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Lessons From France's Nuclear Program

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France has embarked on an ambitious program to build at least six new large nuclear reactors, applying lessons from recent overruns and delays. While success is far from guaranteed, there are important lessons for the United States as it seeks to jump-start its own nuclear sector through recent ambitious executive orders.

KEY TAKEAWAYS

- A U.S. nuclear strategy must have strong bipartisan support. Nuclear designs often take decades, and private investors need certainty. We cannot afford to change the strategy with every new administration.
- The United States cannot and should not replicate France's highly centralized government structure and dependence on EDF as a single national champion for energy. It must find alternative solutions to the functional problems this model addresses.
- Existing fragmented government structures—both inside and beyond DOE—must be systematically reorganized into a coherent and consistent whole that is able to demand (and provide) full accountability and oversight.
- A large order book is the key to cost reduction—but will be hard to build in the United States, where other sources of energy are highly competitive, there is no national security reason to build nuclear (unlike in France), and markets are fragmented.
- France is highly focused on large reactors, but that is a historical legacy, not a well-grounded strategy. U.S. advantages in SMRs could offer a much better alternative.
- Construction support can be provided through federal loans at cost, but further de-risking is needed to encourage private investment in extremely long-range and high-risk projects.
- The U.S. model of providing tax credits as effectively indefinite operating subsidies is flawed. There are better alternatives that connect energy sources to the market more effectively, such as contracts for difference.

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INTRODUCTION

The Trump administration has moved quickly to supercharge development in the U.S. nuclear sector. The White House issued series of executive orders this spring seeking to accelerate reactor licensing and testing, amp up domestic nuclear fuel production, and add 300 gigawatts of new nuclear capacity by 2050, among other short- and long-term goals.[1] The orders are part of the administration's effort to ensure an abundant, reliable, and affordable energy supply that can meet increasing demands from AI and the broader U.S. economy. Against this backdrop, takeaways from France's long experience in the nuclear sector will be invaluable, particularly as France is three years into an equally ambitious nuclear expansion of its own: the Evolutionary Power Reactor 2 (EPR2) program. President Macron's pivotal speech at Belfort on February 10, 2022, called for the construction of six new 1.6 gigawatt (GW) reactors by 2035, with an option for eight more units. Additional initiatives covered the supply chain, waste disposal, and small modular reactors (SMRs).[2]

Macron's speech addressed four strategic problems: rising energy costs, climate concerns, the replacement of French nuclear plants built in the 1980s, and the need for more energy as France electrifies and data centers proliferate. The war in the Ukraine had also begun only weeks before the speech, and Europe was understandably panicked about its overreliance on natural gas from Russia. Nuclear was framed as essential for European strategic autonomy, a way to reduce dependence on volatile fossil fuel markets and potentially hostile suppliers. That's why Macron could successfully overcome German and Belgian opposition, pushing the European Commission to reclassify nuclear power as "green" under EU rules, opening the door to new financing mechanisms. In addition, Macron hoped that EPR2 would allow Électricité de France (EDF) to offer cheap energy to French industrial companies suffering from high energy costs.[3]

But EPR2 is not just more reactors; it's an effort to learn from previous failures and to develop an industry that can deliver large reactors on time and on budget, using more buildable nuclear designs, better project management, and improved oversight. EPR2 is partly a reaction to the previous Flamanville 3 project, which began in 2007 but ballooned from an original estimate of €3.3 billion to €23.7 billion, along with a 12-year delay. Flamanville 3 is still not fully operational.[4]

Macron's nuclear plans have prevailed (so far) despite significant domestic opposition. Environmental groups and left-wing parties have argued, wrongly, that nuclear expansion is a costly distraction from renewable energy development, and some are still fundamentally antinuclear. Following Macron's 2022 re-election, the French political landscape has been very unstable. Parliamentary elections in July 2024 led to a hung parliament, and a succession of weak governments. Yet, the political turmoil has not significantly affected nuclear policy, even though the third Multiannual Energy Programming (PPE3) was recently rejected by the French parliament; Macron intends to implement it via decree.[5]

To understand EPR2 and its possible lessons for the United States, we must start with the past—specifically, with the Flamanville 3 reactor. Much of EPR2 is an explicit effort to learn the right lessons, and to avoid making the same mistakes.

Key lessons include the following:

- The United States needs to build the capacity to develop, implement, monitor, and adjust a long-term strategic plan for nuclear. That capacity is currently absent.
- Focusing on buildability and reducing costs through scaleup is critically important, but it also risks blocking better designs that could emerge later.
- A large order book is necessary for success. It is unclear whether a sufficient order book can be developed for large reactors, especially in the United States.
- Developing and then sustaining a skilled workforce is necessary. Without it, costs will not fall even with a substantial order book.
- The nuclear sector will need a lot of government support at various stages of the development cycle. But support will not be effective if policies are partisan. Development simply takes too long.

FLAMANVILLE 3: A FINANCIAL AND POLICY DISASTER

The new EPR nuclear reactor at Flamanville (“Flamanville 3”) was the evolutionary descendant of the Framatome N4 and Siemens “Konvoi” reactors, aiming to merge the best of the two designs. It received French design approval in 2004, and construction began in 2007 with a budget of €3.3 billion and a construction timeline of 54 months.

After 17 years of construction, Flamanville 3 finally achieved grid connection in December 2024. It was among the most spectacular infrastructure failures in modern European history. Construction ultimately cost between €13.2 billion (according to EDF) and €23.7 billion (according to the French Court of Auditors). Notably, Flamanville 3 does not now expect to be operating at full power until the winter 2025 and will then be out of service for refueling for some months in 2026.[6]

What drove this disaster? French analysis points to a toxic combination of technical hubris, organizational dysfunction, and the erosion of industrial expertise.

The Prototype Penalty

The EPR was France’s most ambitious nuclear design, incorporating enhanced safety features and digital control systems far more complex than previous reactor generations. It contained thousands of specialized parts and many special welds, while the project also exposed gaps in manufacturing capabilities and quality control processes. Digital instrumentation and control systems required extensive validation, while the reactor pressure vessel demanded precision manufacturing capabilities that strained even established suppliers. Japan Steel Works, for example, operated the only forge capable of processing the EPR’s large vessel components, creating supply chain vulnerabilities that contributed to delays.[7]

A New Workforce

Like other large reactors, the construction of Flamanville 3 required a trained workforce. But that workforce had dissolved in the years since the previous reactor (Civaux-2) was completed in 1999. This generational discontinuity meant that engineers and technicians lacked recent experience with the highly technical demands of large-scale nuclear construction.

