Canadian firm Cameco (19%), and the U.S. firm ConverDyn (18%).

In terms of enrichment services supply (calibrated in the standard SWU measure), Europe has, in the last three years, produced between 55% and 60% of its needs within its borders.[13] Russia covered about 30% in 2021 and 2022, even up to 38% in 2023. The reason for the increase in 2023 is mainly due to operators of

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Russian-technology reactors stockpiling fuel (Bulgaria, the Czech Republic, Finland, Hungary, Slovakia), in a bid to provide some headroom while alternative suppliers become operational. The ESA notes that all operators, apart from Hungary, have contractually diversified their fuel supplies, but that replacing Russia in the long term will take time, not least to ensure quality fuel assembly production.[14] The ESA stresses the imperative for investment in new conversion and enrichment capabilities in Western countries, and the need to set up long-term contracts to secure fuel supplies for both the European Union and the United States. As such it encourages countries with VVER reactors to continue their efforts to diversify their fuel supplies and to avoid being dependent on a single supplier of nuclear materials and fuel.

In the conversion sector, today's strategy is focused on raising production levels at existing plants. Orano is continuing to ramp up production at the Philippe Coste plant that was commissioned in 2018 with a nominal capacity of 15,000 tU per year (8,900 tU in 2022 and 10,060 tU in 2023). In addition, the U.K. government has provided Westinghouse with funding to study the construction of conversion capacity at the U.K. Springfields site. In the enrichment sector, new capacity opportunities have been announced. Orano has launched a 30% capacity increase at the Georges Besse II enrichment plant at Tricastin, and has a project for a new plant in Tennessee. Urenco has announced capacity increases both in the Netherlands and at its New Mexico plant. ■

HIGHLIGHT 2024

In moving towards a worldwide replacement of Russian fuel conversion and enrichment services, Urenco (Netherlands) and Orano (France) have announced increases in their enrichment capacities. In the U.K., Westinghouse is planning to build a new conversion plant at its Springfields site.

The ESA insists on how crucial it is for the West to invest in new fuel conversion and enrichment capacity.

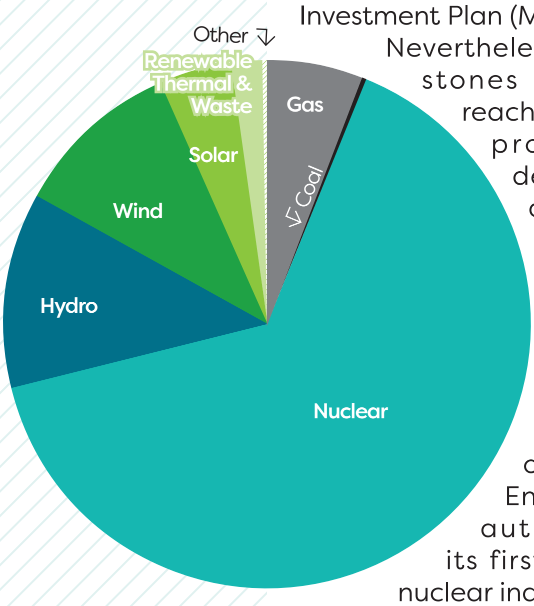
France

2 France mobilizes its nuclear industry for the EPR2 program

OVERVIEW **France is preparing to renew its nuclear fleet with the EPR2 program, which includes the construction of three pairs of EPR2 reactors plus the option of building eight additional units. France is also focused on new players that are emerging to take nuclear power beyond electricity production.**

The revival of nuclear power in France is relatively recent if we take as our starting point the announcement of the EPR2 program in February 2022 and the call for projects for innovative reactors under the French government's 2030 Investment Plan (March 2022).

Nevertheless, a number of milestones have already been reached. In 2024, the EPR2 program entered its detailed design phase, and the authorities have green-lighted preparatory work on the future Penly EPR2. In terms of small reactors, France 2030 has selected twelve candidates, one of which, Jimmy Energy, has applied for authorization to build its first reactor. Lastly, the nuclear industry was delighted to see the Flamanville EPR officially diverge in September 2024, thus starting a new chapter in its nuclear power story.



2• Electricity mix 2023

- **Gas**: 6.1%
- **Coal**: 0.2%
- **Nuclear**: 64.8%
- **Hydro**: 11.9%
- **Wind** (onshore & marine): 10.3%
- **Solar**: 4.4%
- **Renewable** Thermal & Waste: 2.1%
- **Other** 0.2%

Source: RTE 2023 Electricity report

2.1 Maintaining nuclear power generation

Nuclear power's primary contribution to security of supply and the fight against global warming is by maintaining its output. This is a major task for the industry, which accounts for between 60% and 70% of France's electricity production. As part of EDF's 'Grand Carénage' (Great Refit) program, major maintenance work is being carried out on the fleet, not only to extend reactor operation, but also to repair existing piping affected by the stress corrosion cracking phenomenon that reduced nuclear output in 2022 and 2023.

In 2014, EDF embarked on the program, which involves renovating or replacing major components that are approaching the end of their technical lifespans, and undertaking the modifications required to improve safety and ensure the equipment is up to standard beyond forty years of operation.

The 'Grand Carénage' program has been carried out on almost all the 900 MW reactors, and work should start on the 1,300 MW reactors as early as 2026 with the Paluel plant (Normandy).

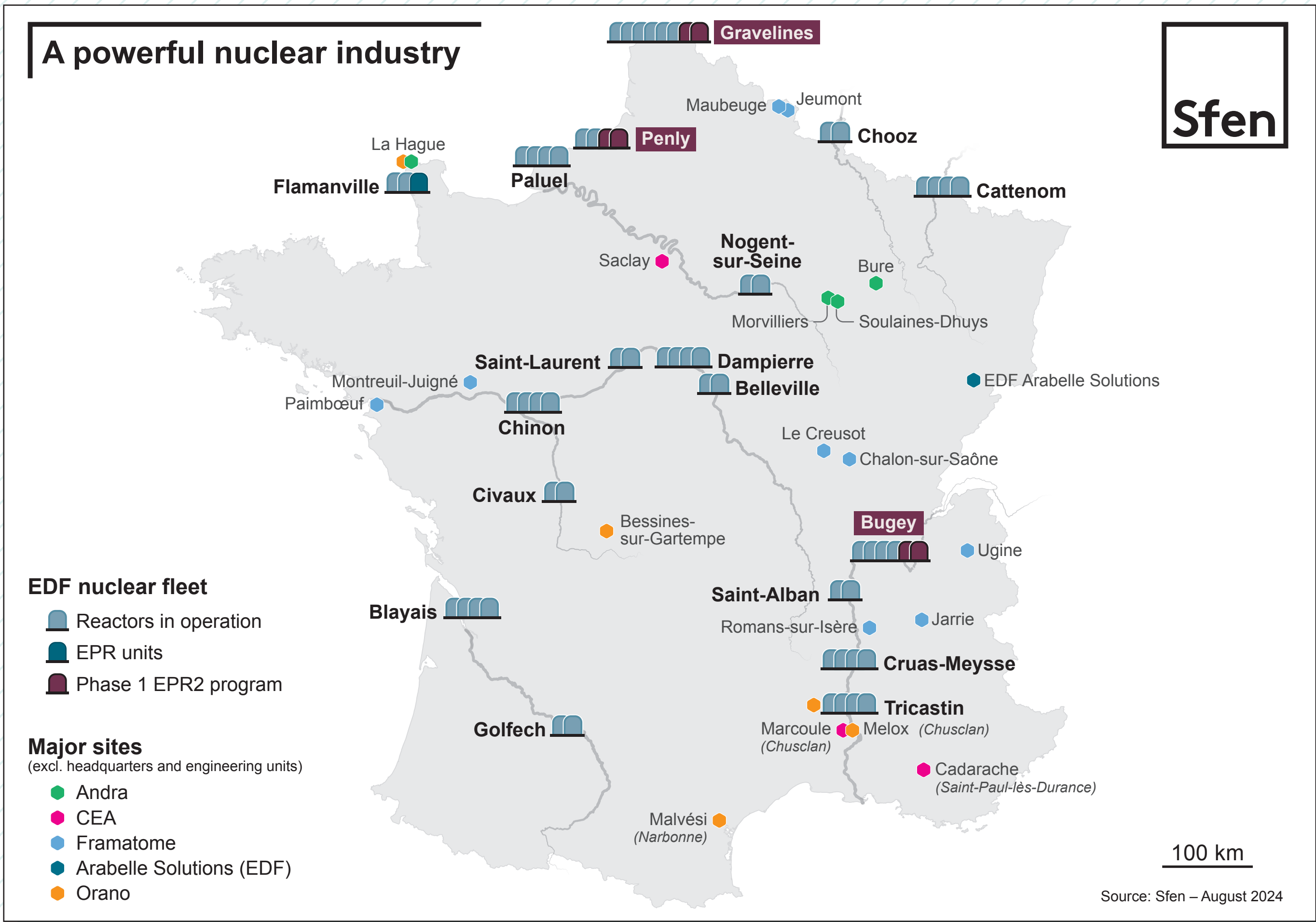
2024 also marks a return to growth in nuclear output thanks to "further progress in operational performance" and "better control of unit shutdowns," according to EDF, following two years (2022- 279 TWh, 2023-320 TWh) of managing stress corrosion cracking. In fact, EDF is now aiming for the upper end of the 315-345 TWh range for 2024 and confirmed its goal of generating between 335 and 365 TWh in 2026.

2.2 The EPR2 program gets underway

The EPR2 program involves the construction of six EPR2 reactors at three sites (Penly, Gravelines, Bugey), with an option for eight additional units. Construction of the first unit is scheduled to start in late 2027 at Penly, Normandy, with commissioning expected in 2035.

Following the public debate that ran from October 2022 to February 2023, and the publication in the Journal officiel (Official Bulletin) in summer 2024 of the decree approving the convention over the use of public maritime areas,

France



preparatory works can now commence. Alongside, the EPR2 program has entered the detailed design phase. The reactor represents an optimization of the EPR model design, particularly in terms of construction, thanks to the experience and feedback from the four EPR units in service in China (Taishan-1 and 2), Finland (Olkiluoto-3) and France (Flamanville-3), as well as from the two units under construction in the UK at Hinkley Point C.

2.3 New players emerging to address and meet new needs

The France 2030 Investment Plan has sparked the emergence of new players with reactor projects that are based on disruptive technologies. Depending on their size and characteristics, they aim to meet a whole range of new needs, including the production of urban and industrial heat, hydrogen, and fresh water etc.

With the announcement in March 2024 of the final three companies successfully selected, the investment plan has selected a total of twelve players, ten of which are in the nuclear fission field.

Four of these players are start-ups with support from the CEA (French Atomic Energy and Alternative Energies Commission).

WHO IS BUILDING the reactor vessels and steam generators?

Framatome has its forging business and workshops for large components located in Burgundy, some thirty kilometers apart. Framatome continues to modernize its sites so as to reach the capacity needed to manufacture equipment for two EPRs per year (or the equivalent of 3.5GW per annum), with projects launched in 2023 to extend the Saint-Marcel plant (equipment manufacturing) and bring the manufacture of reactor vessel internals back in-house.

