ENERGY

The Next Nuclear Renaissance?

Will a new wave of nuclear power projects deliver the safe and economical electricity that proponents have long predicted?

BY STEVE THOMAS

Over the past decade, there has been a growing interest in building new nuclear power stations, particularly among policymakers. This comes some two decades after a previously forecast "nuclear renaissance" petered out, having produced few orders, all of which went badly wrong.

This article reviews the previous renaissance: What was promised, what was delivered, and why it failed. It then considers the current claims of a new renaissance led by Small Modular Reactors, forthcoming "Generation IV" designs, new large reactors, and extending the lifetime of existing nuclear plants. Despite the need for clean generation, the growing demand for electricity to power new technologies and global development, and claims of nuclear generation breakthroughs that are either here or soon will be, this new renaissance appears destined for the same failure as the previous ones.

THE LAST RENAISSANCE

Around the start of this century, there was a great deal of publicity about a new generation of reactors: so-called Generation III+ designs. These would evolve from the existing dominant "Gen III" designs—Pressurized Water Reactors (PWRs) and Boiling Water Reactors (BWRs), collectively known as Light Water Reactors (LWRs)—rather than be radical new designs. There was no clear definition of the characteristics that would qualify a design as Gen III+ rather than just Gen III LWRs. However, Gen III+ was said to incorporate safety advances that would mitigate the risks of incidents like the 1979 partial meltdown at Three Mile Island (a Gen II design) and the 1986 Chernobyl meltdown (a Soviet design that used Gen I/II technology). Three Gen III+ designs received the most publicity: the Westinghouse AP1000 (Advanced Passive), the Areva EPR (European Pressurized Water Reactor), and the General Electric ESBWR (Economic Simplified Boiling Water Reactor).

The narrative was that Gen III designs had become too complex and difficult to build because designers were retrofitting safety features to avoid another Three Mile Island. Gen III+ supposedly went back to the drawing board, rationalizing existing systems and incorporating new safety features, thereby supposedly yielding a cheaper and easier-to-build design. A particular feature of these designs was the use of "passive safety" systems. In an accident situation, these did not require an engineered safety system to be activated by human operators and were not dependent on external sources of power; instead, the reactor would avoid a serious accident by employing natural processes such as convection cooling. These had an intuitive appeal, and a common assumption was that because they were not mechanical systems, they would be cheaper, and because they involved natural processes, they would never fail. Neither assumption is correct.

Another major safety feature resulting from the Chernobyl disaster was a system that, if the core was melting down, prevented the molten core from burning into the surrounding ground and contaminating it. A common approach was a "core-catcher" (already used in a few early reactors) that would be placed underneath the reactor. An alternative, often used for smaller reactors, was a system to flood the core with so much water that it would halt the meltdown.

After the September 11, 2001, terrorist attacks, designers attempted to further increase safety by strengthening the reactor shell so it could withstand an aircraft or missile impact. The core-melt and aircraft protection features inevitably tended

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to increase the size and complexity of the Gen III+ designs.

Nuclear advocates also claimed that the large cost and time overruns of previous plants were caused in part by the high proportion of work carried out on site. To combat this and the additional complexity noted above, designers vowed to rely more on factory-made modules that could be delivered by truck, reducing sitework mostly to "bolting together" the pieces. In practice, there was significant variability between the Gen III+ designs, with the AP1000 and ESBWR relying much more on passive safety and modular construction than the EPR.

What sold these designs to policymakers were some extraordinary claims about construction costs and times. It was claimed that their cost (excluding finance charges; so-called "overnight cost") would be around $1,500–$2,000 per kilowatt (kW), meaning a large, 1,000-megawatt (MW) reactor would cost $1.5–$2 billion. Construction time would be no more than 48 months. While there were few existing nuclear projects then to compare the new designs with, these projected costs and times were far below the levels then being achieved with existing designs.

These claims convinced the US government, under President George W. Bush, and the UK government, under Prime Minister Tony Blair, to launch large reactor construction programs. As those countries were two of the pioneering users of nuclear power, this appeared to be a strategically important victory for the nuclear industry.