Construction Failures

By 2015, the French Nuclear Safety Authority (ASN) had identified serious defects in the reactor vessel, including abnormal steel composition in components manufactured at Areva's Le Creusot facility. The reactor pressure vessel head and bottom had carbon heterogeneity problems that reduced the steel's mechanical toughness to one-third below specifications. Even more damaging were the extensive welding defects throughout the plant. EDF discovered that 33 of 148 inspected welds in the main secondary system required repairs, while an additional 20 welds had to be redone preventively despite showing no visible defects. ASN ultimately required an additional eight critical welds in steam transfer pipes to be repaired before commissioning, rejecting EDF's request to postpone repairs until after start-up. The reactor's containment structure also suffered from cracking in the concrete dome, discovered during testing in 2014, while quality problems plagued the plant's instrumentation and control systems. These systemic failures reflected the EPR's unprecedented complexity, as well as its first-of-a-kind design.[8]

Perhaps most damaging was the decision to begin construction on several elements before design completion, requiring sections to be demolished and rebuilt. The project ultimately required over 7,000 design changes, each adding cost and delay, and some requiring that work be halted all together.[9]

Organizational Chaos

The project also suffered from poor coordination between key stakeholders and from lack of clear lines of authority in both the private sector and on the government side. The Cour des Comptes (Court of Auditors) noted insufficient oversight and coordination among project participants, including EDF and regulatory authorities. Organizational dysfunction was compounded by rivalry between EDF and construction manager Areva and by a bitter fight about who should pay for mounting cost overruns, a conflict that French authorities failed to arbitrate effectively. Areva—which until it went bust in 2018 was majority owned by the French state—was in charge of construction, but its failures at Flamanville 3 and at the Olkiluoto 3 plant in Finland led to insolvency and its eventual sale to EDF. And while there is little documentation (perhaps not surprisingly), it appears that the French government had insufficient capacity to exercise effective oversight.[10]

Financial Catastrophe and Future Implications

Flamanville 3 was substantially subsidized by France. It received cheap loans covering ~50 percent of the construction cost for the project. The remainder was financed by EDF through a mix of debt and equity. The Cour des Comptes now estimates Flamanville 3's total cost at €23.7 billion, including financing costs and first-cycle operations. It predicts "mediocre profitability" for the reactor, with returns below 2 percent—insufficient to cover EDF's cost of capital. Financing pressure caused by Flamanville 3 surely also drove the 2022 decision to take EDF fully into state ownership, at least in part.[11]

EPR2: FASTER AND CHEAPER?

Designed to address the many failings at Flamanville 3, EDF expects to pour first concrete for the EPR2 reactors at Penly (on the Normandy coast) in 2028, with commercial operation beginning in 2038 (three years later than originally announced). Subsequent twin reactor pairs are expected to follow at Gravelines and Bugey, on an approximately 18-month schedule, thus extending the construction program into the 2040s. But despite its length, this is a very ambitious timeline, especially for Gravelines and Bugey.[12]

EDF hopes that the accelerated timeline will be feasible, given the multiple efforts to apply lessons learned from Flamanville 3, including the following:

- **Improved design,** which is both simplified and much more easily buildable
- **Workforce development** built on the commitment to a fleet of new reactors
- **Public and private sector reorganization** to provide clear lines of authority up to and including President Macron himself, and putting EDF firmly in charge on the industry side
- **Financing support** that de-risks both construction and operations
- **Life-cycle support** for both the nuclear supply chain and nuclear waste
- **Site selection limited to existing plants** to avoid regulatory delays

Notably, while there have been important regulatory reforms, regulatory problems were not seen as a primary driver of Flamanville 3's problems, and reform has not been the priority that it has become in the United States.

Simplified Design

EPR2 has significantly changed the underlying design philosophy to prioritize buildability over redundancy, and hence to simplify major reactor systems. Indeed, simplification has been a goal across the entire design. According to EDF, the EPR2 design has reduced piping components from 437 to 256 types and door references from 294 to 89 types along with simplified compartmentalization for concrete construction.[13]

One central change has been to eliminate the fourth emergency cooling system. Its removal cuts construction time and cost, but means that maintenance can only occur during plant shutdowns. Similarly, the original EPR featured a double-layered concrete containment building with a liner, designed to provide multiple barriers against radioactive release. EPR2 abandons this redundancy for single-layer containment, trading an additional layer of safety for lower costs.

The EPR2 design also aims to fundamentally change construction methodology, emphasizing prefabricated elements that can be manufactured in controlled factory environments before site assembly. Electrical buildings can, for example, be completely prefabricated, while the design anticipates structural modules weighing up to 1,000 tonnes that can be assembled off-site, transported mainly by water, and lifted into place. The hope is that enough components can be factory built to drive down costs. Overall, EDF claims that EPR2's simplified design could reduce construction costs by approximately 30 percent compared with the original EPR. It is also expected to reduce fuel use and cut waste.[14]

EDF is still negotiating with the Autorité de sûreté nucléaire et de radioprotection (ASNR), the French safety regulator. A 2019 safety opinion, while broadly positive, identified critical areas requiring further examination before any construction authorization, including EPR2's "break exclusion approach," which assumes that primary and secondary cooling circuit piping would not fail catastrophically. The new design philosophy depends heavily on the reliability of primary components.[15]

These concerns led to a September 2021 ASN position statement requiring EDF to modify its break exclusion approach, adding separating walls, whip-restraint devices, and steam evacuation vents as mitigation measures. As a result, ASN has also demanded additional safety demonstrations, and has raised concerns about the reactor's approach to handling hazards, particularly fire and explosion risks. It remains unclear how much additional cost and time these measures will require.[16]

More broadly, independent review committees have identified significant concerns about EPR2's design maturity. For example, while power island design was sufficiently mature for detailed engineering by July 2024, nuclear island designs were not, which necessitated construction delays.[17]

These design challenges reflect the inherent tension between accelerated construction schedules and the extensive engineering requirements for nuclear systems—and especially new or highly modified designs. The need to incorporate lessons from additional EPR reactors in China and Finland has added complexity to an already challenging design optimization process. Given that both Flamanville 3 and Vogtle (in the United States) suffered badly from incomplete designs at the start of construction, there are clearly red flags above the horizon here.