France

From those that were successfully awarded projects, Jimmy Energy stood out with the announcement that it would be setting up its manufacturing facilities in Le Creusot, as well as submitting an authorization request to build an initial unit at the industrial Cristanol bioethanol distillery site. The aim is to build a small 10 MWth high-temperature reactor (HTR). EDF subsidiary Nuward has announced an upgrade of its eponymous 340 MW power plant, comprising two pressurized water reactors. The idea today is to “rely on tried-and-tested technological building blocks,” as potential international customers look to minimize their risk-taking.

HIGHLIGHT 2024

On 03 September 2024, the EPR at the Flamanville site diverged and commenced operations, becoming the 57th nuclear reactor generating power in France.

2.4 An industrial base dedicated to security of supply

France is one of the few countries to master all stages of the fuel cycle, with plants for fuel conversion (Orano, Malvési, and Tricastin), enrichment (Orano, Tricastin), fuel fabrication (Framatome in Romans and Orano Melox in Gard) and even reprocessing (Orano, La Hague). France has launched its ‘Aval du futur’ (Supporting the Future) program to plan its recycling strategy out to the year 2100, by sustaining and renewing part of its industrial base.

EDF uses a variety of players to supply its fleet of nuclear power plants, each one of which has its own diversified business portfolio. For example, Orano has mines in several countries (Canada, Niger,* Kazakhstan), and is developing others (Uzbekistan, Mongolia). National nuclear industries do not operate in a vacuum, but the ability to diversify across a range of partners offers greater resilience to international upheavals. In addition, following its build permit approval, Orano launched the extension of the Georges Besse II enrichment plant in June 2024, thereby increasing its production capacity by 30% to meet global demand.

2.5 Mobilizing skills

The nuclear industry is actively evolving, both in terms of training and within the sector’s companies themselves. Every year Gifen, (Groupement des industriels français de l’énergie nucléaire - employers’ body established in 2018) produces a profile of the nuclear industry “To ensure that the industry’s capacities and needs are in step and aligned with future challenges.” In 2023, the Université des métiers du nucléaire (UMN- multi-stakeholder project aimed at nuclear industry skills development) submitted the nuclear industry’s skills action plan to the government. This plan, co-driven by the Délégation interministérielle au nouveau nucléaire (DINN- oversees the implementation of industrial programs for the construction of new nuclear power reactors in France), aims to secure some 100,000 new recruits to the industry over the next ten years.

Lastly, the Excell plan, launched in 2020 by EDF and Gifen to “Enable the nuclear industry to return to the highest levels of rigor, quality and excellence,” achieved its objectives in 2023. The nuclear industry continues to work on the issue of skills and attractiveness, so as to be ready to commit fully to the EPR2 program and the new nuclear cycle programs. ■

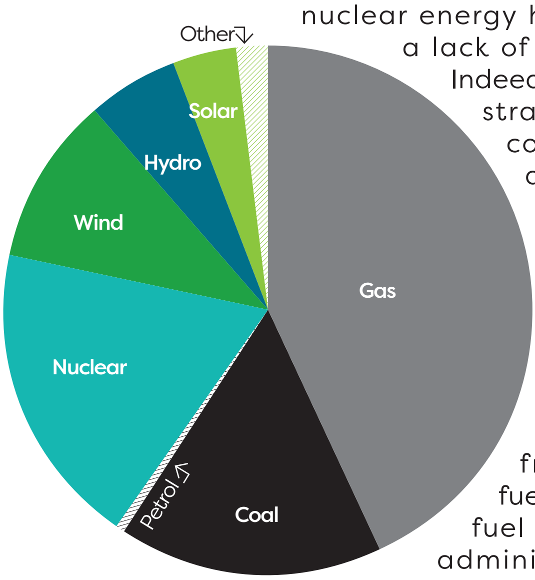
** In Niger, production resumed at the Somaïr site on 05 February 2024. However, the continued closure of the border between Niger and Benin prevents production from being exported along normal channels. On 20 June 2024, the Nigerien authorities informed Imouraren SA (jointly owned by Orano and the State of Niger) of the withdrawal of its operating license. Imouraren SA and Orano believe that this withdrawal breaches the agreements made and the licenses granted. Orano states that it ensures security of supply for its customers by diversifying its sources of uranium production worldwide.*

United States

3 The United States aims to regain nuclear leadership

OVERVIEW The United States is aiming for an installed capacity of 300 GWe by 2050. To achieve this, the administration is focusing on three areas. The first is to keep the currently operating fleet in operation for as long as possible. The second is to develop and deploy small modular light-water reactors as well as more innovative technologies. The third is to regain a degree of autonomy in the fuel cycle, given that the U.S. currently relies on external actors for up to 70% of its enrichment services.

With 94 reactors in operation at 55 plants, the United States has the world's largest nuclear fleet, producing nearly 20% of the nation's electricity. However, nuclear energy has suffered from a lack of political support. Indeed, despite nuclear's strategic profile, the country has seen a dozen reactor closures in the space of a decade, most of which were due to economics, not least because gas-fired power plants have been benefiting from cheap fossil fuels. In the upstream fuel cycle, the current administration is experiencing the results of policy weaknesses. Firstly, the country is 70% dependent on foreign enrichment services. Secondly, the medium-enriched uranium (Haleu) required for many of the innovative reactors being developed in the U.S. is provided by a single global producer, Rosatom. To overcome these weaknesses, successive administrations have put major levers in place to safeguard the nuclear fleet, deploy new reactors, and regain fuel sovereignty.



3• Electricity mix 2023
- Gas : 43.1 %
- Coal : 16.2 %
- Petrol : 0.4 %
- Nuclear : 18.6 %
- Wind : 10.2 %
- Hydro 5.7 %
- Solar : 3.9 %
- Other : 1.9 %

Source: US IEA

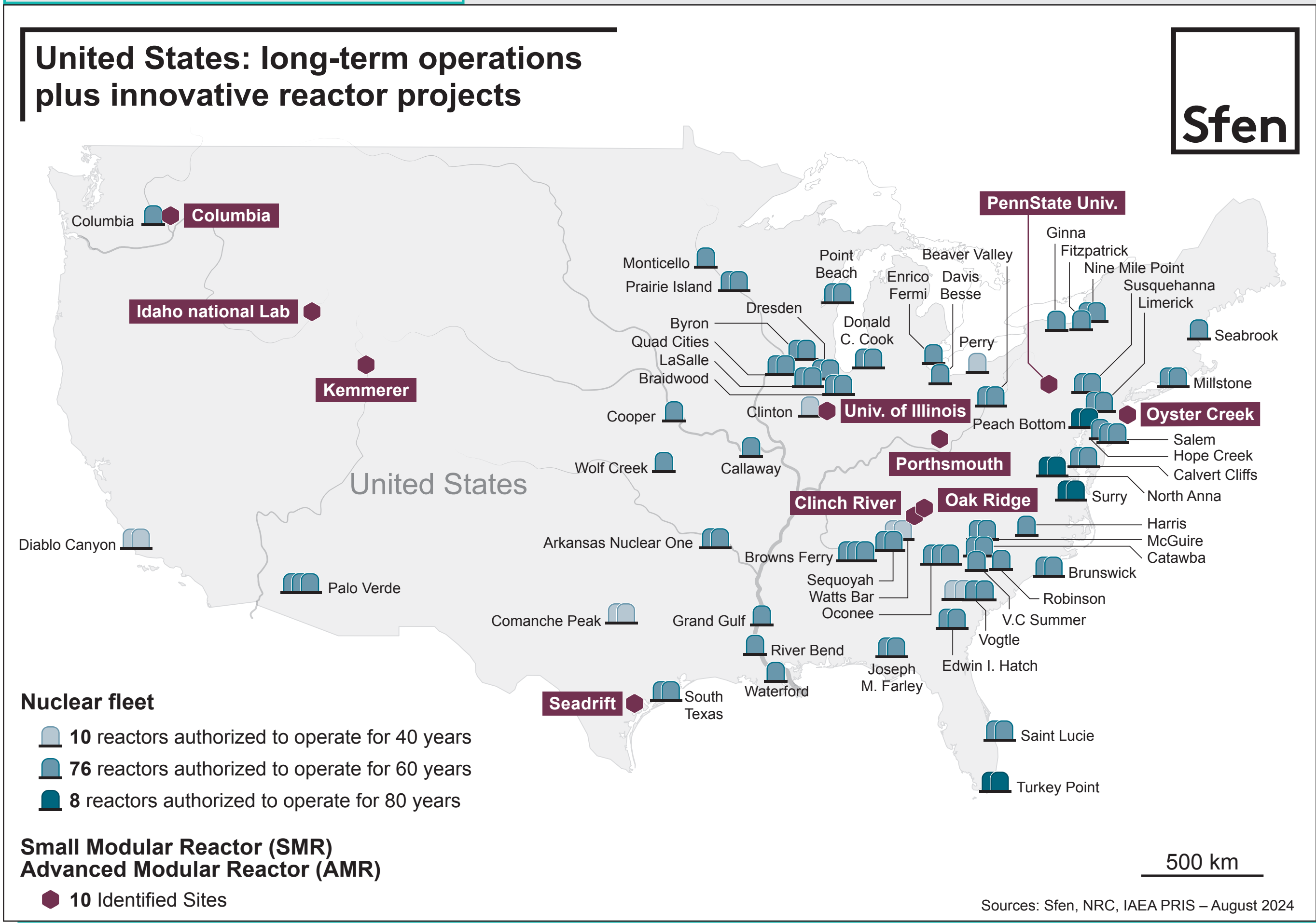
3.1 Safeguarding the nuclear fleet

The first aspect of U.S. nuclear policy is to keep the current nuclear fleet in operation. It has suffered from competition from gas-fired power plants in a deregulated electricity market. Indeed, twelve reactors closed over the period 2013-2021.[15] In a bid to change that trajectory, the country introduced the Inflation Reduction Act (Ira), which includes provisions for financial support for units that would otherwise have to close for economic reasons. Furthermore, two closed reactors could even soon be put back on the grid. In Michigan, Holtec, which had acquired the Palisades plant in order to shut it down in 2022, ahead of ultimately dismantling it, will instead access a federal loan of $1.5 billion, in addition to local authority support (via an electricity purchase agreement), in order to restart the unit by the end of 2025.[16] In Tennessee, five years after it was shut down, Constellation Energy announced plans to restart the Unit 1 reactor at Three Mile Island in a deal to power Microsoft's data centers for the next twenty years.

The aim is to bring the entire fleet up to an operating life of eighty years. Today, eight units, i.e., an additional two since 2023, 'only' in operation since the early 1970s have already been authorized to operate for eighty years, if safety levels remain satisfactory.

Some fifteen additional units have lodged their applications with the safety

United States



authority, and the vast majority of the fleet has already been licensed for sixty-year operating lifespans. Of note is that in the United States, once commissioned, a unit receives a forty-year operating license, which is then extendable in twenty-year increments, whereas in France this authorization to extend the operating life is renewed every ten years. This means that license extensions occur much earlier compared to France.