US / In 2002, President Bush announced his Nuclear 2010 program, so-called because it was expected the first reactor under the program would come online in 2010. It was assumed the new nuclear designs would be competitive with other forms of generation, but utilities would need to see this demonstrated for them to order the plants. The government's proposal was that a handful of nuclear projects would receive federal subsidies, such as sovereign loan guarantees and subsidies to the kilowatt-hour (kWh) price, and these would kick-start nuclear ordering, with no further subsidies needed. The subsidies were contained in the Energy Policy Act of 2005.

Utilities quickly responded and more than 30 reactors were proposed, most using one of the three designs noted above. Some were to be built in states where they would be exposed to a competitive electricity wholesale market, and analysts soon determined this made them too economically risky even with substantial federal subsidies, resulting in the projects quickly being abandoned. In states with regulated electricity markets, utilities were concerned that regulators might not allow them to recover their costs from consumers if there were time and cost overruns. Most of the other projects were abandoned on these grounds, leaving only two to enter the construction stage: a two-reactor project to join an existing reactor at the V.C. Summer plant in South Carolina, and a two-reactor project to join two existing reactors at the A.W. Vogtle project in Georgia. All four new reactors would be Westinghouse AP1000s.

In those two states, regulators gave clear signals that the utilities would be allowed to recover all their costs. The state governments broke with regulatory practice by passing legislation allowing the utilities to raise rates and start recovering their costs from the date of the investment decision, not the date when the reactors entered service. Previously, utilities would make their own investment decisions, but they would only be allowed to recover costs from their customers when the facility was in service and after the state energy regulator had determined the facility was "used" and "useful" and the costs "prudently incurred." If those tests were not passed, the regulator could disallow recovery of some or all of the costs, requiring the utility to pay them from its profits.

Some units were to be built in states with competitive electricity wholesale markets, and analysts soon determined this made them too economically risky.

Consumers started paying for the reactors in 2009–2010, even though construction didn't start until 2013. By 2015, both projects were in bad shape, way over time and budget. Westinghouse, then owned by Toshiba of Japan, was required to offer fixed-price terms to complete the projects. Those prices soon proved far too low, and in March 2017 Westinghouse filed for Chapter 11 bankruptcy protection. The whole of Toshiba was reportedly at risk as a result. In August 2017, the V.C. Summer project was abandoned. The A.W. Vogtle project continued, and the first reactor was completed in July 2023 with the second unit following in April 2024, six or seven years behind schedule and at more than double the forecasted cost. There are now no proposals for additional large reactor projects in the United States.

UK / In 2003, a UK Energy White Paper (DTI 2003) concluded there was no case for nuclear power because renewables and energy efficiency measures were cheaper. According to the report, "the current economics of nuclear power make it an unattractive option for new generating capacity and there are also important issues for nuclear waste to be resolved." Only three years later and despite the lack of evidence that nuclear had become cheaper or that renewables and energy efficiency had become more expensive, Blair reversed the government's position, claiming nuclear power was "back on the agenda with a vengeance."

As with the US program, the assumption was that the new designs would be competitive. A key promise that made the program politically acceptable was there would be no public subsidies. Politicians—even those who were favorable to nuclear—were aware that previous UK nuclear projects had gone badly and the costs of this had fallen on taxpayers and electricity consumers. The energy minister told a Parliamentary Select Committee:

> There will be no subsidies, direct or indirect. We are not in the business of subsidizing nuclear energy. No cheques will be written; there will be no sweetheart deals.

This promise of no subsidies remained government policy until 2015, despite it being clear long before then that new nuclear projects were only going forward in anticipation of large public subsidies.

In another white paper (BERR 2008), the government's central estimate for the overnight cost of a new nuclear power plant would be £1,250 per kW ($3,532 in today's dollars), so a 1,600MW reactor like an EPR would cost £2 billion ($5.6 billion in today's dollars). This was substantially less than the estimated cost of the EPRs then under construction at Olkiluoto, Finland, and Flamanville, France, both of which were forecast to cost about €3 billion ($6.2 billion in today's dollars).