New Financial Structure

Costs

Despite promises of improved economics, the EPR2 program faces some familiar financial challenges. In 2022, EDF estimated that six EPR2 reactors would cost €46 billion, but the Cour des Comptes's central estimate for the first six EPR2s is €67.4 billion (in 2020 euros), with an indicative levelized cost of electricity (LCOE) of ~€92.9/megawatt hours (MWh) (in 2023 euros) at 4 percent weighted average cost of capital (WACC); all figures carry wide uncertainty ranges.[18]

EDF breaks out estimated costs into four elements: [19]

- **EPR2 series development:** €8.7 billion (compared with €3.8 billion in the 2022 estimate)
- **Penly site (first pair):** €23.6 billion (compared with €16.9 billion in 2022)
- **Gravelines site:** €18.1 billion (compared with €15.8 billion in 2022)
- **Bugey site:** €16.9 billion (compared with €15.3 billion in 2022)

These costs are still preliminary. As the Cour des Comptes observes, the EPR2 design was not finalized at the time these estimates were published in 2023, and in fact still has not been finalized. No final financing plan has been established either, and EDF has not provided profitability projections.[20]

Based on these estimates, EDF expects the cost of construction to decline from about €8,000/kilowatts (kW) for Penly to about €5,870 for Bugey. Gravelines is expected to be 23 percent cheaper to build than Penly, and Bugey is 6 percent cheaper still. These cost reductions are premised on learning curve efficiencies, as a key idea behind EPR2 is that the design must be fixed at the start of the series and only minimal modifications permitted thereafter. In essence, Penly is being treated as a first-of-a-kind reactor. Those estimates are aggressive, but not enormously so, as they approximately match the 2025 projections in the National Renewable Energy Laboratory (NREL) Annual Technology Baseline for large nuclear reactors. However, they are substantially lower than previous EDF reactors, and lower than the cost for any recent new large reactors (outside China, South Korea, and the UAE).[21]

Bluntly, it is not currently possible to project the actual cost of the first six ERP2 reactors with any confidence. We will know more when final estimates are provided in December, but even those estimates will be subject to enormous pressures from the government and EDF, both of which would benefit from lowballing the final cost, especially as lowballed estimates will likely only become a practical problem after years of construction.

Markets and Financing

The economic environment for energy has changed dramatically since the era in which France's initial nuclear fleet was constructed. At that time, electricity prices were set by regulators, and customers were forced to meet EDF's financing needs. Today, markets dominate the distribution of electricity, so stable long-term revenues are hard to find. Hence, EDF cannot finance EPR2 construction independently, and will require government support. EU rules limit direct subsidies, but the EU has recently approved support for the Dukovany project in the Czech Republic (see Dukovany Box). Accordingly, financing for ERP2 has been designed to closely reflect the Dukovany model.

- **Government Subsidized Construction Loans.** The French state will provide preferential loans covering at least half of construction costs. These loans will likely be offered at 0 percent interest during construction, with rates then pegged to 1 percentage point over French government borrowing costs and a minimum of 2 percent once plant operations begin. Repayment will be due over 30 years.[22]
- **Contracts for Difference for operations (CfDs).** Using a CfD, France will guarantee EDF a price of €100/MWh for electricity from ERP2 (in 2024 euros), for the first 40 years of operation. This is known as the "strike price." The government will pay EDF the difference between the market price and €100/MWh. If the market price is higher than €100/MWh, the surplus will be returned to the government. This CfD provides revenue certainty for EDF, while in theory protecting consumers from excessive electricity costs and possibly even returning the equivalent of a dividend.[23]

French wholesale electricity prices have been relatively stable for the past 10 years, at about €55-65/MWh (except for the sharp spike in 2022–2023 following the Russian invasion of Ukraine). On the face of it, this suggests a gap of ~€40/MWh between current market prices and the strike price, which would be covered by ongoing subsidies from the French treasury.[24]

However, electricity taxes are high in France, and the additional electricity generated by the new reactors should generate new tax revenues that could be used to fund the CfD subsidy for EDF. As of August 2025, the French government collects an excise tax (formerly TICFE, now accise sur l'électricité - ASE) of €29.98/MWh, and a VAT of 20 percent, which is applied to the final price paid by the consumer, after TURPE fees (which include transmission and distribution costs and fees, plus profit margins) and the ASE.[25]

