FRANCE DRIVING EUROPE'S NUCLEAR POWER RENAISSANCE

— LOOKING TO SECURE CLEAN ENERGY SUPPLY AND EXPORT NUCLEAR POWER PLANTS —

Michael Fuhrmann
Europe & Russia Dept., Global Economic & Political Studies Div.
Mitsui & Co. Global Strategic Studies Institute

SUMMARY

- As of January 2023, nuclear power generation became eligible for green investments (i.e., those that contribute to curbing climate change) under the EU taxonomy, which promotes sustainable economic activities. There has been increasing attention on the nuclear power strategy enacted by France, Europe's largest owner of nuclear power plants.
- In February 2022, French President Emmanuel Macron announced the country's plans to build six new EPR2 reactors – improved versions of the European Pressurized Reactors (EPRs) developed by France – by 2050. France is also considering building eight additional reactors and installing several small modular reactors (SMRs) with a total power generation capacity of 25 GW.
- France is also expected to begin actively marketing nuclear power plants abroad in the hopes that the active promotion of nuclear power will revive the country's nuclear power industry.

INTRODUCTION

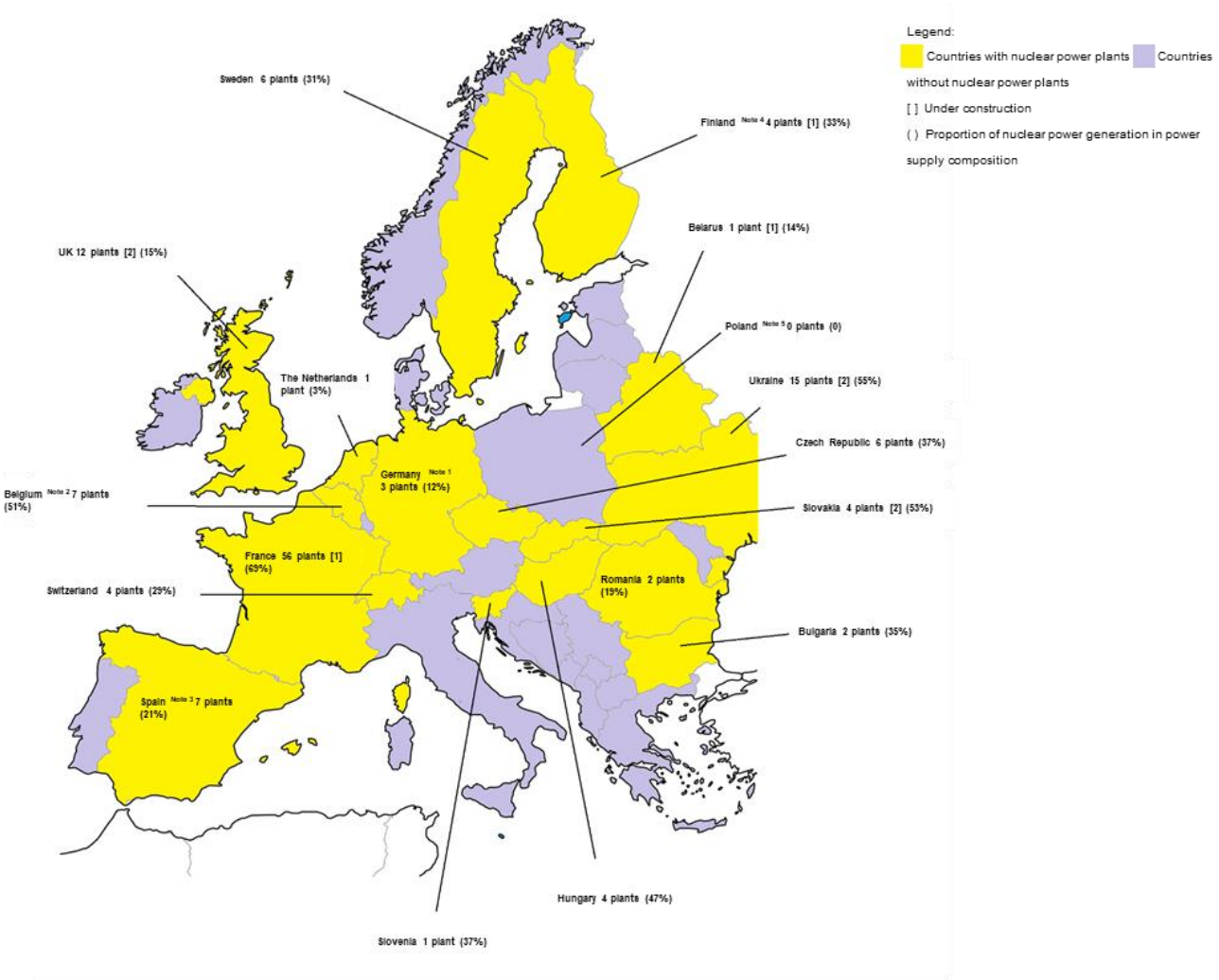
In Europe, over recent years, nuclear power has been increasingly recognized as a clean energy source. As the world moves to reduce its dependence on Russian fossil fuels, nuclear power generation has garnered attention as an important energy source that also contributes to achieving a decarbonized society.[1]

Currently, eight nuclear power plants are under construction in five countries (Figure 1), and new construction plans are being developed one after another. The Czech government began accepting bids to construct one new nuclear power plant in March 2022, and the Polish government placed an order for construction of its first nuclear power plant last December. That same month, the Dutch government also announced its intention to build two new nuclear power plants.