Three consortia were created, each led by some of the largest European utilities. One was Nuclear New Build Generation (NNB), a subsidiary of EDF Energy; another, Horizon, was led by the two largest German utilities (RWE and E.ON); and a third, Nugen, was led by utilities including Iberdrola (Spain) and Engie (France). Government facilitated the provision of sites, selling them land adjacent to existing UK reactors, but choice of design was left to the consortia. Five projects comprising 11 reactors were established, targeted to deliver 16 gigawatts (GW) of new nuclear capacity by 2030. As early as 2007, the consortium led by EDF established a leading presence, with the CEO of EDF Energy, Vincent de Rivaz, notoriously claiming that Christmas turkeys in the UK would be cooked using power from the Hinkley Point C EPR in 2017. In 2010, the UK energy secretary still claimed Hinkley would begin generating no later than 2018.

The Final Investment Decision (FID) for Hinkley was not taken until October 2016, when it was expected the two reactors would be completed by October 2025 at an overnight cost of £18 billion (in 2015 pounds sterling, equivalent to $35 billion in today's dollars). Power would be sold under a 35-year contract at an inflation index-linked price of £92.5 per megawatt hour (in 2012 pounds sterling, equivalent to $196 in today's dollars). A key element of the contract was that the megawatt hour price was fixed and if costs were higher than expected, the additional costs would fall on EDF. In January 2024, EDF issued a new cost and time update—its fifth—with completion now expected to be as late as 2032 at a cost of £35 billion (in 2015 pounds sterling, equivalent to $68.7 billion in today's dollars). As a result, EDF wrote off €12.9 billion ($14 billion) of its investment in Hinkley Point C in 2023. By 2018, EDF recognized the error it made in accepting the risk of fixing the power price, and it abandoned plans for an EPR station at Sizewell using the Hinkley C financial model. In July 2025, an FID was taken on the Sizewell C project using a different financial model and completion is not expected before 2040.

The effect of the 2011 Fukushima, Japan, nuclear plant disaster, where a tsunami resulted in meltdowns in three reactors, combined with the effect of competition in wholesale and retail markets in electricity meant that European utilities could not justify to their shareholders the building of new reactors. The Horizon and Nugen consortia were sold to reactor vendors Westinghouse and Hitachi–GE, respectively. Those firms did not have the financial strength to take significant ownership stakes in the reactors, but they saw this as an opportunity to sell their reactors on the assumption that investors could later be found. Westinghouse (then planning three AP1000s for the Moorside site) filed for Chapter 11 bankruptcy protection in 2017. Hitachi–GE abandoned its two projects (four ABWRs, two each at Wylfa and Oldbury) in 2019 when it became clear that, despite the UK government offering to take a 30 percent stake in the reactors and to provide all the finance, other investors were not forthcoming.

Lessons learned / Thus ended the last nuclear renaissance. Its failure does not determine the outcome of the present attempt, but there are some important lessons that will shape the outcome this time:

- While governments have always had to play a facilitating role in nuclear power projects, such as providing facilities to deal with the radioactive waste, they were centrally involved in the 2000 renaissance. This trend has continued, and governments are now offering to provide finance, take ownership stakes, offer publicly funded subsidies, and impose power purchase agreements that will insulate the reactors from competitive wholesale electricity markets.
- Forecasts of construction costs and times made by the nuclear industry must be treated with extreme skepticism. The claim that the new designs would be so cheap they would be able to compete with the cheapest generation option then available—natural gas generation—

proved so wide of the mark that other claimed characteristics, such as supplying base-load power and offering low-carbon generation, are now given as the prime justifications for the substantial extra cost of nuclear power over its alternatives.

- The technical characteristics claimed to give advantages to the Gen III+ designs (such as factory-manufactured modules and passive safety) have not been effective in controlling construction times and costs.
- The large reactor designs now on offer are the same ones that were offered previously. No fundamentally new designs have started development this century. It is hard to see why these designs that have failed by large margins to meet expectations will now be so much less problematic.