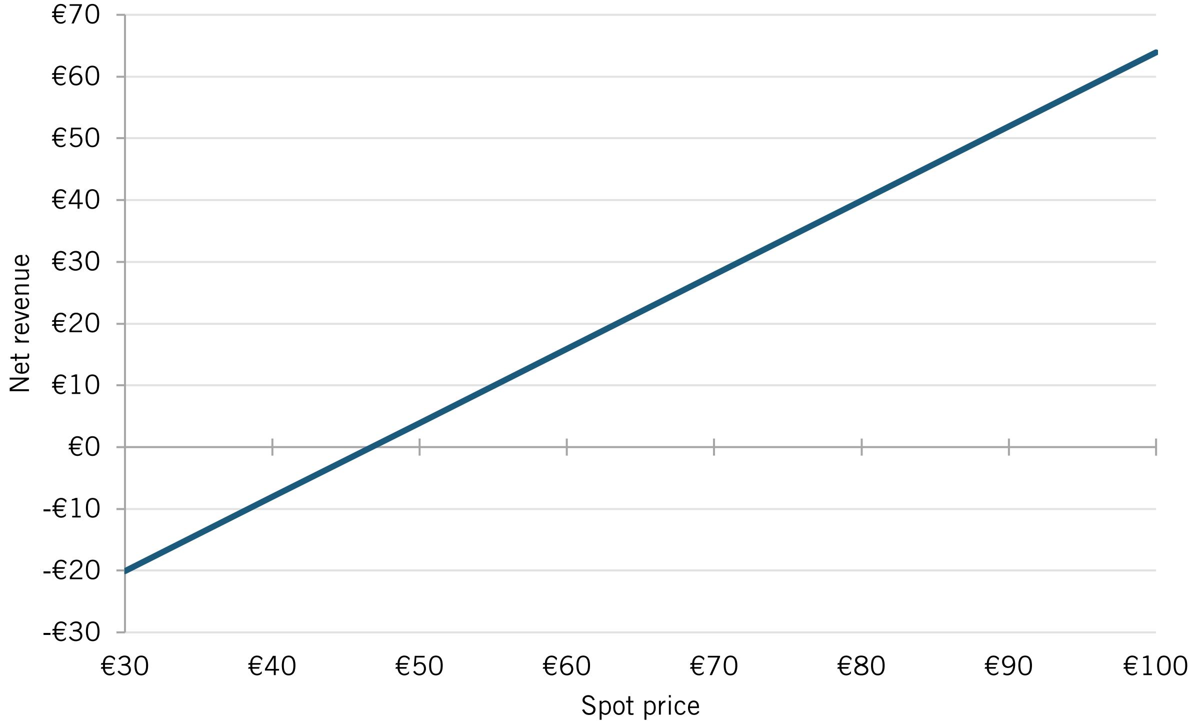
Table 1 shows how this works. Essentially, the excise tax and the VAT together generate enough revenue to fund the subsidy. At a wholesale price of €63/MWh, those taxes even generate a return to the French Treasury of around €26.20/MWh.

Table 1: Taxes from electricity in France, August 2025 (at €63/MWh)[26]

Consumer Costs and Government Revenues	Euros/MWh
Consumer costs	
Wholesale price	€63.00
TURPE costs and fees	€73.00
Excise taxes	€30.00
Pre-VAT total	€166.00
VAT (20%)	€33.20
Total consumer price	**€199.20**
Government revenues	
Total government tax revenue (Excise taxes + VAT)	€63.20
Subsidy to EDF (€100 minus current wholesale price)	€37.00
Net tax revenue for government use	**€26.20**

The actual return varies with the wholesale price. The lower the price, the smaller the return to government will be. At a low enough price—below about €45/MWh—that return turns negative. Figure 1 shows how the wholesale spot price affects both the subsidy and the distribution of tax revenues. Effectively, France is using future taxes on new energy to largely de-risk the project for EDF.

Figure 1: Spot prices and net government revenues per megawatt hour[27]



France may also anticipate that the price of energy will rise over the long term, which would narrow the gap or possibly turn a substantial profit for the government. Although, technological progress such as cheap enhanced geothermal energy could upend those projections.

Dukovany Financing Arrangements

The European Commission approved arrangements in 2024 for ČEZ (the owner and operator) to receive a loan from the Czech state of up to €7.74 billion for construction of the first of two new 1 GW units. This represents a fundamental shift from traditional project financing, placing the Czech state directly at the center of nuclear development funding.[28]

Construction: The plant will be built by Korea Hydro & Nuclear Power (KHNP), which won the contract in July 2024 with a bid of approximately $18.6 billion for two 1 GW reactors.[29]

The state will provide loans at 0 percent interest during the construction phase, transitioning to 1 percent above the state's borrowing rate—with a minimum 2 percent floor—once operations begin. Repayment extends over 30 years and is due once the plant starts operating (expected in 2036).

Operating support is provided through a power purchasing contract and CfD. The Czech Republic will grant direct price support through a power purchasing contract with Elektrárna Dukovany II (EDU II), a fully owned subsidiary of the ČEZ Group that itself is majority state owned, and the only nuclear power plant operator in the country. This contract will guarantee stable revenues for 40 years.

A sophisticated bilateral CfD mechanism then functions as a two-way compensation system. If wholesale electricity prices fall below the agreed strike price of ~€90/MWh, the state will make up the difference. Conversely, if market prices exceed the strike price, the operator must return surplus profits to the state.

The Czech Republic has committed to selling at least 70 percent of the plant's electricity output on open power exchanges—including day-ahead, intraday, and futures markets—throughout the facility's operational lifetime That will encourage market competition while maintaining revenue stability for the project, and was a requirement for EU approval.[30]

Workforce

The Flamanville 3 disaster occurred in part because France suffered a substantial loss of expertise during the period after completion of the Citreux-2 reactor in 1999. Nuclear reactor construction is among the most demanding industrial undertakings in modern engineering, requiring an exceptionally specialized workforce with skills that extend far beyond conventional construction projects. Building a large light-water reactor employs an average of 7,000 workers at peak construction, but the technical complexity and safety requirements demand personnel with highly specific qualifications and extensive training. As "learning by doing" is a key factor in long-term cost reduction, it is therefore critically important to retain the workforce by building a series of reactors rather than just one—hence the need for a consistent order book of upcoming reactors.[31]

Skilled tradespeople working on reactor construction must meet stringent certification requirements. In the United States, nuclear plant welders must possess advanced certifications, including Certified Welding Inspector (CWI) credentials from the American Welding Society, which requires a combination of education and extensive work experience. Welders must, for example, demonstrate proficiency in Manual Shielded Metal Arc Welding (SMAW), also known as stick welding, and Gas Tungsten Arc Welding (GTAW), also known as TIG welding. These are widely used techniques, but they must be performed to a high level in nuclear construction. Nuclear welding inspection technicians must both understand all nuclear industry quality control requirements for welding and be able to complete all three stages of weld inspection. These roles require a minimum of five years of relevant experience as a quality inspector, along with knowledge of non-destructive testing (NDT) techniques, specifically liquid penetrant inspection (LPI), magnetic particle inspection (MPI), radiographic (RT), and ultrasonic (UT) testing.[32,33,34]

Nuclear construction also demands professionals across multiple disciplines, involving boilermakers, carpenters, scaffolders, electricians, insulators, ironworkers, laborers, millwrights, and many more. Each trade may require nuclear-specific qualifications and adherence to unique nuclear safety protocols.