> ***The first pillar of American nuclear policy is to keep the current nuclear fleet in operation.***

3.2 The United States is launching the deployment of small modular reactors

The second aspect of U.S. nuclear policy involves the deployment of small less powerful reactors. Small modular reactors (SMRs and AMRs) are designed using a diverse range of technologies with different levels of maturity and are developed by both start-up companies and established players. Modular reactors refer not only to the type of reactor, but also to a business model that is based on series construction and on maximizing the amount of factory-based manufacturing. Neither exists in the United States, although these reactors remain the cornerstone of the U.S. nuclear industry.

The administration is focused on two main priorities. The first is to innovate at pace and the second is to rapidly deploy its first 'proven technology' SMRs. The innovation piece lies with the

United States

2024 HIGHLIGHT

Although the United States has a strong export presence with the Westinghouse AP1000 reactor, there are no high-power projects underway domestically. This could change dramatically if U.S. Energy Secretary Jennifer Granholm is to be believed, “To achieve carbon neutrality by 2050, we need to at least triple our country’s nuclear capacity. That means adding 200 GW,” the U.S. Secretary of State said at the AP1000 Vogtle-4 start-up event.

Advanced Reactor Demonstration Program, launched in 2021, while the prompt deployment piece is being supported by a new funding campaign, announced in March 2024, for the roll-out of two design-proven light-water reactors. The funding is designed to break the deadlock in a situation where electric utilities are reluctant to bear the risks of a first of its kind reactor, not least since they believe State support to be insufficient and all the more so if the model is based on innovative technologies. The cancellation of the NuScale project at the end of 2023 for economic viability reasons did nothing to encourage participation. In summary, projects abound, and the initial effects of series production will become apparent given Big Tech’s massive energy demands, as a result of their data center needs (e.g., Amazon, Google).

WHO IS BUILDING the reactor vessels and steam generators?

The USA relies on BWXT and Westinghouse for the supply of heavy components. Historically, Westinghouse has subcontracted the manufacturing piece to Korea’s Doosan and Spain’s ENSA, and more recently has been trying to ramp up activity at its Italian Mangiarotti plant. In terms of SMRs, designers are looking abroad, primarily to Korea.

3.3 Reinvesting in fuel

To secure the third aspect of its nuclear policy, the United States is fast-tracking its way back to securing sovereignty over its fuel supply. Following the phasing out of imports from Russia, as initiated by President Biden’s signature in May 2024 of a bill banning Russian enriched uranium imports, the U.S. nuclear industry will benefit from $2.7 billion in federal funding under the Government Funding Bill, as well as $700 million under the Inflation Reduction Act, which together aim to build domestic capacity for the production of enriched uranium for the current fleet, and medium-enriched uranium (Haleu) for advanced small-modular reactors (AMRs).

In terms of low-enriched uranium, the United States relaunched the Metropolis uranium conversion plant in 2023, and Urenco plans to raise capacity by 15% at the Eunice enrichment plant. Robust fuel assembly (RFA) production is handled by three plants: Framatome (Richland), General Electric (Wilmington), and Westinghouse (Columbia).

In terms of the supply of medium-enriched uranium (Haleu) for its future nuclear fleet, the U.S. Department of Energy (DoE) has issued calls for tenders for enrichment and deconversion activities. The Piketon plant, owned by industrialist Centrus, has been producing Haleu for some time now, but not yet on a commercial scale. ■

China

4 China's impressive nuclear growth

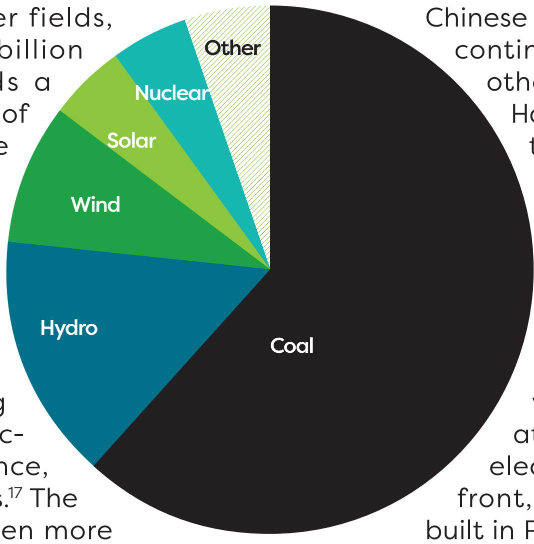
OVERVIEW **China has a powerful nuclear industry that is focused essentially on supplying its domestic market at a time when demand for electricity continues to grow strongly. The country also stands out for having a remarkably dynamic research and development policy and it is consequently building reactors at an unprecedented rate. To ensure that uranium supplies are sufficient to meet projected levels, China is actively seeking out providers, particularly in Africa and Kazakhstan.**

Just as in many other fields, China, with its 1.4 billion inhabitants, stands a giant in the domain of nuclear power. The country is commissioning new reactors at an unprecedented rate. Since 2018, approximately 20 nuclear reactors have been connected to the grid! Furthermore, since 2023, China has been able to boast of its number two global ranking in terms of nuclear power production (406 TWh), ahead of France, albeit behind the United States.[17] The Chinese fleet is set to grow even more and when the recent announcement of eleven new reactor projects (August 2024) are included, then total capacity comes to 55 GW, which is within touching distance of France (63 GW)!

R&D activity is also continuing apace and has produced a number of major achievements both in the area of reactor technologies (fast-neutron, high temperature, small modular) and uses (urban heating, industrial steam, seawater desalination, etc.).

4.1 Proven series construction effects

China commissioned its first nuclear power plant in 1991 and now has 56 reactors in operation. It has developed a 100% Chinese IP-owned third-generation reactor, the Hualong-One, six units of which have been commissioned, with the lead unit in 2020. The average construction time for these units is just 6.5 years.



4• Electricity mix 2022
- **Coal:** 61.7%
- **Hydro:** 15.1%
- **Wind:** 8.5%
- **Solar:** 4.8%
- **Nuclear:** 4.7%
- **Other:** 5.2%

Source: IEA

Chinese industrialists are determined to continue performing, including with other reactor technologies. At the Haiyang power plant, for example, the construction schedule for the two CAP1000s, a Chinese version of the American AP1000, is based on a building timeframe of fifty-six months i.e., under five years.[18]

Today, China's skills are almost exclusively at the service of national projects aimed at meeting its colossal domestic electricity demand. On the export front, only two reactors have been built in Pakistan, and while another was planned for Argentina, that project seems to have come to a halt.

No fewer than 46 reactors have been approved or are under construction, representing a capacity of 55 GW.

China

A rich network of research institutes, universities, and industrialists enables Beijing to engage in major R&D activities.

4.2 A land of innovation

Beijing's extensive network of research institutes, universities, and industrial companies enables the country to engage in major R&D activities. China is developing several reactor technologies, in particular sodium-cooled fast neutron reactors (RNR-Na) and high-temperature reactors (HTR). The former are designed to extract maximum value from nuclear materials, while the latter are intended for new uses such as hydrogen and heat production.

In terms of RNR-Na, Beijing set up a fast-track program with a first prototype (20 MW) commissioned in 2011, the launch of construction projects for two 600 MW units in 2017 and 2020, and finally, the plan to connect a 1,200 MW reactor to the grid in 2035. In the field of HTRs, the China stands out with its commissioning in December 2021 of the first HTR-PM (high temperature gas-cooled small modular reactor) with an electrical capacity of around 200 MW. Tsinghua University's Institute of Nuclear Energy and New Technologies (INET) has also launched the design of a 600 MW reactor.

China has also turned its attention to molten-salt reactors. It has an experimental 2 MWth reactor commissioned in 2023 and plans to build a 30 MWth unit by 2025.

4.3 Nuclear to be deployed for a variety of uses

China wants to use nuclear power for several different purposes including urban heating, industrial steam production, hydrogen production, and seawater desalination.[19] The Haiyang power plant is a perfect case in point. This showcase project, comprising two AP1000 reactors, has been meeting the heating needs of around 1 million people in Shandong since Q4 2023. The site is also home to a seawater desalination demonstration project. Once the salt is removed, the water supplies heat to the plant's employee

WHO IS BUILDING the reactor vessels and steam generators?

With a large order book acting as a catalyst, China now has a formidable nuclear industry, capable of building 40 reactors simultaneously! The main players involved in the manufacture of large, forged components (vessels, steam generators, pressurizers, primary pumps, etc.) include Dongfang, Shanghai Electric, China First Heavy Industries, Harbin Electric Corporation, and FDJV (Framatome Dongfang Joint Venture).

China

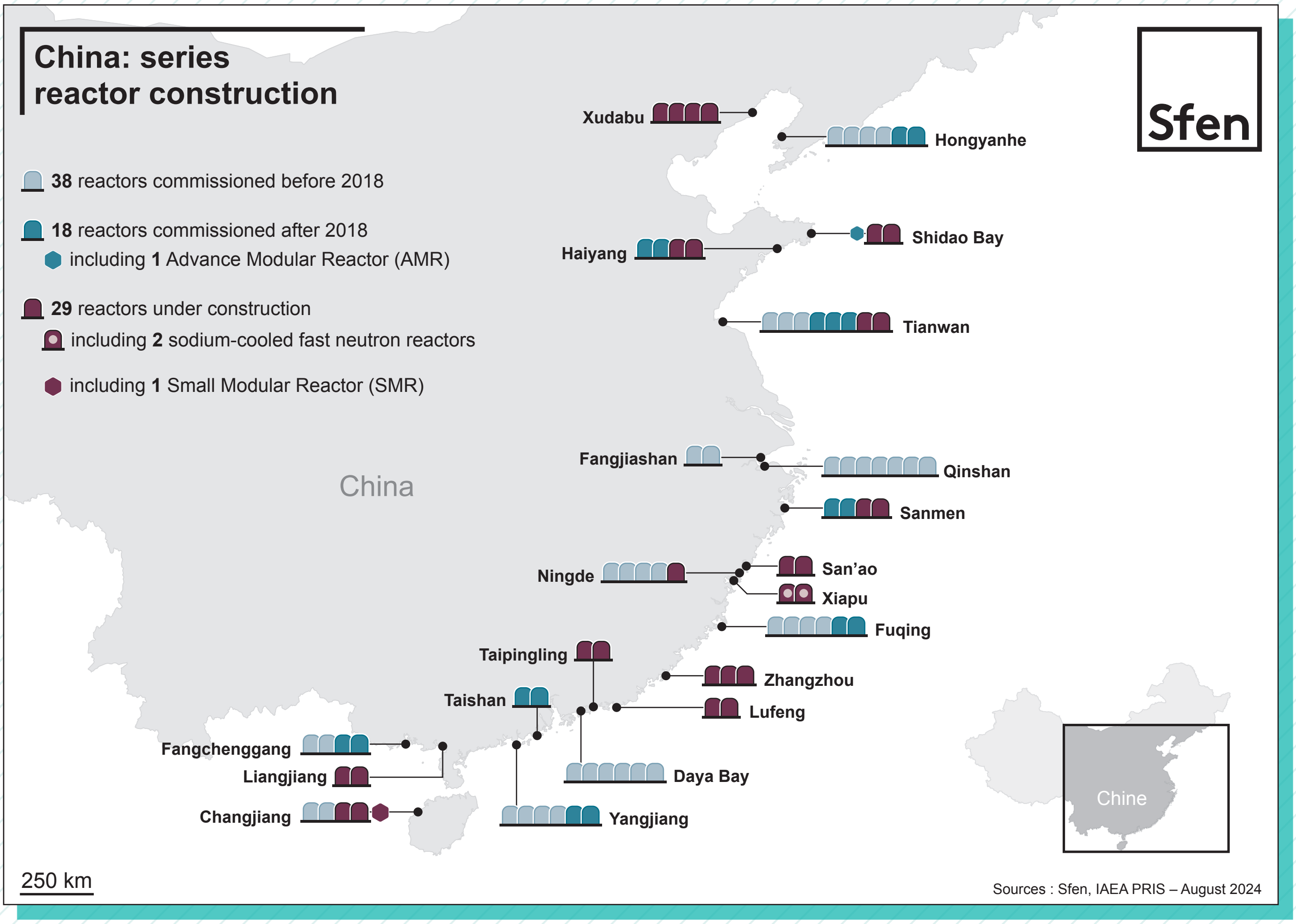
housing units before being used like regular tap water. New projects, including both small and large reactors, are already being planned for a variety of uses, and nuclear-powered urban district heating will continue to expand, particularly in Shandong and northern China.