SMALL MODULAR REACTORS

Instead of another round of large nuclear plants, one of the focal points of the new renaissance is Small Modular Reactors (SMRs). The International Atomic Energy Agency (IAEA) defines SMRs as having an electrical output of 30MW–300MW. Among their ostensible virtues:

- They are cheaper and easier to build and so are less prone to cost and time overruns, making them easier to finance.
- They are safer; for example, some are said to be meltdown-proof and "walk-away safe."
- They produce less waste (per kW of capacity) than large reactors.
- Being smaller, there will be less opposition to their siting.
- They will create large numbers of new jobs.

SMR proponents give the impression that large numbers of the units are being ordered around the world. These claims are unproven or misleading or simply wrong. No current SMR design is under construction, much less operating, so these claims—notably those on cost and construction time—are unproven and no more than marketing hype. There are two SMR-*sized* units under construction, in China and Russia, but they are prototypes or one-offs. The true SMR project nearest to construction start (as defined by pouring of first structural concrete) is the Darlington project for Ontario, Canada, for up to four GE–Hitachi BWRX–300s (explained below). The Ontario government approved construction of the first reactor in May 2025.

No SMR design that is expected to be offered as a commercial reactor has completed a full safety review by an experienced and credible regulator. The Canadian Nuclear Safety Commission will examine the design during the Darlington construction phase rather than before construction starts. Until a comprehensive safety review is successfully completed, it will not be known if the design is licensable or what the costs will be.

The designs most likely to progress to commercial availability are those based on the PWR and BWR designs in LWR large reactors. There are 65 years of operating experience with these types of reactors, so there is a reasonable expectation that SMR LWRs could be reliable, if not necessarily economic, sources of power.

Many designs for these units are said to be under development, but only a handful have progressed beyond the conceptual stage and are being offered by firms with the credibility to deliver a facility expected to cost several billion dollars. The main options are the GE–Hitachi BWRX–300, the Holtec SMR300, the Rolls Royce SMR, and the Westinghouse AP300. Below are overviews of these four designs, along with some other possibilities.

GE–Hitachi BWRX–300 / General Electric, along with Westinghouse, has by far the longest and most extensive experience in designing and supplying nuclear power reactors. The 300MW BWR is based on its ESBWR 1,500MW reactor design. Although the ESBWR completed US Nuclear Regulatory Commission (NRC) safety review in 2014, GE–Hitachi has won no orders, and it currently does not appear to be actively marketing the unit.

Like the ESBWR, the BWRX–300 relies heavily on passive safety features. GE–Hitachi received an order for up to four of the reactors to be built at the Darlington site. It has completed a pre-licensing review in Canada and a construction license has been given. A detailed review of the design will be carried out during construction prior to an operating license being granted.

The BWRX–300 was one of four designs shortlisted by Great British Energy–Nuclear (GBE–N), with the UK government-owned energy organization expected to choose two designs for installation in Scotland and England. But in June 2025, GBE–N announced only that it had selected the Rolls Royce SMR design, discussed below.

The UK Office of Nuclear Regulation (ONR) is carrying out its Generic Design Assessment (GDA) on the BWRX–300, and it completed the first of the three stages of the GDA in December 2024 (primarily information exchange). GE–Hitachi has only committed to carry out the first two stages of review, and is unlikely to undertake the third stage given that it was not selected by GBE–N.

Holtec SMR 300 / Holtec has a long history in the spent-fuel handling and plant decommissioning sectors of the nuclear power industry, but not as a reactor designer and vendor. It launched its PWR SMR design in 2010, initially proposing a 160MW reactor. The unit is designed to be housed deep underground, relying on passive safety (claimed to be "walk-away safe"). In 2023, Holtec doubled the thermal output of the plant and renamed it SMR 300. It is not willing to say when it decided to make that change or why, but the most likely explanation is to gain scale economies.