Reactors also need highly trained operators. After all, the International Atomic Energy Agency (IAEA) claims that 80 percent of "significant events" in nuclear power plants result from human error. Many positions require a college degree or equivalent, often in addition to various certificates of qualification. The operations workforce also receives extensive pre- and post-deployment training. Written and oral exams are ongoing, sometimes once a week; and in some companies, technicians are dismissed from their job for failing to pass just a single training exam. The selection process itself is rigorous and entails intensive screening, including identity checks, FBI fingerprint checks, drug and alcohol tests, psychological tests, and credit checks.[3536]

In short, nuclear plant construction requires many highly skilled workers whose training in many cases takes up to four years. Industry estimates in France call for hiring 10,000 additional workers annually for 10 years. This recruitment challenge is compounded by competition from other industrial sectors and demographic changes.[37]

Organization

To address the weaknesses that infected Flamanville 3, the French government has transformed the organizational structure. In place of multiple autonomous industrial partners left to muddle through, there is a new system of management and oversight on the government side, while EDF has been given operational authority over all aspects of construction and operations.

On the government side, the Nuclear Policy Council (CPN) sits at the apex, chaired by President Macron and established as the supreme decision-making body for nuclear policy. The council's March 2025 meeting formally approved the financing framework for EPR2 while simultaneously pushing back expected operations by three years. CPN's decisions reflect complex political calculations balancing energy security, economic competitiveness, and industrial policy.[38]

The Interministerial Delegation for New Nuclear (DINN) was created in 2022 and serves as the government's project management office for nuclear expansion. Its introduction reflects a new understanding that nuclear programs require unprecedented coordination across government departments, along with tighter monitoring of costs and schedules. DINN is expected to supervise EDF's performance, facilitate supply chain development, manage relationships with the European Commission, provide overall risk management, and maintain political support as construction challenges inevitably emerge. Given that DINN only has a very limited number of staff members, its capacity seems certain to be stress tested.[39]

Actual construction and operations are the industrial backbone of the EPR2 program. EDF, fully nationalized by the French state in September 2022, is the primary project owner and operator and is also the primary offtaker of electricity from the project. Framatome is a major partner (owned by EDF (80.5 percent) and Mitsubishi Heavy Industries (19.5 percent)). RTE, the French grid manager, is also a partner.[40]

Edvance (a joint venture between EDF (80 percent) and Framatome (20 percent)) is responsible for the complete design, procurement, construction, and commissioning of nuclear islands for EPR-type reactors. The company partners with nearly 4,000 companies across France and the United Kingdom, managing not only EPR2 development but also ongoing projects at Flamanville 3, Hinkley Point C, other international projects, and potential future facilities. Some partnerships are substantial. For example, in 2023, EDF and French company Eiffage signed a €4 billion contract for the main civil engineering works at Penly, including the two EPR2 units and 69 associated civil structures. Framatome provides reactor technology and specialized manufacturing capabilities, such as reactor life cycle services, fuel fabrication, and maintenance operations. The new structure gives EDF clear responsibility for the industrial side of the entire EPR2 project, including construction, operations, and life cycle aspects. It has also created specialized companies (Edvance and Framatome) to manage different aspects of the project.[41]

EPR2 is therefore completely vertically integrated: it is co-funded by EDF and the state, EDF and its subsidiaries will manage construction and operations as well as the fuel cycle, and EDF is (as a utility) also the dominant offtaker for electricity. EDF is 100 percent owned by the French state.

Safety Regulation: ASNR

As in the United States, France has sought to unravel the tangled threads of nuclear regulation. EPR2 will be the first test for the new model.

Regulatory simplification has been under way for several years, accelerated by France's 2023 Nuclear Acceleration Act. Key provisions include separation of nuclear permits from land development approvals, streamlined environmental assessments, and shortened litigation timelines. Additional reforms in 2024 exempted nuclear projects from certain public procurement rules, allowing greater contractual flexibility for complex nuclear construction projects, as traditional regulatory frameworks proved inadequate.

Nuclear safety oversight was further streamlined on January 1, 2025, with the creation of ASNR, which merged the former ASN and the Institute for Radiological Protection and Nuclear Safety (IRSN) into a single independent administrative authority. ASNR operates through a five-member commission appointed for six-year terms, offering—at least in theory—independence from both government and industry. It is responsible for regulations, facility licensing, safety monitoring, and public information related to safety. For EPR2, ASNR reviews safety files and issues binding opinions on reactor designs before construction is authorized.[42]

Site Selection

Given the difficulties of persuading new locations to accept a large new nuclear plant, EPR2 will deploy reactors only at existing nuclear sites: Penly in Normandy (first pair), Gravelines between Dunkirk and Calais (second pair), and Bugey near Lyon (third pair). This strategy leverages existing nuclear infrastructure while distributing construction across France's industrial regions. Technical studies for potential future reactors continue at the existing Tricastin site. It seems likely that beyond existing plans, plants will be expanded rather than greenfield options sought.[43]

FRANCE'S COMPREHENSIVE NUCLEAR STRATEGY

EPR2 is only part of France's overall nuclear strategy, which includes large-scale power generation through EPR2 reactors, distributed energy through Small Modular Reactors (SMRs), and transformational fusion technology for the longer term. All three function in the context of a vertically integrated program covering the entire nuclear cycle, including upstream fuel supply and manufacturing for nuclear, through waste disposal.

This multitechnology approach seeks synergies across reactor types and fuel cycle stages. EPR2 reactors will utilize uranium and plutonium recovered through La Hague reprocessing, while SMRs can address market segments unsuitable for large reactors. Fusion research provides long-term technological options while advancing plasma physics applicable to both fission and fusion systems.

France is of course also a nuclear military power; EPR2 is notably silent on any cross-fertilization between civilian and military nuclear developments.

SMRs: The NUWARD Initiative

SMR development in France centers on the NUWARD project, a collaboration between EDF, the French Alternative Energies and Atomic Energy Commission (CEA), the Naval Group, and TechnicAtome.