France's Macron administration is the driving force behind this nuclear renaissance. In February 2022, President Macron announced a plan that includes the construction of at least six new nuclear power plants and several SMRs[2] as part of a key initiative toward achieving carbon neutrality by 2050. France is working to secure stable, clean energy and export nuclear power plants to strengthen its industrial base.

[1] Efforts toward abandoning nuclear power generation, which gained momentum due to the Fukushima nuclear disaster and nuclear waste disposal concerns, have been forced to reverse course out of a need for stable energy procurement.
[2] While the definition of an SMR varies by country and design developer, the International Atomic Energy Agency (IAEA) defines it as a nuclear reactor with a power output of 300 MW or lower.

Figure 1: Nuclear power plant ownership by European countries (as of December 31, 2021)



Note 1: Germany has extended its deadline for phasing out nuclear power generation, which had been set for the end of 2022, to April 2023.

Note 2: Although Belgium had planned a complete phase out by 2025, the country decided to extend operation of its two newest nuclear reactors to 2035.

Note 3: Spain plans a complete phase out by 2035.

Note 4: Finland commenced operation of its fifth nuclear power plant in 2022.

Note 5: The Polish government plans to have up to six nuclear power plants in operation by 2043.

Source: Compiled by MGSSI based on IAEA, "Nuclear Power Reactors in the World" (2022) and media reports

1 NUCLEAR POWER AS A STEPPING STONE TOWARD DECARBONIZATION

1.1 Expectations for nuclear power generation in the EU

In January 2023, amendments were made to the EU taxonomy regulations, which promote sustainable economic activities, and nuclear power generation and natural gas power generation were once again endorsed as being eligible for green investments that contribute to curbing climate change. For the EU to achieve its goal of virtually zero greenhouse gas emissions within the region by 2050, it is considered essential to (1) construct new nuclear power plants and (2) continue operating natural gas power plants that can meet strict greenhouse gas emission standards. In the future, the EU is expected to focus on attracting private investments for both initiatives.

1.2 EU taxonomy regulations revised through German-French compromise

Recent revisions to the EU taxonomy regulations were achieved through a compromise between Germany and France, the largest and second-largest economies in the region. Due mainly to the need for long-term management of the highly radioactive waste generated from spent nuclear fuel, many countries in the EU – notably Germany, which has declared its intention to phase out nuclear power generation – consider nuclear power generation unsuitable as a sustainable energy source.

Meanwhile, France, as Europe's largest nuclear power producer, has long criticized Germany for its energy policy, which relies heavily on natural gas, more than half of which is procured from Russia, by pointing to the unsustainability of the policy as well as insufficient energy security. However, the two countries were finally able to revise the EU taxonomy regulations by coming to terms with each other's energy policies.

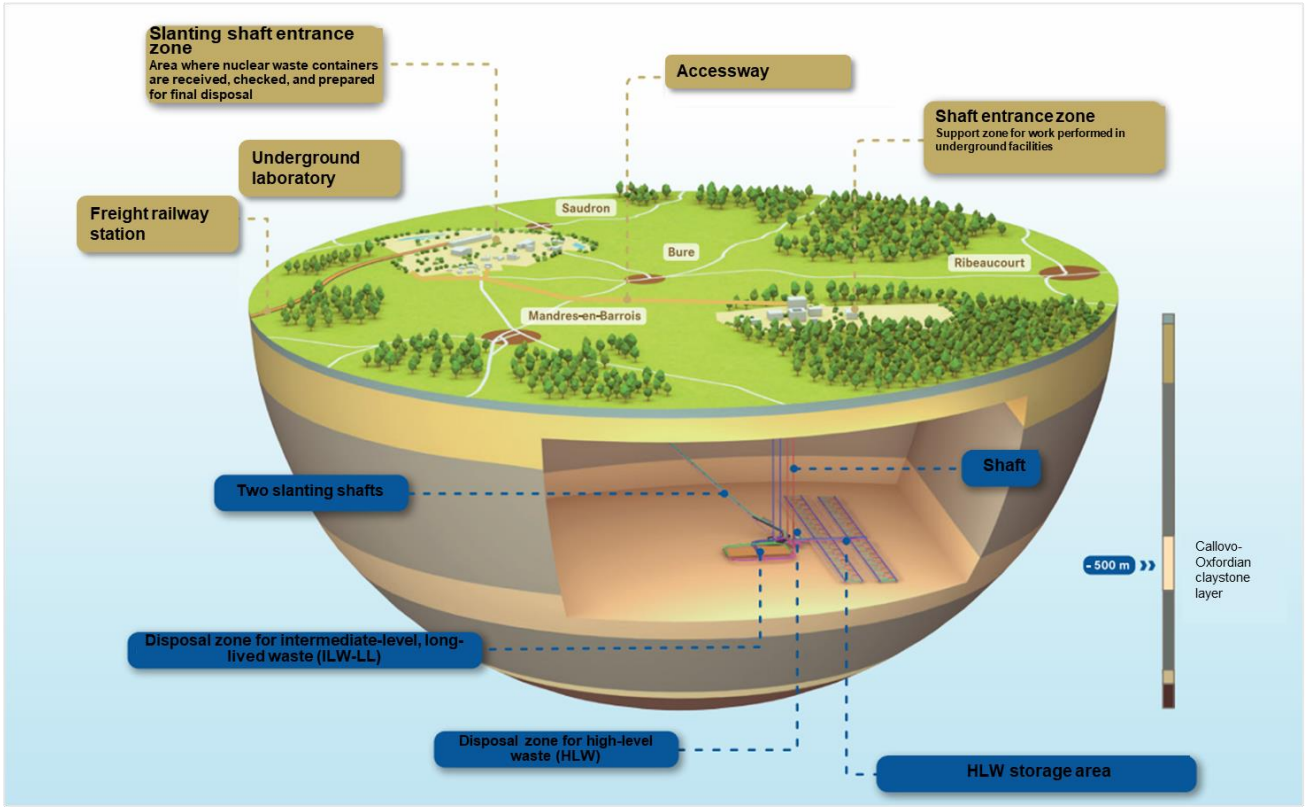
1.3 France takes the lead in establishing final repositories for nuclear waste

France is the largest producer of radioactive waste in Europe.[3] According to Andra, the French National Radioactive Waste Management Agency, the total volume of nuclear waste accumulated to date, from both military and civilian sources, amounts to 1.7 million cubic meters.[4] Finally, however, a solution to final disposal is in sight.