Its main sales prospect is to initially build two reactors at Holtec's Palisades site in Michigan, adjacent to an 801MW reactor Holtec owns and is preparing to reopen after it was idled in 2022.

It was one of the four designs shortlisted by GBE–N. ONR is carrying out its GDA on the Holtec SMR 300, but like GE–Hitachi, Holtec is unlikely to carry out the third stage given that it was not selected by GBE–N.

Rolls Royce SMR / Rolls Royce has a long history of supplying nuclear submarine reactors based on US designs. It is not clear how well this equips the firm to design and supply land-based power reactors. Its design is a 470MW PWR, making it significantly larger than the top of the IAEA's range for SMRs.

The argument that, because SMRs are smaller, they will be cheapier, quicker, and easier to build and site is not supported by any evidence.

Unlike the other three designs, it is much more conventional, not relying so much on passive safety and not housed underground. Its main sales prospects are in the UK and the Czech Republic. In the UK, it submitted a Final Tender to GBE–N in April 2025 and was selected by the government. ONR is carrying out its GDA on the reactor. It completed the second of the three stages in July 2024, and the third stage is expected to be completed in 2026.

Rolls Royce signed a deal in October 2024 with the Czech utility CEZ for it to help develop the design. It expects that three initial orders will be placed for the Czech Republic, with them coming online in 2034–2037. In February 2025, there were reports of tension between Rolls Royce and CEZ—in particular, over how much local Czech content there would be in reactor orders.

Westinghouse AP300 / Westinghouse has supplied substantially more power reactors worldwide than any other vendor. Its SMR design, the AP300 PWR, was launched well after its competitors in May 2023 and is based on the AP1000 large reactor design. It relies on passive safety.

In the UK, it applied for the design to undergo a GDA. In August 2024, it passed the government's "readiness" test and was allowed to move on to a GDA. However, by December 2024, no funding package to pay for this process (expected to be funded by the vendor) had been agreed upon, and Westinghouse asked ONR to defer the start of the GDA. By May 2025, the GDA had not started, and there is no indication whether Westinghouse expects to proceed.

It chose not to respond to GBE–N's Invitation to Submit Final Tenders for its project discussed above. Westinghouse has not commented on its decision not to proceed with the GDA or its decision not to submit a Final Tender to GBE–N. It may be that it has halted work until there is more concrete buyer interest in the design. If the design is not pursued, this would be the second time Westinghouse has carried out development work on an SMR design only to abandon it before it had won any orders, the previous attempt being halted in 2014.

Other possibilities / Besides those reactors, the French nuclear engineering firm Framatome began developing a design, Nuward, in 2019. It abandoned the design in the summer of 2024 in favor of a more conventional layout, and there is no timeframe for when this new design might be available.

A US firm, NuScale, has a design that has been under development since 2005. It started out as a 35MW PWR, then expanded to 40MW, 50MW, 60MW, and finally 77MW. The design, which successfully completed NRC review in May 2025, is "integrated" with all components housed within the reactor containment and would be built underground. It was designed to be built in clusters of 12 reactors, but the 77MW version is now also offered in clusters of four and six reactors. It appeared to have won an order in 2015 from Utah Associated Municipal Power (UAMPS) for a cluster of 12 reactors of 50MW, which then evolved into a cluster of six 77MW reactors, but the project was abandoned in December 2023 because of sharply escalating cost.

Arguments for SMRs / At the heart of the case for SMRs is the claim that being smaller, they will be cheaper, quicker, and easier to build and easier to site. While this argument might appear plausible, it is not supported by any evidence. The first reactors from more than 60 years ago were 150 MW or less, and reactors subsequently became larger, increasing in size 10-fold, primarily to gain scale economies. The case for this is clear: A 1,500MW reactor vessel will, all things being equal, be cheaper than ten 150MW reactor vessels. So, SMRs start with a disadvantage compared to large reactors because of the lost scale economies over large designs.