Originally conceived as an innovative dual-reactor design delivering 340 megawatt electrical (MWe) through two independent 170 MWe units, the NUWARD program has undergone significant strategic revision. In late 2024, EDF abandoned the complex NUWARD design in favor of a simplified 400 MW reactor utilizing proven technologies. This strategic pivot commits France fully to existing rather than innovative nuclear technologies, even for SMRs, and likely reflects a win for EDF over possible competitors. It also contrasts sharply with the United States, where numerous companies are racing to complete designs, receive Nuclear Regulatory Commission (NRC) approval, and start building.[44]

NUWARD now expects to finalize conceptual designs by mid-2026, and then to construct at least one demonstration unit in France, targeting market deployment in the 2030s. This timeline positions SMRs as complementary to EPR2 deployment, addressing smaller electricity markets and industrial applications where large reactors prove unsuitable. It should gain some synergies from EPR2, but as a result, misses out on possible innovation. It also appears that France has little to no significant interest in smaller SMRs and microreactors, which may again reflect the dominance of "big nuclear" in the form of EDF.[45]

The government has provided initial funding of €200 million, but the initial call for proposals identified only 2–4 designs out of the 12 companies shortlisted for potential support as being viable even by 2040. Overall, it seems that SMRs are a relatively low priority in France, and that smaller SMRs and microreactors are not even part of the discussion.[46]

Fusion Research and Long-Term Nuclear Vision

France's nuclear strategy extends to fusion research that could eventually supersede conventional reactors. The country hosts both the International Thermonuclear Experimental Reactor (ITER) project and the record-setting WEST (Tungsten Environment in Steady-state Tokamak) facility.

- **WEST Tokamak.** In February 2025, France's WEST Tokamak facility achieved a world record by maintaining plasma for 22 minutes and 17 seconds, surpassing China's previous record by 25 percent.[47]
- **ITER International Collaboration.** France hosts the €20 billion ITER project in Cadarache, a collaboration among China, the European Union, India, Japan, South Korea, Russia, and the United States. ITER targets first plasma operations in 2033–2034, with full deuterium-tritium operations planned for 2039.[48]

Nuclear Fuel Cycle Management

France's nuclear strategy emphasizes a domestic supply chain to the maximum extent possible, across all technology platforms. This is in part a response to France's military needs. Because there is no uranium mined in France, uranium ore is sourced from multiple countries. That ore is then processed into fuel within France.

While France has no significant uranium or plutonium ore of its own, it seeks to control as much of the fuel cycle as possible. Orano's new conversion plants (Orano Malvési at Narbonne and the

Philippe Coste plant at Tricastin) and the enrichment plant (Georges Besse II at Tricastin) have the capacity to fully meet demand from both existing reactors and ERP2 reactors when they come online. Orano's La Hague Reprocessing Complex has processed 34,000 tonnes of spent fuel since 1976, and processes about 1,150 tonnes of spent fuel annually, recovering 96 percent of materials for reuse in new MOX (mixed oxide) fuel. [49]

This reprocessing capability will reduce the amount of uranium needed for ERP2 reactors, and minimize the volume of high-level waste, although will create plutonium, which raises national security issues in relation to the Nuclear Nonproliferation Treaty. The Nuclear Policy Council has approved the "Back End of the Future" program to modernize La Hague facilities, including construction of a new spent fuel storage pool, to be operational by 2040 in order to accommodate EPR2.[50]

The CIGEO Deep Geological Repository is France's permanent waste disposal solution. It is designed to safely contain high-level and long-lived intermediate-level waste for hundreds of thousands of years. CIGEO can accommodate approximately 83,000 cubic meters of waste from both existing reactors and EPR2, and is a critical enabling technology. CIGEO's planned operational period of over 100 years will span the entire EPR2 life cycle, providing assured waste disposal capacity for the program's duration.[51]

CONCLUSIONS: LESSONS FROM FRANCE

France has made a dramatic recommitment to nuclear, and has done so in the context of lessons learned from Flamanville 3 (and other recent financial disasters such as Vogtle), including the following:

- **Strategic positioning.** Nuclear is strategic for France in both civilian and military contexts. Unlike the United States, France has limited domestic access to other power sources: its geography is not optimal for hydro, solar, or wind, and it has no significant domestic natural gas supply. Coal is being phased out. Militarily, nuclear capabilities are a key pilar of defense doctrine.
- **Cost.** That strategic positioning means that cost is relatively less important in France. In the United States, however, large reactors must compete directly with other energy sources; perhaps a premium for reliable 24/7 energy is feasible, but €100/MWh for electricity would not be competitive, and that is the pre-construction estimate for EPR2 before the inevitable overruns. France's strategic concerns make higher prices tolerable.
- **Streamlined and hierarchical organization.** After Flamanville 3, France opted to streamline and create much more accountability. Design and construction will be led by EDF, which is now also a majority investor in the fuel supply company Orano and in the companies tasked with constructing EPR2 reactors (Framatome, Edvance). On the government side, DINN is now tasked with direct project oversite, and the Cour des Comptes appears to be acting as a permanent U.S. Government Accountability Office-equivalent with much more muscle. Nuclear strategy overall is decided by a committee chaired by President Macron. Clear lines of authority, independent monitoring, and a single responsible private sector counterparty will, France hopes, make ERP2 work.

- **Vertical integration.** EDF not only dominates construction and operations, but is also the primary buyer for EPR2 electricity. Although 70 percent of output from ERP2 must be sold on the open market per EU insistence for competition reasons, EDF is by far the largest buyer in that market. Effectively guaranteed demand is a key part of the project.
- **Simplified design.** EPR2 is designed for buildability. It has been substantially simplified and modularized, including an effort to standardize parts for factory production. This raises some safety concerns (which are still to be fully addressed), and it is unclear how much factory production will be achieved. But buildability is now a central design parameter.
- **De-risking.** The government accepts that private investors will not take on all the risk in EPR2, so it is providing subsidized loans to cover at least 50 percent of construction costs (with the remainder funded by market-rate loans and perhaps additional EDF equity), along with a CfD that subsidizes operations. If EPR2 can deliver energy at €100/MWh (or less), it is guaranteed a profitable price for 40 years. Significant cost overruns would threaten that target, and it is unclear who would be on the hook for construction delays and overruns. This is a key missing piece.
- **Decisive commitment to scale-up; more innovation is on the back burner.** For both EPR2 and SMRs, France has decided that the new EPR2 design is good enough, and that the race to scale can start. Its financial projections rely on substantial cost reductions for subsequent units, so it needs to get this key strategic decision right. It has also committed fairly decisively to large reactors, retaining only a relatively small interest in SMRs. This is another major strategic decision.
- **The scale-up commitment is reflected in a substantial order book.** That will, France hopes, drive nuclear down the cost curve, based in part on an expanded and sustainable nuclear workforce. Without that order book, each reactor must build its own workforce and validate its own designs, which makes costs much higher. Hence EDF's continuing commitment to nuclear reactors outside France, such as Sizewell C in the United Kingdom (despite warnings from the Cour des Comptes that international projects could distract EDF attention from ERP2 in France).