In 2022, Andra received approval from the French Ministry of Ecological Transition 2022 for the installation plan for the Industrial Centre for Geological Disposal (Cigeo), a deep geological repository to be built as a public utility in the village of Bure, Meuse, France (Figures 2-1 to 2-3). Following this, Andra applied in January 2023 to the French Nuclear Safety Authority (ASN) for permission to begin construction. Although most of the high- and intermediate-level, long-lived waste (HL/ILW-LL) is currently in interim storage at the La Hague nuclear fuel reprocessing plant in northwestern France, Andra is scheduled to begin construction of Cigeo in 2027 and expects the site's final processing capabilities to become fully operational in 2040.[5]

[3] France produces approx. 1,150 tons of radioactive waste annually.
[4] 60% of waste is from nuclear power plants. High-level waste (HLW) and intermediate-level, long-lived waste (ILW-LL) account for 47,000 cubic meters of this.
[5] The French government estimates the total cost of the facility to be 25 billion euros over the course of its service life, closing in 2150, and Electricite de France (EDF), Orano, the largest nuclear fuel producer, and the French Alternative Energies and Atomic Energy Commission (CEA) must bear this burden.

Figure 2-1. Cigeo storage center



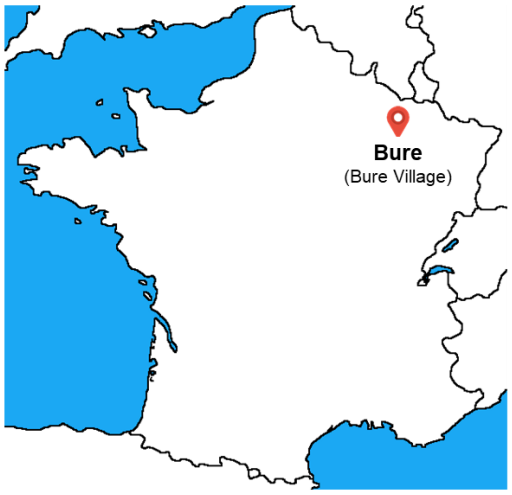
Source: Translated by MGSSI based on ANDRA material «Plan directeur de l'exploitation de Cigéo» (December 2022)
https://www.andra.fr/sites/default/files/2023-02/Plan%20directeur%20de%20l%27exploitation%20de%20Cig%C3%A9o%20-%20web.pdf
(accessed March 10, 2023)

Figure 2-2. Major milestones of the plan

1991	Legislation established to study three areas, including Bure Village, for suitability as final repositories of HLW and ILW-LL
2000	Construction of the underground laboratory begins
2005	Andra positively evaluates the feasibility and safety of deep geological disposal in Meuse, and the French Nuclear Safety Authority (ASN) and other authorities deem the evaluation justified
2016	Legislation established that clarifies the conditions for approving the installation of deep geological repositories (e.g., final repositories for HLW and ILW-LL must have a reversibility of at least 100 years)
2022	The French Ministry of Ecological Transition issues a public utility declaration (PUD) certifying the legality and benefit to public interest of the Cigeo project
2023	Andra submits application to ASN for permission to install Cigeo
2027	Construction of deep geological repository begins
2035-2040	Deep geological storage of HLW and ILW-LL commences (trial phase)
2040	Full-scale deep geological storage of HLW and ILW-LL commences
2150	Final closure of the deep geological repository

Source: Compiled by MGSSI based on ANDRA material «Dépôt de la demande d'autorisation de création de Cigéo» (January 2023)
https://www.andra.fr/sites/default/files/2023-01/ANDRA-CIGEO-Mag-4p-2023-depot_DAC.pdf
(accessed March 10, 2023. translated by MGSSI)

Figure 2-3. Location of the geological repository (Cigeo)



Source: Compiled by MGSSI

2 THE ROLE OF NUCLEAR ENERGY IN FRANCE

2.1 Balancing military and civilian usage

French nuclear energy development began with the establishment of the Atomic Energy Commission by General de Gaulle[6] immediately after World War II, and the country has always sought to strike a balance between civilian and military usage (i.e. nuclear deterrence). The Macron administration also reaffirmed the importance of nuclear energy in its strategic review of national defense and national security released in 2017.[7]

Following the oil crisis in the 1970s, France promoted large-scale development of nuclear power plants, and its existing 56 reactors provided 68% of the total 532 TWh it generated in 2021. However, the aging of these plants has become increasingly problematic in recent years, with 17 plants having been in operation for more than 40 years (Figure 3).[8]

2.2 French industry shouldering the country's hopes toward decarbonization

The French government is focusing on further promoting renewable energy under its current multi-year energy plan (Figure 4), but this assumes the operation of nuclear power plants for the stable supply of electricity. While setting the target of raising the proportion of renewable energy in its final electricity consumption to 50% by 2050, France plans to use nuclear power generation to cover the remainder.