2024 HIGHLIGHT

China's nuclear industry can build a third-generation Hualong-One reactor in under six years.

4.4 Securing fuel supplies to meet future needs

The strong growth of China's nuclear fleet means that fuel supplies must be secured. This begins with domestic natural uranium production, which accounts for around 3% of world production.[20] However, domestic fuel production alone falls short of meeting the needs of the fleet. Companies in the sector are therefore looking to foreign suppliers and are actively seeking international providers, particularly in Kazakhstan and Africa. In terms of conversion and enrichment, while capacity at the Lanzhou, Hanzhong, and Emeishan plants are currently deemed to be sufficient, doubts hang over the future, given that some thirty additional reactors are already under construction.[21] Lastly, Chinese industry has sufficient capacity to meet the fuel assembly needs of the country's PWR nuclear fleet. ■

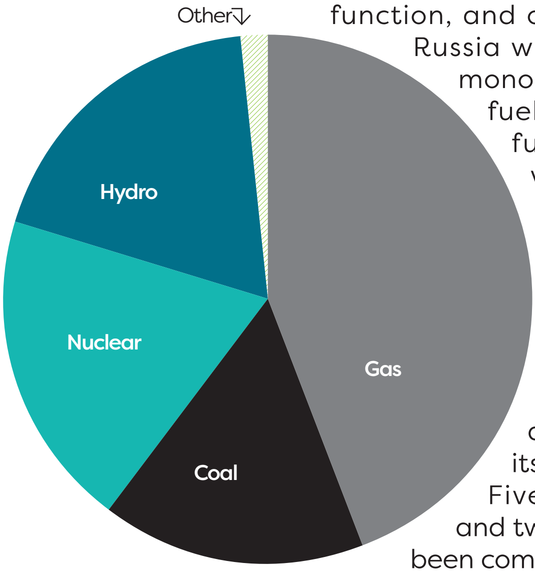


Russia

5 Russia is renewing its nuclear fleet

OVERVIEW **Russia is pursuing a very ambitious nuclear policy that is marked by export success, the renewal of its nuclear fleet, and a serious innovation-led commitment to lowering its dependence on natural uranium.**

Since Russia's invasion of Ukraine in February 2022, the West has been progressively stepping away from Russian enrichment services. Notwithstanding, many of Russia's foreign projects continue to function, and over the medium-term Russia will continue to hold its monopoly position in certain fuel cycle operations. The fuel cycle is an area in which Russia is innovating in order to reduce its dependence on natural uranium.



5• Electricity mix 2021
- **Gas:** 44.3%
- **Coal:** 16.2%
- **Nuclear:** 19.3%
- **Hydro:** 18.7%
- **Other:** 1.5%

Source IEA

5.1 Nuclear fleet is expanding

Russia is steadily adding new reactors to its electric power system. Five high-power reactors and two 30 MW reactors have been commissioned since 2016.

Of the 36 reactors in operation, almost a third were connected to the grid after 2010. In particular, Russia launched the deployment of its third-generation pressurized water reactor, the VVER-1200.[11] Four of these have been connected to the grid since 2016, with an average construction time of just under ten years. In addition, Rosatom is currently building a VVER-1200 in Leningrad. It is also building two VVER-TOI reactors in Kursk, an optimized model that Rosatom is hailing as the VVER of the future. This momentum looks set to continue. In September 2024, the power grid operator published a provisional working document listing some thirty nuclear projects out to 2042.

Russia is also counting on small modular reactors to replace certain thermal and nuclear facilities, as demonstrated by the commercial operation in 2020 of the Akademik Lomonosov, a barge equipped with two 30 MW reactors docked at the port of Pevek in Russia's far east. The country is also aiming to commission one or two 55 MW reactors on land in Yakutia in 2028, and also plans to build two barges with two reactors of the same capacity.

5.2 The industry is actively limiting its dependence on natural uranium

On top of this active commitment in the reactor domain, Russia is demonstrating a marked engagement in the fuel cycle.

Although Russia has substantial uranium reserves, they are nonetheless difficult to exploit. The country produces less than half of its nuclear fleet's natural uranium requirements. Russia pulls on a number of levers to secure its uranium.

The first involves sourcing ore from outside the country, in particular from Kazakhstan, where joint ventures between

2024 HIGHLIGHT

Russia is gearing up to commission up to two 55 MW SMRs in Yakutia by 2028. It has also signed a contract with Uzbekistan for a power plant comprising six small modular reactors.

Russia

Kazatomprom and Russia's Uranium One operate six major deposits. The Rosatom conglomerate is also looking to build new partnerships in Kyrgyzstan, Namibia, and Tanzania. The second lever involves taking full advantage of enrichment overcapacity by operating those plants with very low Uranium 235 operational tails assay levels (underfeeding), and supplementing uranium in those plants with higher operational tails assay levels. The third lever involves recycling reprocessed uranium (RepU), currently used in RBMKs and soon to be used in VVERs. The fourth and final lever aims to close the cycle with the operation of a sodium-cooled fast-neutron reactor (BN800, commissioned in 2015), plus an additional lead-cooled fast-neutron reactor (BREST-OD-30, under construction since 2021). Since 2023, BN800 has been 100% power loaded with MOX (mixed oxide fuel). A new fuel composed of uranium nitride and plutonium is being developed for the BREST-OD-30.

Also, with a view to saving materials, Rosatom is working on a new fuel for its fleet of water-cooled reactors and commenced loading the first assemblies at the Balakovo plant's Unit 1 in 2021.

5.3 Russia enjoys a lead position in reactor exports

The success of Russian exports is due to the State's willingness and ability to finance nuclear projects. This is a particularly attractive factor for new nuclear adopters. Of the six countries where Russia has reactor construction sites (Bangladesh,

Russia

> ***The success of Russian nuclear power exports is due to the government's determination and ability to finance projects.***

China, Egypt, Hungary, India, Turkey), three are building their first nuclear power plants (Bangladesh, Egypt, Turkey). Today, two financing models coexist. The first is by way of a substantial state loan and the second is called the build-operate-own (BOO) model. Bangladesh has opted for the first model, where Russia finances 90% of the Rooppur project via a state loan. Similarly in Hungary an inter-state loan of €10 billion has been agreed for a project estimated at €12.5 billion. The second model currently only operates in Turkey, where the Rosatom conglomerate is building the Akkuyu plant and will repay itself by selling the electricity as majority owner. The first Turkish unit, scheduled for start-up at the end of 2023, is expected to be on the grid in 2025.

5.4 Fuel cycle

Russia has four enrichment facilities, namely Angarsk, Novouralsk, Zelenogorsk, and the most significant, Seversk. These facilities account for around 40% of the world's enrichment capacity, enabling Russia to enrich uranium for many foreign customers. For example, Russia supplies around a quarter of the needs of the U.S. fleet's 94 nuclear reactors. However, due to supply security concerns, Western customers are seeking to exit the Russian industry, and several American and European players in the sector have announced capacity boosting measures to meet this new demand. ■

WHO IS BUILDING the reactor vessels and steam generators?

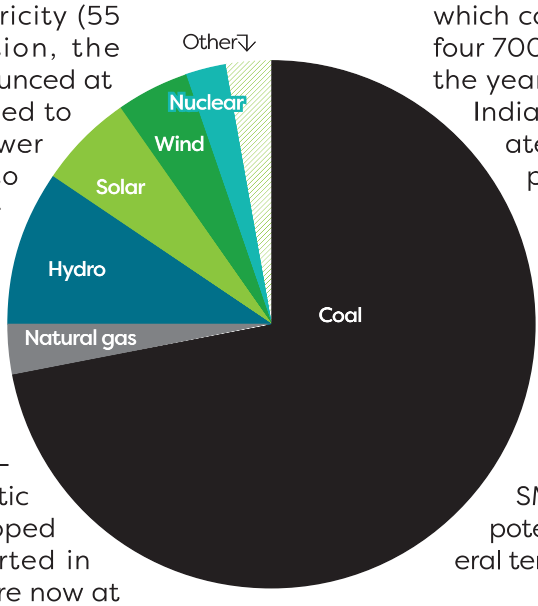
Russia has a powerful industry, underpinned and driven by an order book that continues to grow. JSC AEM-Technologies, part of the JSC Atomenergomash structure, manufactures forged and cast parts for the petrochemical, thermal power plant, and nuclear markets (shells and other parts for reactor vessels, steam generators, primary pump sets, etc.). The company has four major plants (AEM-SpetsStal, Atommash, Izhora, Petrozavodskmash) and has produced five reactor vessels and 18 steam generators for the VVERs under construction in 2023.

India

6 India's nuclear industry continues its transformation

OVERVIEW India's nuclear sector has embarked on a major transformation that is opening the door for public-private partnerships as a way to accelerate the deployment of new units. The government has set the target of tripling nuclear capacity by 2032, primarily through reliance on its domestic technology sector.

While the country's 20 reactors (6.9 GW) contribute only around 3% of the country's electricity (55 TWh) generation, the government's strategy as announced at the end of 2022 stated the need to grow the national nuclear power plant fleet. India will have to respond to a sharp rise in electricity demand (+150% by 2040 vis-à-vis 2019), while aiming for carbon neutrality by 2070. To reach its ambitious target of 22.48 GW of nuclear capacity by 2032, the government has launched the construction of a fleet of 700 MW natural uranium reactors, with the domestic technology piece being developed from Canadian models imported in the 1960s. Two of these units are now at full power, a third started up at the end of September 2024, and two more are under construction. Ten additional reactors using this technology are planned for commissioning by 2032. Added to this is the construction of four Russian VVER-1000 reactors (Units 3,4,5,6) representing 4 GW of capacity, following the commissioning of initial Units 1 and 2 in 2013 and 2016. To bolster this momentum, the government is studying the deployment of small and high-power technologies, both Indian and foreign, and it is seeking to attract new public and private players to participate in and/or finance the projects.