However, there is no clear evidence on why the real cost of large reactors has continuously increased over the history of nuclear power. Is it because of their size or because of how complex the designs have become? If it is complexity, why would SMRs be less complex than large reactors? The most obvious way this could happen is if not all the safety systems added to large reactors over the past 40 years were required for SMRs. Given that the SMRs on offer are not that small, this seems unlikely. For example, the output of the 470MW Rolls Royce SMR is about the same size as that of the Fukushima Daiichi 1 reactor that melted down in 2011.

The history of the Westinghouse AP design reactors illustrates the nuclear industry's confusing position on reactor size. Its 1989 AP600 design was found to be uneconomic and was scaled up to the AP1000 in 2002, then scaled up again in 2013 to the CAP1400 and, in 2023, scaled down to the AP300.

Safety Many SMR safety claims are based on their use of passive safety measures. The intuitive impression is that because passive safety does not require the operation of an engineered system, it would be cheaper and, because it is passive, it cannot fail (Ramana 2024). Neither assumption is true. Building reactors underground appears likely to increase site work and make it more difficult and expensive. The ESBWR and AP1000 large reactor designs are both heavily reliant on passive safety, yet the ESBWR was too expensive to win any orders and the AP1000 proved very expensive to build in practice. That experience does not support the contention that passive safety will reduce costs. If all the safety systems required for large reactors are required for SMRs, this will adversely affect their economics.

Ease of production The idea that SMRs would emerge in several modules from factories and be transported to the site on the back of trucks, requiring only bolting together at the site, also has an intuitive appeal. However, in practice SMRs are substantial-sized reactors and will inevitably require considerable on-site civil works to provide the foundations and services required.

The narrative of factory production lines conjures an image of a conveyor belt producing multiple identical reactor modules, perhaps similar to automobile production lines producing thousands of cars per year. However, this is not the expected reality. Rolls Royce plans to only produce two reactors per year. Although production lines can be a cheap method of manufacture, they must constantly operate at near capacity to pay off their high fixed costs. If demand is less than planned, the high fixed costs will not be spread across many units of electricity, and if the design changes, the production line will have to be re-tooled. The AP1000 was expected to be built in factory modules, yet this did not prevent all the projects using this design from going far over time and budget.

Waste All things equal, a large PWR or BWR will create less waste than the same capacity of SMRs. Former US NRC chair Allison Macfarlane has said that SMRs would increase the volume and complexity of waste between two- and 30-fold because of such factors as greater neutron leakage.

Jobs Both politicians and nuclear power advocates like to claim a new plant will create many new jobs. But an operating reactor requires few permanent employees, and those workers typically have highly specific skills unlikely to be found among the local population. Nuclear reactors do require large numbers of workers during construction, but they too have specific skills unlikely to be found in the local area, and sometimes these workers have to be recruited from abroad. This is very disruptive to the local area, requiring a large amount of short-term accommodation and facilities.

Moreover, if the promises that SMRs will be cheaper and quicker to build than large reactors are fulfilled, they will create less work and over a shorter period. If factories with production lines are efficient, they will require fewer workers than other manufacturing methods. To minimize costs, the number of factories will have to be minimized, and factories will not be built in most export-country markets. The number of factory jobs that are created is likely to be small and will mostly not be in the country buying the reactor.

GENERATION IV DESIGNS

Around the time of the previous nuclear renaissance, there was talk of the designs that would succeed Gen III+, so-called Gen IV designs. Gen III+ designs were seen as transitional technologies filling the gap until their long-term successors were developed. The Gen IV International Forum (GIF), an international intergovernmental organization funded by the governments of nearly all the nuclear-using countries, was set up in 2001 to promote development of these designs.