To achieve this, in 2021, President Macron announced France 2030, an investment plan aimed at enhancing the economy's competitiveness and creating future-oriented industries. Appealing to the need for industrial revival, he plans to invest 30 billion euros, of which 8 billion is earmarked for conversion to clean electricity produced using nuclear and hydrogen energy and for decarbonization of the manufacturing industry.[9]

2.3 Initiatives toward enhancing nuclear energy

In 2021, the French transmission system operator RTE released Energy Pathways to 2050, a report on a comparison and study of three main scenarios for final electricity consumption in 2050 (1. Baseline, 2. Sufficiency, and 3. Extensive reindustrialization) based on the final energy consumption in 2050 projected in France's national low carbon strategy (Stratégie nationale bas-carbone, SNBC) published in 2020. According to the report, France's final electricity consumption in 2050 will at least remain the same and could (under the "Extensive reindustrialization" scenario) increase by a maximum of 32% compared to 2020. One projected power supply composition (Scenario N03) based on this latter scenario would require a minimum of 14 nuclear power plants and several SMRs to be newly installed by 2050. According to estimates, the total capacity would reach just over 25 GW.

In February 2022, President Macron stated the intention, as per Scenario N03, to build six new EPR2 reactors – improved versions of the European Pressurized Reactors (EPRs) developed by France – by 2050. France is also considering building eight additional reactors and installing multiple SMRs (Figure 5).

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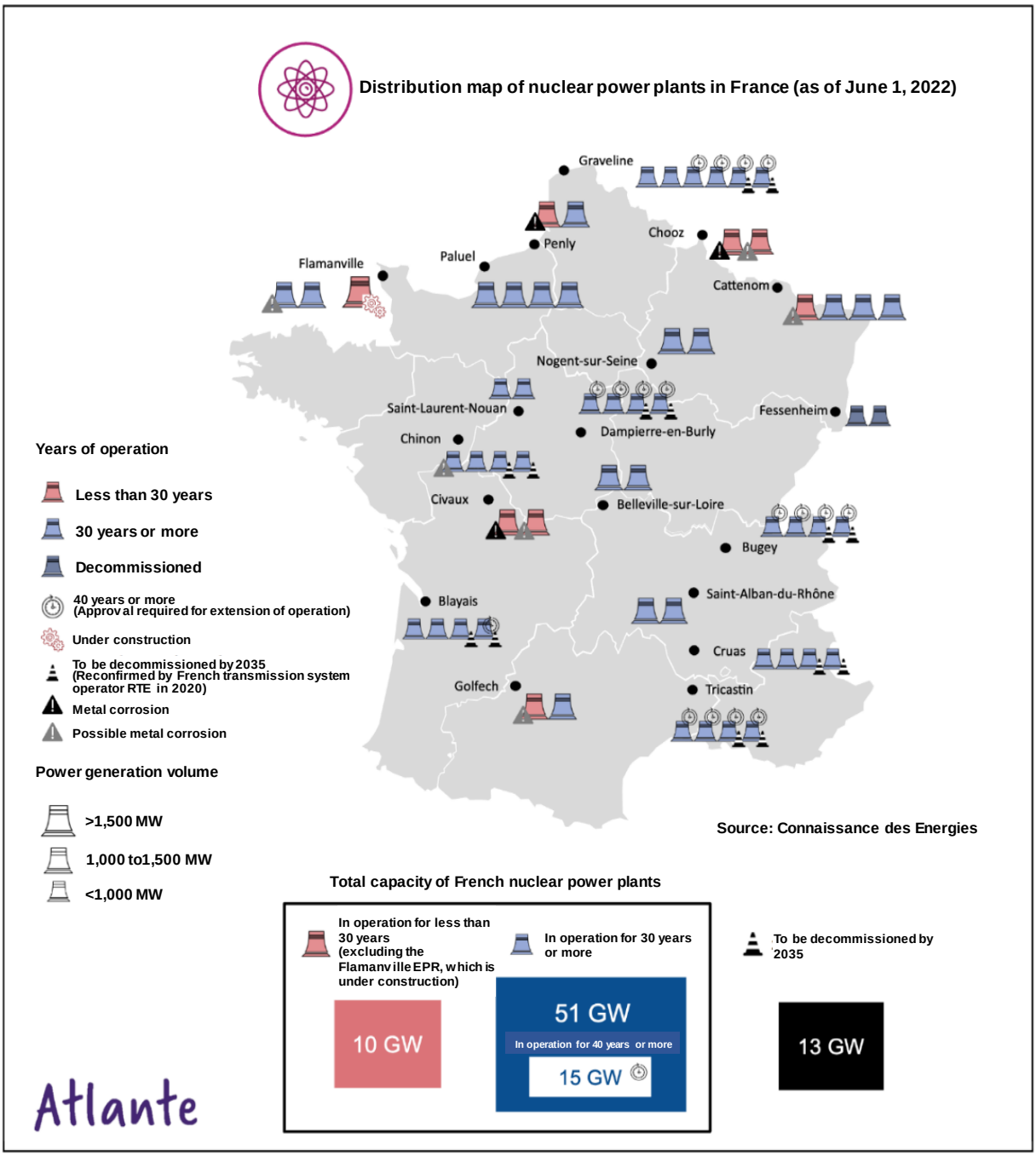
[6] President of the then-Provisional Government of France, and appointed as the first president of the Fifth Republic in 1959.

[7] In the strategic review of national defense and national security, President Macron emphasized that for France to maintain its international influence, it is essential for the country, which adheres to a nuclear strategy, to take the lead in strengthening the EU's defensive capabilities and promoting energy independence. Against this background, France has requested Germany to revise its policy of phasing out nuclear energy and its reliance on Russian natural gas, and has continued to call for increased usage of nuclear power to achieve the goal of virtually zero greenhouse gas emissions by 2050.