6• Electricity mix 2022
- **Coal:** 72%
- **Natural gas :** 3%
- **Hydro:** 9.6%
- **Solar:** 5.8%
- **Wind:** 4.4%
- **Nuclear:** 2.5%
- **Other:** 2.7%

Source: IEA

6.1 Transforming the nuclear sector

Nuclear power is generating interest both at government level and in the private sector. The government, albeit with legislative work still outstanding, is keen to involve private actors in the nuclear sector, even though nuclear power is currently entirely in the hands of the state-owned NPCIL (Nuclear Power Corporation of India Limited- tasked with constructing and operating nuclear power plants). The latter has set up a joint venture with India's largest and state-owned operator, NTPC, which could launch an initial project for four 700 MW reactors before the end of the year. NTPC and Tata Group, one of India's largest industrial conglomerates, are also focused on the small power market with the Bharat Small Reactor, which is based on the design of the 220 MW reactors currently in operation. This concept could then be further developed into a modular design the (BSMR). India is aiming to replace thermal power plants and produce decarbonized hydrogen with innovative SMR/AMR reactors, along with the potential for installed capacity of several tens of gigawatts by 2040.

6.2 International cooperation to boost nuclear power

India's nuclear program is one of the largest in the world, with six reactors under construction and a further ten already approved and financed by the government.[22] In addition, negotiations are continuing with foreign suppliers of high-power reactors, including with EDF for six EPRs (in Jaitapur), with Rosatom for six VVER-1200 reactors, and with Westinghouse for six AP1000 reactors. If the EPR project is confirmed, the Jaitapur plant would be the most powerful in the world, with an installed capacity of

India

WHO IS BUILDING the reactor vessels and steam generators?

India has an industrial base serving its national nuclear program. For the manufacture of large nuclear boiler components, India can rely on Larsen & Toubro, which has been involved in virtually all nuclear construction projects, and Bharat Heavy Electricals Limited (BHEL), India's largest engineering and manufacturing company in the energy sector, with the capacity to manufacture the entire range of power plant equipment.

almost 10 GW. In addition to importing foreign technologies, India is keen to participate in international projects to promote its own domestic nuclear industry.

A noteworthy example dates to September 2024, when NPCIL signed a Memorandum of Understanding (MoU) with the Emirates Nuclear Energy Corporation ENEC, which operates the UAE's four reactors, to contribute to the maintenance and operation of the Barakah power plant.

6.3 A stable supply of ore and fuel

India's eight domestic uranium mines supplies its domestic nuclear fleet. The IAEA, NEA 2022 benchmark report notes that "Conventional uranium resources are sufficient to meet the needs for forty years of a 10-15 GWe nuclear fleet of Indian heavy-water reactors operating in the nuclear sector at a capacity factor of 80%."[23] However, units operating with enriched uranium, notably both Russian reactors currently in operation and the four others currently under construction, do require the involvement of outside players. Apart from imported light-water technologies, fuel assemblies are also manufactured at the Hyderabad industrial complex in Telangana, and a second plant, to provide fuel for the new reactors, is under construction at Kota in Rajasthan.

6.4 Closing the cycle: a fast-neutron reactor is soon to be commissioned

To guarantee the long-term reliability of its nuclear power, India is developing fast-neutron reactors and is interested in the use of thorium as a potential fuel. As well as a small research reactor that is based on the French Rapsodie model, India has also built a 500 MW sodium-cooled industrial demonstrator reactor. Launched in 2004, the project has been severely delayed, but is now well on the way to commissioning. The MOX (mixed oxide) fuel has been loaded, and India's Atomic Energy Regulatory Board authorized the unit to start up in summer 2024.[24] On the basis of this demonstrator, India plans to build a fleet of six power reactors. In addition to MOX, the country plans to use thorium, a mineral that is available in the east of the country.[25]

The development of such reactors goes hand-in-hand with the construction of spent fuel reprocessing facilities. India has three small plants dedicated to the reprocessing of fuel from existing reactors, and in January 2024 inaugurated the pilot Demonstration Fast Reactor Fuel Reprocessing Plant. In this way India is establishing itself as a leader in the development of these technologies. ■

2024 HIGHLIGHT

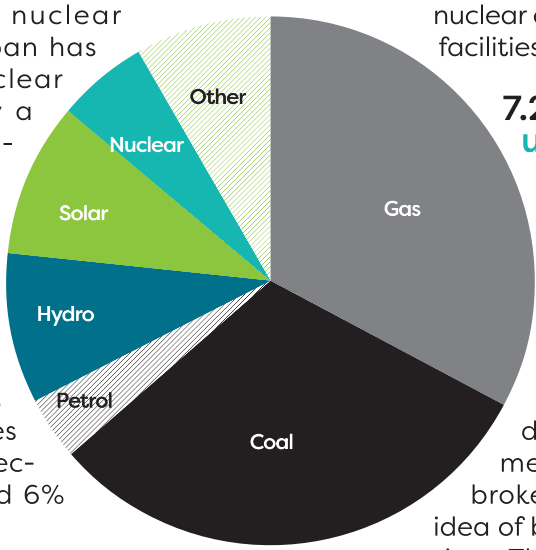
In addition to the six units under construction, India has a further ten reactor projects approved and financed by the government.

Japan

7 Japan's timid return to nuclear

OVERVIEW Japan's priority is to restart its nuclear fleet in line with new safety standards. Alongside this, the government is seeking to facilitate the construction of new reactors and support R&D efforts to develop new technologies. In terms of the fuel cycle, one of the main challenges is managing fuel assembly storage and the commissioning of reprocessing and MOX fabrication at the Rokkasho facilities.

Since the Fukushima nuclear accident in 2011, Japan has restarted twelve nuclear reactors, i.e., barely a third of the units considered operable. Restarting the nuclear fleet remains the government's priority, even though the question of renewing the fleet has attracted greater attention since Fumio Kishida became Prime Minister in 2021. The stated aim is that by 2030 nuclear power reaches 20% to 22% of the nation's electricity, compared with around 6% currently.[26]



7• Electricity mix 2022
Gas: 32.9%
Coal: 30.8%
Petrol: 4%
Hydro: 9.2%
Solar: 9.4%
Nuclear: 5.5%
Other: 8.2%
Source: IEA

7.1 Restarting the fleet very gradually

Following the 2011 Fukushima nuclear accident, production at all of Japan's nuclear reactors was suspended to give time to establish a new safety authority, the NRA, and new safety standards. After the closure of 24 reactors, 33 are currently considered to still be operable. Of these, twelve have restarted, five are awaiting restart after receiving the NRA's green light, while eight other restart applications are still being processed. At present, eight reactors have made no restart applications. The challenge facing operators is not only to meet the NRA's requirements in terms of quality and deadlines, but also to convince the public and local representatives who are also stakeholders in the restart decisions.

In May 2023, the government, in seeking to accelerate reactor restarts and provide the industry with greater visibility, replaced the original sixty-year operating limit calculation with an alternative method. The sixty-year limit had previously been calculated using the unit's commissioning date as the calculation commencement point. The new method uses a non-calendar sixty-year limit so that means that the decade of shutdown following the Fukushima accident will not be deducted from a unit's operating life. This will open up new opportunities for nuclear operators to invest in their current facilities.

7.2 Fleet renewal under debate

For several years after the Fukushima accident, the construction of new units was not even a topic for discussion. The only priority was to restart those reactors that could be restarted. It was only in the summer of 2022, against the backdrop of the energy crisis, that former Prime Minister Fumio Kishida broke this taboo by mentioning the idea of building new reactors for the first time. The government is actively mobilizing to address the issue and is seeking to improve the regulatory framework. It remains to be seen whether this momentum in favor of new reactors will last, despite political fluctuations, at a time when the question is being raised of how to maintain skills in a nuclear sector that appears somewhat directionless.

7.3 Japan continues to develop new reactor technologies

Japan is pursuing its research and development activities vis-a-vis two reactor technologies. As part of its strategy to close the fuel cycle, Japan has a long history of developing fast-neutron reactors. A small experimental sodium-cooled reactor that has been shut down since 2007, is due for restart in 2026.

Japan

2024 HIGHLIGHT

According to initial statements by the new government, Shigeru Ishiba's accession as Prime Minister on 01 October 2024 is unlikely to call Japan's nuclear policy into question.

Furthermore, in July 2023, the government selected Mitsubishi Heavy Industries to lead the conceptual design of a demonstration sodium-cooled fast reactor for start-up in 2040.

Japan is a long-standing partner of the French nuclear industry in this type of FBR technology.

Japan is also focusing on high-temperature gas cooled reactors due to their intrinsic safety features and is one of the few countries to have such a reactor in operation, namely an experimental 30 MWth unit, the HTTR. The HTTR is currently undergoing various tests to study its safety and hydrogen production.

WHO IS BUILDING the reactor vessels and steam generators?

Japan relies on Mitsubishi Heavy Industries (MHI) and Japan Steel Works to manufacture large, forged components (vessels, steam generators, pressurizers, etc.). Although Japan benefits from export orders, notably with EDF as part of the 'Grand Carénage' (Great Refit) program, concerns over safeguarding necessary skills and the attractiveness of the country remain an issue amid uncertainty over where exactly Japan's nuclear journey is headed.

7.4 Fuel supplies secure via Western partnerships

Japan imports its uranium from two main partner countries, Australia, and Canada.[27] It also partners with the West for conversion and enrichment. Fuel assembly manufacturing is handled by four plants owned by three players. First, Global Nuclear Fuel (Japan (GNF-J)) has a facility in Kanagawa dedicated to boiling water reactor (BWR) fuel. Second, Nuclear Fuel Industries (Japan (NFI)) has two plants making BWR fuel (Tokai-Mura) and fuel for pressurized water reactors (PWR) (Kumatori). Third, Mitsubishi Nuclear Fuel (MNF) has a PWR assembly manufacturing plant (Tokai-Mura). As of 30 September 2024, all the reactors that have been restarted are PWR-type units.

Lastly, the nuclear industry is experiencing difficulties in getting the Rokkasho plant up and running. The latest messaging slates commissioning for the reprocessing plant in fiscal 2026 and for the MOX fuel fabrication plant in fiscal 2027.[28] A further delay was announced in August 2024, following a change in the NRA's seismic calculation rules, requiring operator JNFL to embark on extensive recalculations. The delayed schedule is now weighing on the restart of the overall plant, where pool storage capacity is limited, even though dry storage capacity is also being developed.