The GIF has stated, "The objectives set for Generation IV designs encompass enhanced fuel efficiency, minimized waste generation, economic competitiveness, and adherence to rigorous safety and proliferation resistance measures." It identified six designs as the most promising, and these remain its focus. Some are designs that have been pursued since the 1950s and built as prototypes and demonstration plants but never offered as commercial designs. Among these are sodium-cooled fast reactors and high temperature gas-cooled reactors (HTGRs). Some, such as the lead-cooled fast reactor and the molten salt reactor, have been talked about for 50 or more years but never actually built. Others, such as the supercritical-water-cooled reactor and the gas-cooled fast reactor, do not appear to be under serious commercial development. When GIF was created, it expected some of the designs to be commercially available by 2025, but it now does not expect this to happen before 2050.

When the Gen IV initiative began, there was no expectation they would be small or modular. Gen IV designs are now sometimes known as Advanced Modular Reactors (AMRs) in an apparent attempt to profit from the positive press that LWR SMRs are receiving. However, they are very different from LWRs, with different designs and safety requirements, so the claims made for LWR SMRs compared to the large LWR designs are not relevant to AMRs.

There is particular interest in HTGRs because of the hope that they can operate at high temperatures (above 800°C /1,500°F). This would allow a plant to also produce hydrogen more efficiently than conventional electrolysis, providing the plant an additional revenue stream. However, existing HTGRs have only operated at 750°C /1,380°F, much higher than the 375°C /700°F of PWRs but not ideal for producing hydrogen. Increasing the temperature to the levels GIF anticipated originally, 950°C–1,000°C/1,750°F–1,850°F, would require new, expensive materials and would raise significant safety issues. The British government is concentrating its efforts on HTGRs, but it has said, "It is not currently aware of any viable fully commercial proposals for HTGRs that could be deployed in time to make an impact on Net Zero by 2050." Nevertheless, the UK is still subsidizing development of HTGRs.

Overall, there are high-profile promoters of these Gen IV designs. For example, Microsoft cofounder Bill Gates is investing in sodium-cooled fast reactors through his nuclear innovation firm Terrapower. However, given the 50+ year history of these efforts, it is hard to see why these new companies would succeed now. Few of the more prominent Gen IV designs are being developed by firms with any history of supplying nuclear reactors. At most, Gen IV designs are a long-term hope.

LARGE REACTORS

If we exclude Russia and China (see below), three large reactor designs are currently available, at least in theory: the Westinghouse AP1000, Framatome (formerly known as Areva NP) EPR, and the South Korean KHNPC APR1400. These were all also available at the time of the previous nuclear renaissance, along with the GE–Hitachi ESBWR, but it won no orders and appears to no longer be marketed.

The only work in recent decades on a new design for a large reactor is for a modified version of the EPR, the EPR2. Despite this work starting in 2010, it had not entered detailed design phase as of the start of 2025, and the first reactor using this design is not expected online before about 2038. A new version, Monark, of the Canadian heavy water reactor CANDU has been publicized, but it seems to be at an early stage of development and the only interest in it appears to be from Canada.

The lack of new designs may reflect in part the very high cost of developing a nuclear reactor coupled with the uncertainty whether such research and development will lead to sufficient (if any) sales to recover those costs. For example, in 2023 NuScale stated that work developing its SMR design had cost $1.8 billion. In 2014, Westinghouse estimated it would have to sell 30–50 SMRs to get a return on its R&D investment. The GE–Hitachi ESBWR was carried through to detailed design and successfully completed the US NRC's design evaluation, but commercial sales failed to materialize, and the vendor appears to no longer offer it. Another factor may be that vendors have exhausted their ideas for improving the economics of large reactors. During the previous renaissance, concepts such as passive safety, modularization, and use of production-line-made components were unable to solve the financial problems associated with large reactor designs (Thomas 2019).

Despite these setbacks, there is growing interest in Europe in large reactors, not just in the well-established markets of France and the UK, but also in countries such as the Czech Republic, Poland, the Netherlands, and Sweden. Below is a more careful look at these units.

Westinghouse AP1000 / The AP1000 (Advanced Passive) 1,100MW PWR won eight orders, four for the United States (two for the Summer plant in South Carolina and two for Vogtle in Georgia) and four for China. The Summer orders were abandoned after four years' construction, but the others have been completed. The most recent orders were placed in 2010, and all six completed reactors were late and over budget. The Vogtle project took 11 years and cost more than double the forecasted cost. Similarly, the four reactors in China each took about 10 years to complete.