[8] France is currently experiencing a series of nuclear power plant shutdowns due to repairs and other reasons, and neighboring Germany, which has a close trading relationship with France under the EU's Single Electricity Market system responsible for coordinating EU demand for electricity, is also facing a threat to its stable access to French-produced electricity.

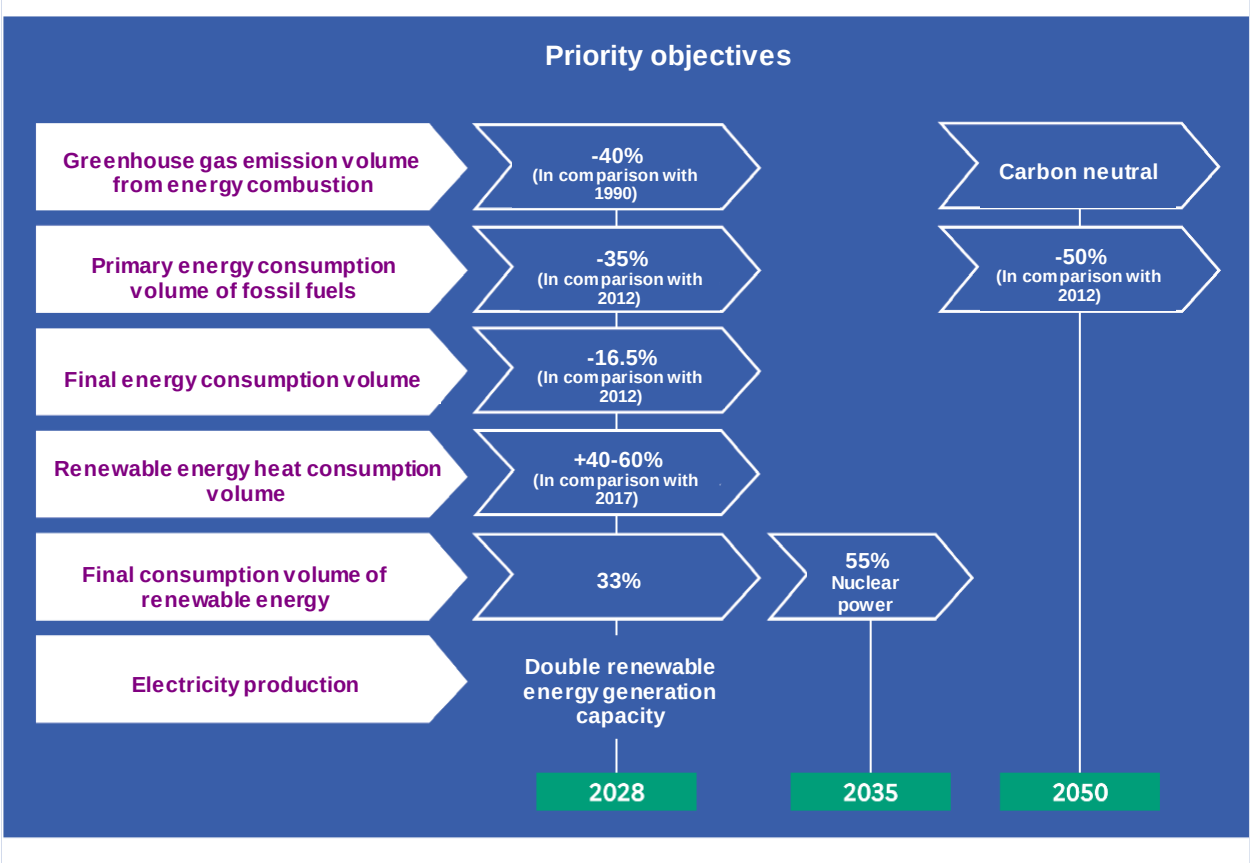
[9] Promoting nuclear power generation will create many employment opportunities, raising expectations for reindustrialization. There are an estimated 400,000 nuclear power-related jobs in France, including those in peripheral industries, and the French government will seek solutions by strengthening its nuclear power industry. Providing no serious accidents or scandals occur, public opinion in France will likely continue supporting the government's strategy of promoting nuclear power.