7.5 Dismantling Fukushima Daiichi

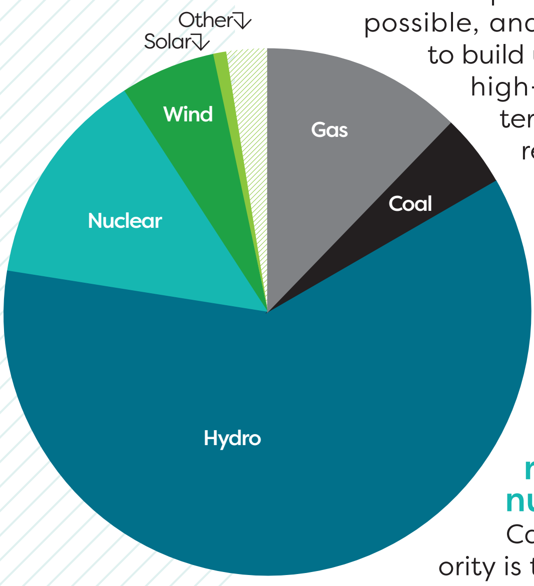
Japan is aiming for full dismantling of the Fukushima Daiichi nuclear power plant by 2060. Nearly 2,000 assemblies have been removed from the used fuel pools at Reactors 4 (2014) and 3 (2021), and Tepco plans to continue working on those of Reactors 1 and 2 through to 2031. In August 2024, Tepco also launched the first tests to recover corium from melting reactor cores. ■

Canada

8 Canada fully behind nuclear power irrespective of size

OVERVIEW Canada's nuclear policy is based on three elements, the long-term operation of its current nuclear fleet via major refurbishment programs, the construction of large new reactors, and the development of small modular reactors.

Canada's nuclear fleet comprises 19 reactors based on Canada's domestic technology (Candu). These are heavy water moderated reactors using natural uranium as fuel. The province of Ontario, bordering the west of Quebec, is home to 18 of the 19 units in operation. Canada is seeking to keep its current fleet in operation for as long as possible, and it is also planning to build up to 4.8 GW of new high-power reactors. In terms of small modular reactors, the country is involved in several projects and also benefits from significant synergies with neighboring USA.



8• Electricity mix 2022

- Gas: 12.4%
- Coal: 4.5%
- Hydro: 60.8%
- Nuclear: 13.3%
- Wind: 5.7%
- Solar: 1%
- Other: 2.3%

Source: IEA

8.1 Long-term operation and renewal of the nuclear fleet

Canada's first key priority is to keep the 19 reactors that supply around 15% of the country's electricity in operation, via a maintenance program that was launched in 2016. These 'refurbishment' operations are undertaken at a unit's thirtieth 'birthday', or thereabouts, and they enable the units to operate for an additional thirty years. Alongside this enormous and thorough maintenance program that extends right down to a reactor's core, Ontario is pursuing the second priority. It is looking to new construction projects that could deliver installed capacity of up to 4.8 GW, close to the site of the Bruce Power Nuclear Generating Station Power generating station.

At the end of 2023, Atkins-Realis (formerly SNC-Lavalin) took advantage of the World Nuclear Exhibition in Paris to present the design of a brand-new reactor, the Candu Monark, which at 1,000 MW will be more powerful than those currently in operation.

8.2 Small power coming into favor

Canada's third priority focuses on small modular reactors (SMRs) as part of the country's Small Modular Reactor Action Plan. This roadmap, published in 2018, is the result of a pan-Canadian approach that "Brings the key players together - the federal government, and the provincial and territorial governments, Indigenous peoples and communities, businesses and state services, industry (...) and civil society."[29]

> ***The first priority is to keep the 19 reactors that supply around 15% of the country's electricity in operation.***

Canada

2024 HIGHLIGHT

In February 2024, the Canadian government released C$50 million (€33 million) from the Federal Electricity Pre-Development Program to support the project to build new nuclear capacity near the Bruce Power Nuclear Generating Station.

Indeed, the very interest in these reactors stems from their suitability for small-scale power grids to supply isolated civil or industrial sites, too often powered by diesel generators. To implement this plan, the government is adding resources to its Ministry of Energy and the Nuclear Safety Authority, and supporting manufacturers developing SMRs (Moltex Energy, Terrestrial Energy, Westinghouse Canada). For example, since the end of 2022, SMRs have been included among the clean energy technologies eligible for a new investment tax credit equal to 30% of the capital cost.

The province of Ontario has already selected a site for the construction of four GE-Hitachi 300 MW SMRs, for which the first earthworks were completed in March 2024. Other provinces, which have no nuclear reactors of their own, such as Alberta, are also interested in SMRs. In August 2023, the Saskatchewan government approved C$74 million (€50 million) in funding for preliminary studies, and two potential sites were announced in the summer of 2024.

8.3 Canada currently enjoys sovereignty over its fuel supply

Canada's nuclear power industry has certain characteristics that make it a very robust industry. The country is the world's second largest producer of uranium, and around 20% this production is all that is needed to fuel its 19 nuclear reactors.[30] As the fleet operates on natural uranium, Canada is insulated from the dependence on Russian enrichment capacities seen in the United States and Europe. In terms of converting uranium (U3O8) into UO3 and then UO2, the industry can rely on its domestic Blind River and Port Hope plants. Lastly, Ontario also has two domestic fuel fabrication plants, BWXT and Cameco. ■

WHO IS BUILDING the reactor vessels and steam generators?

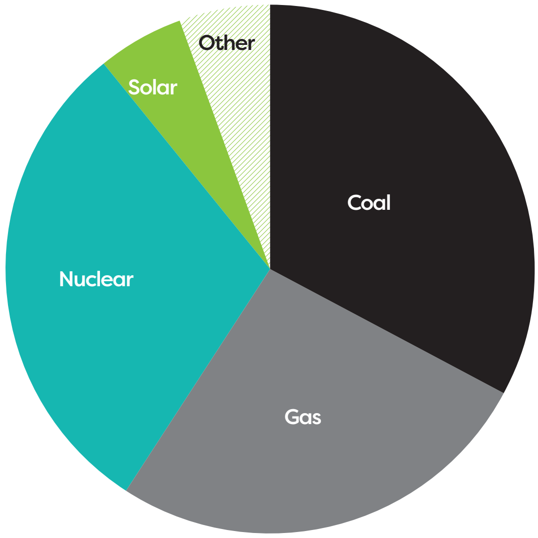
BWXT Canada supplies components for the Candu-type reactors, for example as part of the Major Component Replacement (MCR) program at the Bruce Power Nuclear Generating Station Power station. In terms of SMR construction, Canada is counting on the expansion of BWXT's Canadian capacities, with the announcement in early 2024 of an investment of C$80 million (€53 million) to expand the Cambridge plant.

South Korea

9 South Korea, a key global nuclear player

OVERVIEW South Korea is boosting its nuclear power industry both domestically and internationally by way of high-power reactor exports and the small modular reactor sector, notably by manufacturing components for U.S. projects.

South Korea's 2022 change of government scrapped the previous ambition to eventually phase out nuclear power, and the new government even relaunched construction projects to ensure that by 2030 at least a third of its electricity production will come from nuclear power. South Korea is omnipresent on the nuclear sector export market, with the APR1400 high-power reactor and its 1,000 MW version. Furthermore, the peninsula's expertise in manufacturing large components for small modular reactors is attracting demand from U.S. SMR developers, such as NuScale and X-energy.



9• Electricity mix 2023

- **Coal:** 33%
- **Gas:** 26.4%
- **Nuclear:** 30%
- **Solar:** 5.2%
- **Other:** 5.4%

Source: IEA

9.1 Restarting domestic construction projects

South Korea has been earnestly renewing its nuclear fleet, with eight reactors, or almost 10 GW equivalent connected to the grid since 2010. Half of these have been connected to the peninsula's power grid since 2016. Two more have been under construction since 2017 and 2018 and given the then President Moon Jae's (2017-2022) national long-term nuclear phase-out policy they were to have marked the end for any further projects. This gradual phase-out policy aimed to dismantle all reactors when they reached forty years of operation and that following the final commissioning, nuclear power production was expected to fall to zero by the 2060s. The project to build the Shin Hanul Units 3 and 4 had also been suspended. A new government came to power in 2022 and totally reversed this policy stance. The Shin Hanul project was relaunched and secured its building permit in September 2024. The two 1,400 MW units are scheduled to become commercial in the early 2030s. South Korea is also actively supporting the nuclear industry's export sector.

South Korea has abandoned its ambition to gradually phase out nuclear power and has even relaunched construction plans

South Korea

WHO IS BUILDING the reactor vessels and steam generators?

Domestic construction machinery manufacturing company Doosan produces large components for the nuclear boilers of both Korean and American nuclear reactors. For example, the company was involved in the construction of the AP1000 reactors at Vogtle (USA), Sanmen and Haiyang (China), as well of course the APR1400 at Barakah (UAE). Furthermore, it forged the first components of the NuScale SMR and is a partner of X-energy, which is developing a small high-temperature reactor. South Korea is also developing its own SMR, called SMART (System-integrated Modular Advanced Reactor).

9.2 Ambitious export targets

On the export front, the Ministry of Trade, Industry and Energy (Motie) has expressed the ambition, “To export ten nuclear power plants by 2030,” and South Korea’s nuclear power industry has taken part in several offers for tender (Czech Republic, Netherlands, Poland,...). South Korea has a strong ‘calling card,’ namely the UAE’s Barakah nuclear power plant, where its four units were completed in twelve years, with each reactor taking just over eight years to build. The next success story might well be in the Czech Republic, when in July 2024 the Motie entered into exclusive negotiations with Korea Hydro & Nuclear Power (KHNP) for the construction of between one and four new reactors.

9.3 A framework for the fuel cycle

South Korea’s fuel cycle policy is determined by the ‘123 agreement’ signed in 1974 with the USA. The agreement, which has undergone several iterations since its signing, aims to ensure nuclear non-proliferation while guaranteeing a stable supply of fuel for South Korea’s pressurized water reactors and the Candu natural uranium reactors. The peninsula has its own fuel fabrication plant (KEPCO NF) but has no domestic conversion, enrichment, or reprocessing activities. The U.S. Bureau of International Security and Nonproliferation (ISN) explains the situation thus, “The agreement will allow us to continue and expand our strong collaboration and reap benefits from our commercial relationship. For example, the U.S. provides enrichment services to support nuclear fuel fabrication, and the Republic of Korea (ROK) supplies the U.S. with important reactor components such as reactor vessels.” ■

2024 HIGHLIGHT

In September 2024, South Korea granted a construction permit for the two 1,400 MW Shin Hanul reactors. Commissioning is scheduled for the early 2030s.

Africa

10 Africa is also turning to a nuclear solution

OVERVIEW **The African continent only has one nuclear power plant in operation, located in South Africa, and there is one other plant under construction in Egypt. However, many countries are interested in developing nuclear solutions, including by way of small modular reactors.**

A generalized rise in living standards across the African continent cannot be achieved without electricity and that electricity production must also emit the lowest levels of CO2 as possible.

Nuclear power is a logical option for many of the continent's many nations, although it is not always feasible. Issues relating to infrastructure, skills, governance, financing, and power grids can make navigating the pathway to nuclear power considerably complicated. To overcome the obstacles, small-scale power solutions could prove to be a potentially more suitable option than large reactors.