France's EPR2 program is highly ambitious and quite high risk. Success would secure France's position as Europe's nuclear leader, while providing a proven solution for other nations seeking large-scale nuclear deployment. Failure would likely end France's nuclear construction capabilities, possibly undermining global confidence in civilian nuclear power. The innovative financing structure also offers a potential model for nuclear deployment worldwide, but only if France can demonstrate that advanced reactor construction can be completed on time and on budget. The program's ultimate success thus depends on resolving fundamental tensions between ambitious political timelines and complex technical realities.

POLICY CHALLENGES THE UNITED STATES MUST ADDRESS

Like France, the United States must grapple with key challenges in developing nuclear energy. But unlike France, the United States does not have a highly centralized government bureaucracy with clear top-down lines of authority, or a national champion that dominates each phase of the nuclear cycle, as EDF does in France. These realities are unlikely to change, so the United States will need to address the same challenges in different ways. That will require the following building blocks:

1. **A single coherent strategy for the nuclear sector.** It should cover the complete production cycle for all kinds of nuclear energy, from uranium acquisition to waste management, and safety regulation. It should also cover the full technology development cycle: R&D, product development and testing, first-of-a-kind commercial demonstration, and scaleup. Currently, responsibilities are scattered, strategic decisions and specific initiatives are largely made ad hoc, and activities are heavily siloed. Monitoring and strategic adjustment capabilities are effectively nonexistent.

2. **Sustained, consistent, and long-term bipartisan support, especially in Congress.** The new French nuclear plan passed the French Parliament overwhelmingly (402-130), even though politics in France is as bitterly divided as in the United States over renewables. Nuclear power is seen as strategic across the French political spectrum, aside from a few environmentalist holdouts. Such bipartisan support is starting to emerge in the United States, but it will still be a huge leap for Congress to create steel-clad support for a coherent, persistent, and sustainable program that will probably not deliver national-scale benefits for at least 20 years. Without that, private sector investment simply becomes too risky, and big nuclear projects will not be delivered. That problem needs to be tackled head-on.[52]

3. **Accountability and clear lines of authority—government structure and organization.** Any country seeking to build nuclear must have the capacity to take strategic decisions and stick to them. France is now operating with a unified civilian nuclear command and control structure. Whether or not this structure works in France, the United States will need a governmental structure that can be the functional equivalent, delivering clear strategic choices, solid (and transparent) oversight, implementation across the entire product development cycle, and effective linkages to the private sector, regulators, and both fuel sources and waste management. No such structure exists today. There is no national nuclear council, there is no effective oversight body within government, the Department of Energy's (DOE's) role is hopelessly siloed, many other agencies such as NRC, Department of Defense, and NASA have a role in nuclear operations and policy. Neither Congress nor any recent administration has pressed hard for anything different.

4. **Organizational structure—operations and markets.** In France, EDF and its subsidiaries have been anointed to run the entire nuclear cycle, from design through construction, fueling, operations, waste management, and eventual offtaking. In the United States, there are rumblings that Westinghouse will emerge as the de facto national champion (for large reactors only). But every utility will make its own decision about buying a new reactor; each reactor could use a different construction team; Centrus is emerging as the primary source of fuel; waste management remains under the control of DOE; safety is managed

by NRC, and transportation is regulated by the Environmental Protection Agency. On the positive side, the lack of a centralized industrial champion will allow many SMR companies to compete; France is clearly weak in SMRs, and EDF seems to have little interest beyond delivering scaled-down versions of its own technology. Beyond SMRs, If the United States is serious about developing a large reactor champion, it will need to support development of either a coherent and persistent set of linkages between independent companies or a more vertically integrated entity than Westinghouse is today. Antitrust concerns may also need to be addressed.

5. **Order book and cost reduction.** Every pro-nuclear story starts with the same basic proposition: nuclear can be cheap enough if only a sufficiently large order book of commitments can be developed. Construction costs could then follow the well-known path of solar, wind, and batteries, sliding down the cost curve as volume increases. Wright's Law—which calls for a 10–15 percent reduction in costs of production for every doubling of production volume—is doing a lot of work here. ERP2 strategy is built directly on declining costs from increased production, but Wright's Law applies to factory production. It is not entirely clear that EPR2's gestures toward more modularized and factory-built components will actually drive down costs.

   The need for a significant order book underpins President Trump's executive order calling for the construction of 10 large reactors. But an order book is much more difficult to build in a highly decentralized environment such as the U.S. electricity grid. In France, EDF will benefit from the lower costs of Nth-of-a-kind reactors, which will partly offset the higher cost of first-of-a-kind construction and operations. That won't happen in the United States, as the market is fragmented geographically, so any given utility will face the specific costs associated with the specific reactor that it has purchased. Costs and benefits are not shared across the order book. This raises substantial challenges to the concept of an order book in the United States: no utility will likely pay for more than one reactor at a time, buyers will have to agree on a single design and numerous utilities will then have to buy in, state regulators will have to approve, and then a construction schedule will have to be negotiated with the federal government, other investors, and local stakeholders—all before a single reactor even seeks regulatory approval and financing. This is an immense challenge. Who would want to go first and incur the highest costs? Who would want to go last and go through the pain of committing to a reactor that won't be delivered for at least a couple decades? Public choice theory suggests that the appetite for this among politicians will be very limited indeed. Simply announcing a plan to build 10 reactors and actually doing so are very different things.