Figure 3. Locations of France's 56 nuclear power plants



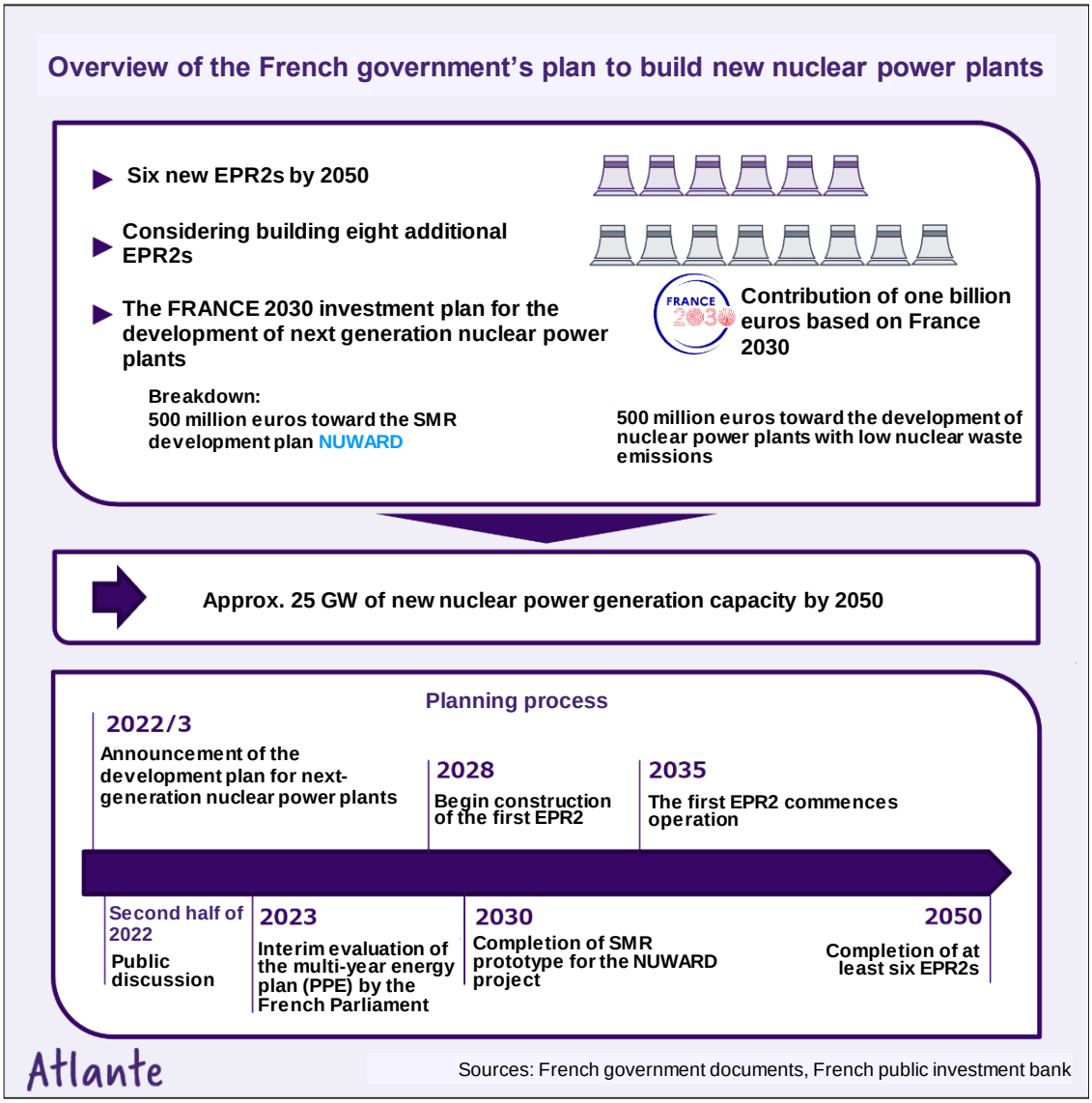
Source: Atlante website
www.atlante.fr/nucleaire-entre-ravalement-et-renouvellement-tout-reste-a-construire/
(accessed March 10, 2023, translated by MGSSI)

Figure 4. Overview of the French multi-year energy plan (PPE, 2019-2028)



Source: Ministry of Ecological Transition (France) «La France accélère sa transition énergétique, PROGRAMMATION PLURIANNUELLE DE L'ÉNERGIE »
https://www.ecologie.gouv.fr/sites/default/files/PPE_2020_en%204%20pages.pdf
（accessed March 10, 2023, translated by MGSSI）

Figure 5. French government's plan to build new nuclear power plants by 2050



Source: Atlante website
www.atlante.fr/nucleaire-entre-ravalement-et-renouvellement-tout-reste-a-construire/
(accessed March 10, 2023, translated by MGSSI)

3 FRANCE ALSO FOCUSED ON MARKETING NUCLEAR POWER PLANTS ABROAD

3.1 The intention behind the nuclear power plant export offensive

In addition to constructing new nuclear power plants domestically, the French government also hopes to export nuclear power plants to other countries. According to International Energy Agency (IEA) projections, the volume of nuclear power generation within electricity production worldwide is expected to double by 2050 (Figure 6), and the government is considering commercial opportunities in central Europe, especially in Poland, which shuns Russian products. Moreover, as a part of the EU's Ukraine reconstruction strategy, there are also plans to increase the number of nuclear power plants in Ukraine and to produce hydrogen using nuclear power.

To date, France has successfully exported nine nuclear power plants (six to China, two to South Korea, and one to Finland).

Figure 6. World power generation volume outlook

	Amount of electricity generated (KWh)					Share (%)			Average annual growth rate (%)	
	2019	2020	2030	2040	2050	2020	2030	2050	2022-2030	2022-2050
Total electricity generated	**26,922**	**26,778**	**37,316**	**56,553**	**71,164**	**100**	**100**	**100**	**3.4**	**3.3**
Renewable energy	**7,153**	**7,660**	**22,817**	**47,521**	**62,333**	**29**	**61**	**88**	**12**	**7.2**
Solar power	665	821	6,970	17,031	23,469	3	19	33	24	12
Wind power	1,423	1,592	8,008	18,787	24,785	6	21	35	18	9.6
Hydroelectric	4,294	4,418	5,870	7,445	8,461	17	16	12	2.9	2.2
Biomass	665	718	1,407	2,676	3,279	3	4	5	7.0	5.2
CO2 collection and storage	-	-	129	673	842	-	0	1	n.a.	n.a.
Concentrated solar power	14	14	204	880	1,386	0	1	2	31	17.0
Geothermal	92	94	330	625	821	0	1	1	13	7.5
Tidal current / wave power	1	2	27	77	132	0	0	0	28	14
Nuclear power	**2,792**	**2,698**	**3,777**	**4,855**	**5,497**	**10**	**10**	**8**	**3.4**	**2.4**
Hydrogen	**-**	**-**	**875**	**1,857**	**1,713**	**-**	**2**	**2**	**n.a.**	**n.a.**
Fossil fuel (CO2 collection and storage)	**1**	**4**	**459**	**1,659**	**1,332**	**0**	**1**	**2**	**61**	**21**
Coal	1	4	289	966	663	0	1	1	54	19
Natural gas	-	-	170	694	669	-	0	1	n.a.	n.a.
Fossil fuel (without CO2 reduction measures)	**16,941**	**16,382**	**9,358**	**632**	**259**	**61**	**25**	**0**	**-5.4**	**-13.0**
Coal	9,832	9,426	2,947	0	0	35	8	0	-11	-40
Natural gas	6,314	6,200	6,222	626	253	23	17	0	0.0	-10
Petroleum	795	756	189	6	6	3	1	0	-13	-15