10.1 Significant demand for electricity

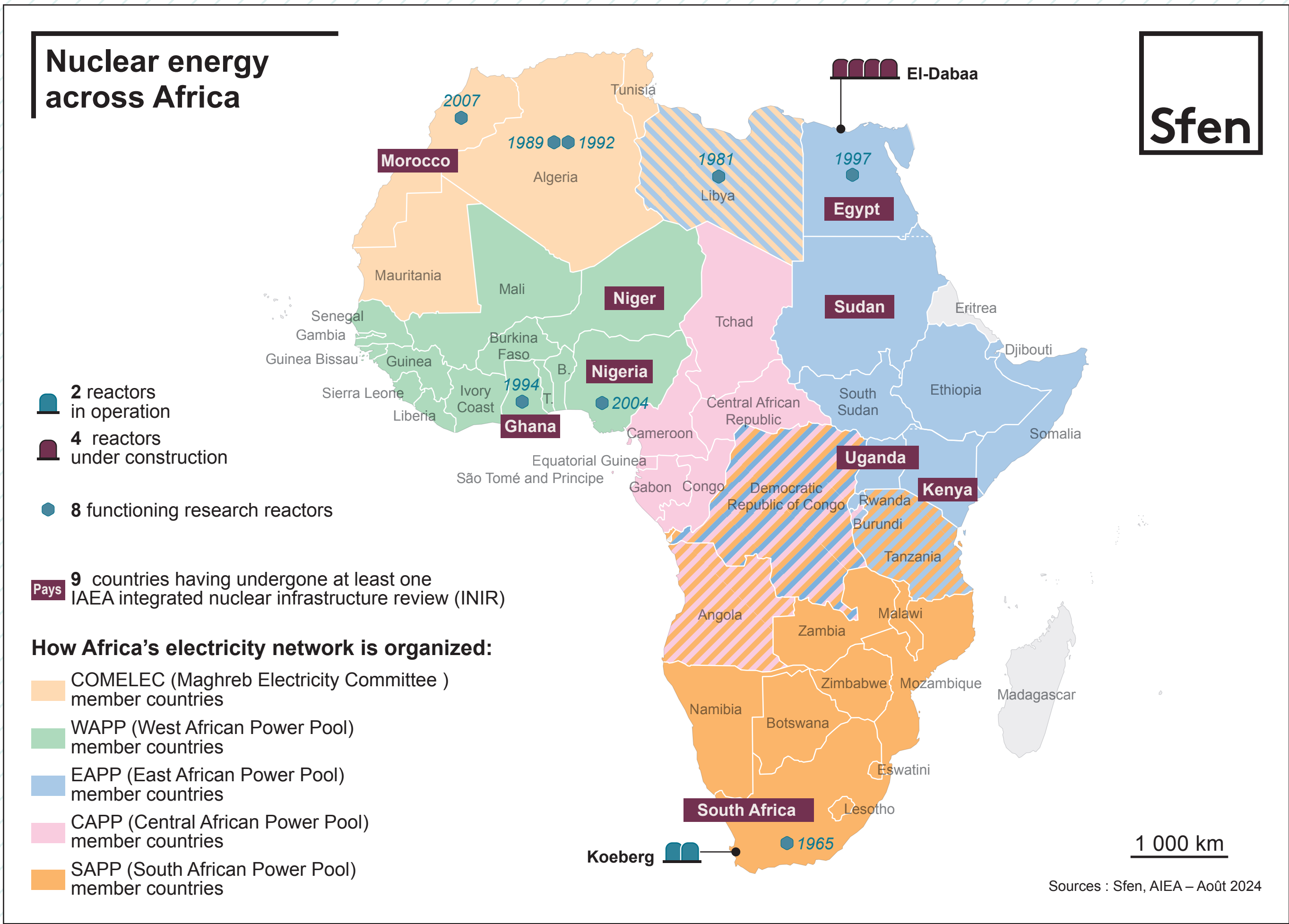
Africa's annual electricity production amounts to approximately 800 TWh, the equivalent of France together with Spain, however, that power is shared across a vastly greater population size of 1.4 billion.[31] This figure reflects both too little electricity for those who can benefit from it, and a problem of access to energy for others (43% of the continent's population has no access to electricity).[32] The International Energy Agency (IEA) noted that in 2021, European per capita electricity consumption bordered on 6 MWh, compared with just 0.6 MWh in Africa. Supply also remains very variable with South Africa, the North African countries, Ghana, Gabon, and Côte d'Ivoire sitting at the top of the league table. However, the Democratic Republic of the Congo, Ethiopia, Nigeria, Tanzania, and Uganda, which together account for half of the sub-Saharan population, have no access at all to electricity. The IEA's sustainable scenario for Africa projects electricity demand to reach 1,200 TWh in 2030, with strong growth in industrial and transport uses. This demand is also driven by demographic growth, with the population having increased five-fold between 1960 and today.[33] The continent caters to a number of densely populated cities, such as Lagos in Nigeria and Kinshasa in the Democratic Republic of Congo, with population counts of around 16-17 million and growing.

Africa's annual electricity production amounts to approximately 800 TWh; to be shared among 1.4 billion people

10.2 Long-standing interest, yet few concrete results

African interest in nuclear power dates back decades. Ghana has been planning to build power plants since the 1960s, Algeria has been interested since the 1970s, and at that time South Africa launched the continent's first nuclear power plant in collaboration with a French consortium. Since then, some fifty years have had to pass before any other new

Africa



project could see the light of day, with 2022 being the construction date for the first reactor at Egypt's El-Dabaa plant.

Despite the lack of concrete results, the overall situation has been evolving and new research reactors were commissioned in the 1990s and 2000s, some ten of which are currently in operation, and IAEA Integrated Nuclear Infrastructure Review (INIR) missions were launched in the 2010s.[34] These mission reviews are designed to assist countries evaluate the status of their national infrastructures and guide their nuclear energy development programs. Eight countries with no current nuclear power plants have engaged with the IAEA INIR process. They evidence the interest in, and commitment to nuclear programs, as well as a growing expertise in the field.

10.3 New nuclear reactors on the horizon

New reactor grid connections are now expected in Egypt and potentially also in South Africa.

Egypt has chosen Russia to construct its initial nuclear power plant comprising four units with a total capacity of 4,800 MW.

Between 2022 and January 2024, Russia's Rosatom poured the first concrete for the four units. The aim is for the plant to contribute fully to the country's electricity production by 2031.[35] Rosatom will supply the fuel for the four units throughout their operating lives and will support the plant's operation for a period of ten years.

In December 2023, the South African government announced that it was preparing a call for projects to build a 2,500 MW capacity plant. In the summer of

2024 HIGHLIGHT

Nine African countries, including eight with no nuclear reactors, have hosted one or more integrated IAEA INIR review missions

2024, however, the government backtracked on the issue, delaying the launch of the process until a consultation phase could be opened. Meanwhile, Energy Minister Kgosientsho Ramokgopa has reaffirmed his intention to build new units.[36]

10.4 A series of Memorandums of Understanding (MoU) for small modular reactors

In recent years MoU have proliferated.[37] In 2022, for example, Ghana announced a partnership with the USA and Japan, as part of the FIRST Program, to look at constructing small modular reactors.[38] Two years later, in September 2024, it announced that it was working with U.S. designer NuScale to study the construction of a power plant. Ghana hopes to benefit from 1 GW of nuclear power by 2034. Russia's Rosatom is expanding the number of its partnerships (Algeria, Egypt, Ghana, Morocco, Nigeria, Rwanda, South Africa, and Sudan), and China is now also a presence in several countries.[39,40] It is hard to say how robust these agreements are, or what concrete progress has been made, but Africa is a continent that is now attracting the interest of the major nuclear energy powers. ■

Rest of the world

United Arab Emirates

With the connection of its fourth unit to the electricity grid in March 2024, the Barakah nuclear power plant is now at full capacity. The four Korean-engineered units will supply the equivalent of 25% of the electricity needs of the 9.3 million inhabitants across the UAE's seven emirates. Thanks to tight scheduling, all four reactors were completed in twelve years, i.e., just over eight years for each unit.

The country is also interested in small modular reactors (SMRs) for desalination and for hydrogen production. At the end of 2023, several Memorandums of Understanding (MoU) were signed on the margins of December 2023 COP28 event between the operator ENEC and SMR developers.

Kazakhstan

Kazakhstan is the world's leading producer of uranium (41% of global production in 2020)) and it is now planning to build its first nuclear power plant.[41] To this end, the country held a referendum on 06 October 2024, and according to the press the project received a 70% approval with a 64% voter turnout. The industrial partner for this project is yet to be identified.

Turkey

Turkey has ordered four 1,200 MW units from Russia. The first concrete for the first unit was poured in 2018, and the Turkish government had announced that it was aiming for commissioning before the 100th anniversary of the Turkish Republic, on 29 October 2023. The project is as such running slightly behind schedule, although the target remains to commission all units by 2028.[42] The plant will generate around 10% of the country's electricity requirements.

Uzbekistan

In 2017, Uzbekistan signed an agreement with Russia for the construction of two 1,200 MW units and in 2024 it signed another for the construction of a power plant with six small modular 55 MW reactors for a total capacity of 330 MW.

Data

Data

Nuclear power worldwide

1• Nuclear reactors worldwide in 2023 and 2024 *(Source: IAEA-PRIS, October 2024)*

	2023	2024 (October)
Reactors currently in operation	410	415
Reactors currently in suspended operational mode	27	25
Reactors under construction	57	62

2• Nuclear power worldwide in 2024 *(Source: IAEA-PRIS, U.S. Energy Information Administration, October 2024)*

Country	Nuclear Capacity (GW)	Reactors under construction	Reactors in operation	% Share of 2023 electricity production
United States	97	0	94	18.6
France	63	0	57	64.8
China	54	28	56	4.90
Russia	27	4	36	18.4
Republic of Korea	26	2	26	30.7
Canada	14	0	19	13.7
Ukraine	13	2*	15	-
Japan	11	2*	12	5.50
Spain	7	0	7	20.3
India	7	7	20	3.10
Sweden	7	0	6	28.6
United Kingdom	6	2	9	12.5
United Arab Emirates	5	0	4	19.7
Finland	4.5	0	5	42.0
Czech Republic	4	0	6	40.0
Belgium	4	0	5	41.2
Pakistan	3	0	6	17.4
Switzerland	3	0	4	32.4
Slovakia	2	1	5	61.3
Belarus	2	0	2	28.6
Bulgaria	2	0	2	40.5
Hungary	2	0	4	49.0
South Africa	2	0	2	4.40
Brazil	2	1	2	2.20
Argentina	1.5	1	3	6.30
Mexico	1.5	0	2	4.90
Romania	1.5	0	2	18.9
Iran	0.9	1	1	1.70
Slovenia	0.7	0	1	36.8
Armenia	0.4	0	1	31.1
Netherlands	0.4	0	1	3.20
Bangladesh	0	2	0	0.00
Egypt	0	4	0	0.00
Turkey	0	4	0	0.00