6. **Workforce.** Both the U.S. government and private stakeholders (e.g., Google) have recognized that building a new nuclear industry in the United States will require both a significant training effort and some guarantee that the jobs will be there after training—which takes ~four years for operators, and shorter but still significant time for skilled tradespeople. So far, there has been a lot of handwaving and not much action—or recognition that the workforce problem is harder than it seems. Will skilled workers want to uproot themselves every five to seven years to move to a new reactor site? Will there be work there? Are there any guarantees? What can persuade workers to accept the huge risk of training for years for specialized jobs, when the U.S. order book remains perennially at

risk from any number of actors? Westinghouse has gone broke once already, government commitment always risks a U-turn, states might suddenly go antinuclear, there could be another big nuclear accident, expected cost savings might not materialize, cheaper energy sources might emerge, SMRs might move into the fast lane, etc. Placing all these risks on workers is not likely to be successful.

7. **Loan financing.** Some form of government help with construction costs will be needed—building large new reactors in the United States is simply too risky and too long term for private investment alone. The Loan Program Office (LPO) at DOE could provide subsidized loans for construction, as the Trump executive order suggests. However, this would require both changes to LPO authorization (which might not be a problem) and annual budgetary approval from Congress for the subsidy component (interest subsidies become part of DOE's budget if loans are made at below government cost). Ideally, LPO will make loans at government cost. Removing an additional subsidy element (available in both the French and Czech programs) would make these very capital-intensive projects significantly more expensive, but would avoid potentially disastrous annual budget fights over subsidies.

8. **De-risking.** While France appears to have found financing for a respectable-sized order book and to have agreed to operating subsidies that might make the project sustainable, there is no clear answer yet to a critical question: who pays for cost overruns? Flamanville 3 and Vogtle unfortunately demonstrated only too clearly that overruns are a real possibility. If EDF is left on the hook, it will likely have to be bailed out (as it has been in the past). If the French government picks up the tab directly, that would be an unwelcome hit to government finances and could threaten further support. Indeed, the order book concept itself depends on the first projects coming in close to on time and on budget. What if they don't?

   In the United States and elsewhere, other ways of de-risking these big projects are emerging. The Energy Futures Institute (EFI) has developed a tranching model, for example, where most risks are shared between vendors and operators, but the government provides what is effectively insurance against catastrophic overruns. The United Kingdom has developed a scheme wherein ratepayers contribute through their monthly bills during the construction phase. Elsewhere, the Finnish model shares risks between vendors, operators, and large end users. This is, therefore, not an insoluble problem, but it does have to be resolved. Currently, no U.S. government entity has the authority or the capacity to do so, and there has been no systematic effort to identify and manage risk across the production cycle.[53]

9. **Operating subsidies** in the United States have been provided via tax credits offered through the Inflation Reduction Act.[54] This may be the only viable U.S. pathway, as both the CfD approach used in France and the Rate Asset Based model in the United Kingdom require that the utility, the regulator, the government, and the operator commit to a very long-term financial structure: French operating subsidies will not kick in until 2038 at the earliest, but the commitment is needed now in order to make the project bankable for private sector partners. Tax credits are much simpler, and require none of this coordination, but they have significant disadvantages. Notably, they eliminate any

relationship between the subsidy paid and market prices. Almost by definition, such fixed subsidies are either too large—allowing operators to pocket an unearned windfall—or too low, in which case the project will struggle financially or won't be built at all, and they are not a contractual arrangement between the government and the operator. The Goldilocks zone for tax credits is quite small.

Overall, evidence from France strongly suggests that a nuclear buildout for large reactors is a high-risk project, and that it requires capabilities that the United States simply does not have today. It might therefore be well advised to start building those capabilities now, before it starts constructing any more big reactors.

APPENDIX: ORGANIZATIONAL ABBREVIATIONS

Abbrev.	Title (French/English)	Description
Andra	Agence nationale pour la gestion des déchets radioactifs	Waste agency; plans and implements radioactive-waste management (incl. CIGEO).
ASN	Autorité de sûreté nucléaire	Former regulator; superseded by ASNR under the 2024/2025 governance reform
ASNR	Autorité de sûreté nucléaire et de radioprotection	Independent French authority for nuclear safety and radiological protection (effective January 1, 2025)
CEA	Commissariat à l'énergie atomique et aux énergies alternatives	Public research body for nuclear and clean-energy research and development
CfD	Contract for Difference	Symmetric revenue-stabilization contract for electricity (France plans a €100/MWh cap (in 2024 euros), for EPR2)
CIGEO	Centre industriel de stockage géologique	Deep geological repository project in Meuse/Haute-Marne for high-level/long-lived waste
CNDP	Commission nationale du débat public	Runs public debates and consultations for major infrastructure projects (incl. EPR2 sites)
CPN	Conseil de politique nucléaire	High-level council (chaired by the president) that sets France's nuclear policy
DG Trésor	Direction générale du Trésor	French Treasury; designs state-support instruments (e.g., subsidized construction loans)
DGEC	Direction générale de l'énergie et du climat	Energy/climate directorate within the environment ministry; drafts policy (incl. Programmation pluriannuelle de l'ênergie)
DINN	Délégation interministérielle au nouveau nucléaire	Interministerial team coordinating delivery of the new-build nuclear program.
EDF	Électricité de France	State-owned utility; owner-operator of the French fleet; EPR2 developer
EPR2	(Fr) EPR2; (En) Evolutionary Power Reactor 2	Simplified large pressurized-water reactor design for series construction in France
IRFM	Institut de recherche sur la fusion par confinement magnétique	CEA institute operating the WEST tokamak at Cadarache
IRSN	Institut de radioprotection et de sûreté nucléaire	Former technical support organization; functions reorganized under the 2025 reform
LCOE	Levelized Cost of Electricity	Lifetime average cost per MWh, including capex, opex, fuel, and financing

Abbrev.	Title (French/English)	Description
PPE3	Programmation pluriannuelle de l'ênergie (3e édition)	2025–2035 energy programming document; government intends to issue by decree after Assembly rejection
RTE	Réseau de transport d'électricité	French electricity transmission system operator
SFEN	Société française d'énergie nucléaire	Professional society; publishes technical briefs and sector analysis
WACC	Weighted Average Cost of Capital	Discount rate reflecting the blended cost of debt and equity used in project valuation
WEST	W Environment in Steady-state Tokamak	CEA's superconducting tokamak used for long-duration plasma experiments

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