Source: IEA, "Net Zero by 2050. A Roadmap for the Global Energy Sector"（2021/10）
https://iea.blob.core.windows.net/assets/deebef5d-0c34-4539-9d0c-10b13d840027/NetZeroby2050-ARoadmapfortheGlobalEnergySector_CORR.pdf
(accessed March 10, 2023)

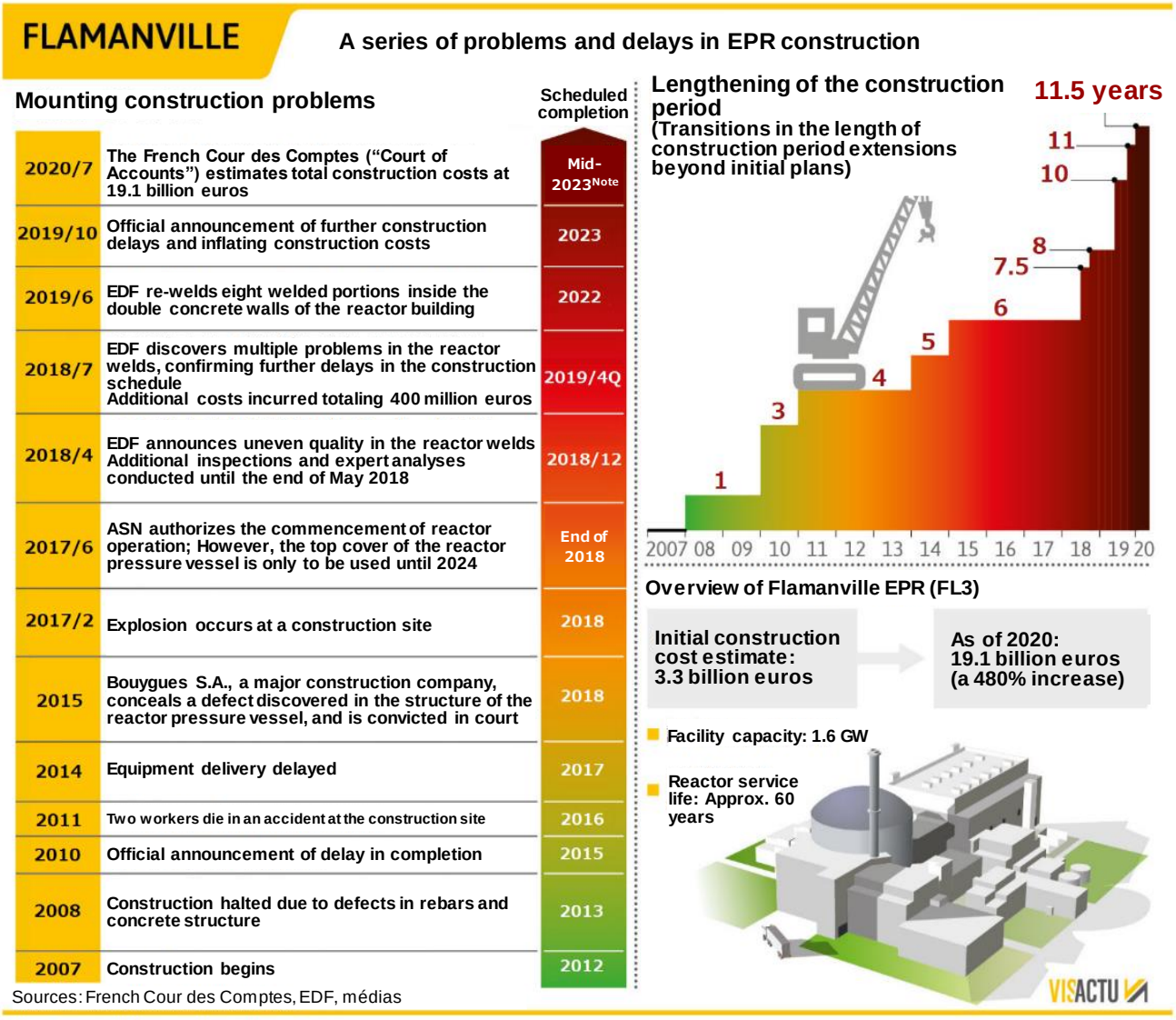
3.2 Existing EPR construction issues hindering progress

EPR construction (FL3), which began in 2007 in Flamanville in northwestern France, has been attracting widespread attention as a model case for further advancements in EPR technology. However, the construction period is expected to be extended from the original plan of five years to 17 years, and construction costs continue to rise (Figure 7). The construction period for the EPR that commenced operation in Finland in 2022 had also been extended from the originally planned 4 years to roughly 17 years, due to component supply delays and other factors, and construction costs ended up being two to three times higher than budgeted for. In the UK as well, there are growing concerns that the total construction cost of Sizewell C (two EPRs, each with an output of 1.6 GW), a new nuclear power station project scheduled to launch in 2024, will rise far beyond the initial 20 billion pounds. In its Energy Security Strategy released in 2022, the UK government stated its intention to build up to eight new nuclear power plants by 2030, but the various problems that arise during construction have cast a major shadow over France's chances of receiving additional orders.