*Project suspended-resumption date unknown

Data

3• Changes in world's nuclear fleet *(2005-2024) Source: IAEA-PRIS*

Year	Nuclear Capacity (GW)	No. of reactors in operation
2005	368	442
2010	372	438
2015	364	423
2020	375	422
2024	374	415

4• New nuclear reactor construction launched in 2023 *Source: World Nuclear Association-World Performance Report*

Reactor	Country	Model	Power (MWe)	First Pour
Sannen-4	China	CAP1000	1,163	22 Mar 2023
Haiyang-4	China	CAP1000	1,161	22 Apr 2023
El-Dabaa-3	Egypt	VVER-1200	1,100	03 May 2023
Lufeng-6	China	Hualong-One	1,116	26 Aug 2023
Lianjiang-1	China	CAP 100	1,224	27 Sep 2023
Xudabao-1	China	CAP1000	1,000	03 Nov 2023

5• Reactors connected to grid in 2023 *Source: World Nuclear Association-World Performance Report*

Reactor	Country	Power (MWe)	Model	Grid connection date
Fangchenggang-3	China	1,105	Hualong-One	10 Jan 2023
Mochovce-3	Slovakia	440	VVER-440	31 Jan 2023
Vogtle-3	United States	1,117	AP1000	31 Mar 2023
Astravets-2	Belarus	1,110	VVER V-1200	13 May 2023
Shin-Hanul-2	South Korea	1,340	APR1400	21 Dec 2023

6• Reactor closures in 2023 *Source: World Nuclear Association-World Performance Report*

Reactor	Country	Power (MWe)
Tihange-2	Belgium	1,008
Kuosheng-2	Taiwan	985
Ernsland	Germany	1,335
Isar-2	Germany	1,410
Neckarwestheim-2	Germany	1,310

7• New reactor construction launched in 2024 (January-October) *Source: IAEA–PRIS*

Reactor	Country	Model	Power (MWe)	First Pour
El-Dabaa-4	Egypt	VVER-1200	1,100	23 Jan 2024
Zhangzhou-3	China	Hualong-One	1,120	22 Feb 2024
Leningrad-2-3	Russia	VVER-1200	1,150	12 Mar 2024
Liangjiang-2	China	CAP1000	1,224	26 Apr 2024
Xudapu-2	China	CAP1000	1,000	17 Jul 2024
Ningde-5	China	Hualong-One	1,200	28 Jul 2024
Shidaowan-1	China	Hualong-One	1,116	28 Jul 2024

Data

8• Reactors connected to grid in 2024 (January-October) *Source: IAEA-PRIS*

Reactor	Country	Power (MWe)	Model	Grid connection date
Kakrapar-4	India	630	IPHWR	20 Feb 2024
Barakah-4	United Arab Emirates	1,310	APR1400	23 Mar 2024
Vogtle-4	United States	1,117	AP1000	06 Mar 2024
Fangchenggang-4	Belarus	1,110	VVER V-1200	09 Apr 2024

9• Reactor closures in 2024 (January-October) *Source: IAEA-PRIS*

Reactor	Country	Power (MWe)
Koursk-2	Russia	925
Maanshan-1	Taiwan	936

Third Generation Reactor Construction

10.1• Korean reactor construction (APR1400)

Reactor (construction location)	Construction commencement	Grid connection	Construction period (months)
Shin-Hanul-2 (South Korea)	2013	2023	126
Shin-Hanul-1 (South Korea)	2012	2022	119
Saeul-2 (South Korea)	2009	2019	116
Saeul-1 (South Korea)	2008	2016	90
Average duration			**112 (9.3 years)**
Barakah-4 (United Arab Emirates)	2015	2024	104
Barakah-3 (United Arab Emirates)	2014	2022	96
Barakah-2 (United Arab Emirates)	2013	2021	102
Barakah-1 (United Arab Emirates)	2012	2020	97
Average duration			**99 (8.3 years)**

10.2• Chinese reactor construction (HPR1000)

Reactor (construction location)	Construction commencement	Grid connection	Construction period (months)
Fangchenggang-4 (China)	2016	2024	88
Fangchenggang-3 (China)	2015	2023	85
Fuqing-6 (China)	2015	2022	72
Hongyanhe-5 (China)	2015	2021	75
Fuqing-5 (China)	2015	2020	67
Hongyanhe-6 (China)	2015	2022	81
Average duration			**78 (6.5 years)**
Karachi-3 (Pakistan)	2016	2022	69
Karachi-2 (Pakistan)	2015	2021	67
Average duration			**68 (5.6 years)**

Data

10.3• Russian reactor construction (VVER1200)

Reactor (construction location)	Construction commencement	Grid connection	Construction period (months)
Leningrad-2-2 (Russia)	2010	2020	126
Novovoronezh 2-2 (Russia)	2009	2019	118
Novovoronezh 2-1 (Russia)	2008	2018	113
Leningrad-2-1 (Russia)	2008	2016	97
Average duration			**113 (9.5 years)**
Astravets-2 (Belarus)	2014	2023	109
Astravets-1 (Belarus)	2013	2020	84
Average duration			**96 (8 years)**

10.4• French reactor construction (EPR)

Reactor (construction location)	Construction commencement	Grid connection	Construction period (months)
Taishan-2 (China)	2010	2019	110
Taishan-1 (China)	2009	2018	103
Average duration			**106 (8.8 years)**
Flamanville -3 (France)	2007	2024	-
Olkiluoto-3 (Finland)	2005	2022	199

10.5• American reactor construction (AP1000)

Reactor (construction location)	Construction commencement	Grid connection	Construction period (months)
Haiyang-2 (China)	2010	2018	112
Haiyang-1 (China)	2009	2018	107
Sanmen-2 (China)	2009	2018	104
Sanmen-1 (China)	2009	2018	110
Average duration			**108 (9 years)**
Vogtle-4 (United States)	2013	2024	124
Vogtle-3 (United States)	2013	2023	121
Average duration			**122 (10 years)**

Small Modular Reactors

11• Small Modular Reactors (SMR) identified worldwide by the Nuclear Energy Agency 2024 *Source: NEA SMR Dashboard, Second Edition, 2024*

Concepts not under active development	Concepts under development without NEA assessments	Concepts under development or operating with NEA assessments
35	7	56

Data

12• Number of SMR concept designer headquarters by region

Source: NEA SMR Dashboard, Second Edition, 2024

North America	18
Europe	16
Asia	7
Russia	2
Africa	2
Middle East	1
South America	1

13• Winning SMR designers selected from the France 2030 Investment Plan

Company name	Reactor name	Technology type	Power Electrical/ Thermal
Blue Capsule Technology	Blue Capsule	Thermal spectrum sodium-TRI-SO	50 MWe/150MWth
Calogena	Calogena	Light-water (LWR)	30 MWth
GenF	Taranis	Inertial confinement fusion	1,000 MWth
Hexana	Hexana	RNR-sodium	2x*170 MWe 2x*400 MWth
Jimmy Energy	Jimmy SMR	High temperature	10 MWth
Naarea	XAMR	Molten salt	40 MWe/ 80 MWth
Newcleo	Newcleo LFR-30	Lead-cooled	30 MWe
Nuward (EDF)	Nuward SMR	Pressurized water	2x*170 MWe 2x*540 MWth
Otrera Nuclear Energy	Otrera 300	RNR-sodium	300 MWe/550 MWth
Renaissance Fusion	RF01	Stellarator fusion	1,000 MWe
Stellaria Energy	Stellarium	Molten salt	2x*110 MWe 2x*250 MWth
Thorizon	Thorizon One	Molten salt	100 MWe/250 MWth

Design comprises two models

Fuel cycle: uranium, conversion, enrichment

14• Per country share of global natural uranium production: 2021 and 2022

Source: Euratom Supply agency

Country	2021	2022
Kazakhstan	45.6%	43.4%
Namibia	12%	11.5%
Canada	9.8%	15%
Australia	8.8%	8.4%
Uzbekistan	7.4%	6.7%
Russia	5.5%	5.1%
Niger	4.7%	4.1%
Other	6.2%	5.5%

Data

15• Global distribution of uranium reserves costing below US$130/kgU as of 01 January 2021 *Source: Euratom Supply Agency*

Country	Tonnes	Share (%)
Australia	1,684,100	28
Kazakhstan	815,200	13
Canada	588,500	10
Russia	480,900	8
Namibia	470,100	8
South Africa	320,900	5
Niger	311,100	5
Brazil	276,800	5
China	223,900	4
Other	907,000	14
Total	**6,078,500**	**100**

16• Uranium conversion nameplate capacity (tU) per company in 2023 *Source: Euratom Supply Agency*

Company	Nameplate capacity (tU as UF6)	Share of global capacity (%)
Orano* (France)	15,000	24.2
CNNC** (China)	15,000	24.2
Rosatom (Russia)	12,500	20.1
Cameco (Canada)	12,500	20.1
ConverDyn*** (United States)	7,000	11.4
Total nameplate capacity	**62,000**	**100**

*Because of rounding, totals may not add up. *Approximate capacity installed 10,500 tU, plant not yet at nameplate capacity **Information on China's conversion capacity is uncertain *** Activity suspended since end of 2017 Data source: www.world-nuclear.org*

17• Uranium enrichment capacity (tSW) per company in 2020 *Source: Euratom Supply Agency*

Company	Nameplate capacity (tSW)	Share of global capacity (%)
Rosatom (Russia)	27,654	46
Urenco (UK/Germany/ Netherlands/	18,230	30
United States)	7,500	12
Orano (France)	6,750	11
CNNC (China)	66	1
Total nameplate capacity	**60 200**	**100 %**

*Some data is estimated; because of rounding, totals may not add up. Data source: WNA, The Nuclear Fuel Report- Global Scenarios for Demand and Supply Availability 2019-2040. *INB, Brazil; JNFL, Japan*

Glossary of terms

AIEA- IAEA	International Atomic Energy Agency
AIE- IEA	International Energy Agency
AMR	Advance Modular Reactor- advanced technology
AP100	American third-generation reactor (1100 MW)
APR1400	Korean third-generation reactor (1400 MW)
ASN	Autorité de sûreté nucléaire (French nuclear safety authority)
Construction period	Period between a nuclear reactor project's first pour and its grid connection
EPR	French third-generation reactor (1650 MW)
EPR2	Optimized version of the EPR (1650 MW)
GenIII+	Third-generation type reactor
FHR	Fluoride Salt-Cooled High-Temperature Reactor
Haleu	High-Assay Low-Enriched Uranium
HTR	High-Temperature Reactor
Hualong -One	Chinese third-generation reactor (1000 MW)
MMR	Micro Modular Reactor
MW	Megawatt
MWe	Megawatt electric
MWth	Megawatt thermal
Na	Sodium
REB- BWR	Boiling water reactor
REP- PWR	Pressurized water reactor
RNR- FNR	Fast neutron reactor
SMR	Small Modular Reactor- small light water modular reactor
VVER1200	Russian third-generation reactor (1200 MW)
WNA	World Nuclear Association

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