The EPR2 design, backed by the Macron administration, inherits the EPR's basic concept,[10] with the added selling points of further improving safety, and reducing construction costs by 30%. This design is expected to restore confidence in EPR technology and help the EPR export business recover from its current unfavorable position.

[10] Power output of 1.6 GW, reactor service life of approx. 60 years, maximum operation cycle of 24 months.

Figure 7. Construction problems at the Flamanville EPR



Note: The reactor welding schedule was further delayed, particularly by the COVID-19 pandemic, which restricted workers' movements, and in December 2022, EDF postponed completion to the first quarter of 2024. (Author's addendum)

Source: Les Dernières Nouvelles d'Alsace
www.dna.fr/economie/2020/07/09/epr-de-flamanville-la-cour-des-comptes-appelle-a-la-vigilance
(accessed March 10, 2023, translated by MGSSI)

3.3 Ambitious SMR development

The French government also aims to develop SMR sales channels by promoting NUWARD (NUclear forWARD), the country's first commercial SMR development project. Based on more than 50 years' experience operating pressurized light water reactors (PWR) in France, NUWARD is developing an SMR with a power output of 34 MW (by combining two smaller-scale PWRs, each with a power output of 17 MW).[11] Construction of the NUWARD demonstration plant is scheduled to commence in 2030, with supply to the world market beginning sometime during the 2030s.

[11] Led by CEA, EDF, Naval Group, a defense company under government jurisdiction, and TechnicAtome, a company specializing in SMRs.

According to Polaris Market Research, a US-based research and consulting firm, the global SMR market in 2030 is projected to expand to $13 billion, a 37% increase over 2021, mainly in Asia, and development is expected to heat up around the world. Russia and China have already succeeded in commercializing SMRs. Meanwhile, France, which plans to introduce SMRs in the early 2030s (Figure 8), is being left behind by the world's major SMR developers, and the country's competitiveness for orders will be put to the test.

Figure 8. Major SMR development plans around the world

Country	Reactor name	Power generation volume (MW)	Design developer	Scheduled period of installation
Russia	KLT-40S (Floating type)	35×2	OKBM Afrikantov	2019 (Operation started in 2020)
	BREST-300	300	N.A. Dollezhal Scientific Research and Design Institute of Energy Technologies (NIKIET)	Mid-2020s
	RITM-200M	55×2	OKBM Afrikantov	Late 2020s
	VBER-300 (Floating type)	295	OKBM Afrikantov	Late 2020s
China	HTR-PM	210	Tsinghua University	Early 2020s (Operation started in 2022)
	ACPR-50S (Floating type)	60	China Guangdong Nuclear Power Group (CGN)	Mid-2020s
	ACP100 / Linglong One	125	China National Nuclear Corporation (CNNC)	Mid-2020s
Argentina	CAREM	30	National Atomic Energy Commission (CNEA) of Argentina	Early 2020s
UK	UK-SMR	470 Note	Rolls-Royce	Mid-2020s
US	NuScale	77×6	NuScale Power	Late 2020s
	SMR-160	160	Holtec International	Late 2020s - Early 2030s
	BWRX-300	300	GE Hitachi Nuclear Energy	2030s
Canada	IMSR	195	Terrestrial Energy	Late 2020s
South Korea	SMART	107	Korea Atomic Energy Research Institute (KAERI), King Abdullah City for Atomic and Renewable Energy (K.A.CARE)	Late 2020s
Japan	4S	10/50	Toshiba Energy Systems & Solutions Corporation	Late 2020s - Early 2030s
France	NUWARD	170×2	CEA, EDF, Naval Group, TechnicAtome	Early 2030s

Note: Although the IAEA defines an SMR as having an output of 300 MW or lower, the UK government and Rolls-Royce classify the UK-SMR as an SMR.
Source: Compiled by MGSSI based on IAEA material "Small Modular Reactors: A new nuclear energy paradigm"（Pre-print, Sepember 2022）, Marco Baroni, «Énergie nucléaire: la nouvelle donne internationale», La Fondation pour l'innovation politique（February 2021）and media reports

4 FUTURE OUTLOOK

The nuclear renaissance plan announced by President Macron in 2022 is based on the premise that 50% of the country's electricity in 2050 will be supplied by nuclear power generation and the other 50% by renewable energy sources, which will optimize economic efficiency. President Macron will likely go on the offensive in actively promoting the development and export of nuclear power plants, leveraging nuclear power generation's receipt of green certification under the EU taxonomy in January.

According to Thierry Breton, European Commissioner for the Internal Market, the EU needs to invest 500 billion euros in the development and construction of next-generation nuclear power plants by 2050 to meet its electricity needs and achieve its goal of virtually zero greenhouse gas emissions. The EU, on its own, will create enormous commercial opportunities for the nuclear power industry.

France may well focus on exporting EPRs and EPR2s in the nuclear power plant market, which is becoming increasingly robust in Europe, particularly among Central European countries. Competition with US and South Korean companies for orders is seen to be intensifying due to a growing trend of avoiding Russian-manufactured nuclear power plants. Amid this, France's competitiveness may be hindered by such issues as increased construction costs due to delays in building schedules of EPRs currently being made. At the same time, the country is likely to develop an export strategy for SMRs, eyeing the entire global market, which is expanding.

In addition, with active backing from France, there is growing momentum in the EU to recognize hydrogen derived from nuclear power plants, which is not a form of renewable energy, as green hydrogen, to accelerate the transition from the existing fossil fuel-reliant economy to one based on renewable energy. It is believed France will take the lead, for example, in producing nuclear-derived green hydrogen in Ukraine for export to the EU as part of the latter's reconstruction plan.