The AP1000 has been chosen by Poland for its first nuclear orders, with construction supposed to begin in 2028 and first power slated for 2036. The design was excluded from the bidding process in the Czech Republic because it "did not meet the necessary conditions." Westinghouse is competing to win orders in Sweden and the Netherlands, neither of which has made a design choice.

Framatome EPR / The French EPR design is in a sort of limbo at the moment. In 2010, Areva NP acknowledged that the EPR design needed significant modification because of construction problems faced at Olkiluoto 3 (Finland) and Flamanville 3 (France). A modified design has been under development since then, and for the last decade Framatome has claimed it will be ready to order in two or three years. The new EPR2 design has long been expected to be used for follow-on orders from Flamanville 3, leaving only the UK as a customer for the original EPR design, for Hinkley Point C (under construction since 2018) and Sizewell C (ordered this year). In 2021, the French government required EDF to build six EPR2s, one every 18 months, with the first one expected to begin construction in 2026 and be operational in 2035. This timeline cannot be met, and the earliest first power is likely is 2038. Given the record of EPR projects, export customers likely want to see an EPR2 built and in operation before they order one. That would mean the EPR2 design is not an option for new export orders before 2040.

Despite the obvious uncertainties and risks, EDF/Framatome offered a scaled-down version of the EPR2, the EPR1200, to the Czech Republic and Poland. In both cases, Framatome's bids were unsuccessful. Ordering an EPR1200 ahead of completion of the first EPR2 would have been an extraordinary gamble given that the reactor is an untested, scaled-down version of an untested design.

KHNPC APR 1400 / Korean Hydro and Nuclear Power Company (KHNPC) is a subsidiary of the state-owned monopoly electric utility KEPCO. The design is derived from the American engineering firm Combustion Engineering's System 80+ design that completed a full safety review by the US NRC in 1997 but has received no orders. Combustion Engineering was absorbed into Westinghouse, and KHNPC purchased a technology license for the design.

In South Korea, six reactors of this design have been completed, the first in 2016, with two under construction as of July 2025. All except one of the completed reactors took more than 10 years to build, and the two under construction are far behind schedule. South Korea's only reactor export has been four units, all using this design and built in the United Arab Emirates. All four took nine years to build.

KHNPC has acknowledged the design that has been built in South Korea and the UAE lacks features that would be essential for it to be licensed in Europe. Besides, under a recent change to its licensing agreement with Westinghouse, KHNPC is prohibited from marketing the unit in EU countries other than the Czech Republic, and also prohibited in Britain, Ukraine, Japan, and North America. Nevertheless, KHNPC appears confident that a scaled-down version of the APR1400, the APR1000, will be ordered by the Czech Republic. As with the EPR1200, ordering this untested design would be a gamble.

Prospects for large reactors / While the large reactor options look dated and their record is poor, in Europe they appear to have better prospects for orders in the next few years than SMRs. All will depend on a national government risking large amounts of public money to make these projects happen. France and the UK seem determined to follow this path, but other countries, which do not have as much financial strength, may waver when they find the scale of the financial commitment needed.

CHINA AND RUSSIA

China, through its home market, and Russia, through its exports, have appeared to buck the trend of apparently increasing difficulty in obtaining new nuclear orders. Does this experience mean they will have a dominant role in future world nuclear power markets?

China / China's first nuclear plant began construction in 1985, and up until 2007 there followed a trickle of 14 orders, six imported from France, two from Canada, and the rest supplied by Chinese vendors. Then, from 2008 to 2010, there was a flood of 20 orders: most of which were to use 1970s technology licensed from Areva NP. China also imported four Westinghouse AP1000s and two Framatome EPRs with the expectation that one of those designs—most likely the AP1000—would be licensed by a Chinese company and form the basis for future orders for China. Those six imports saw the worst construction performance of any nuclear plants in China, all taking about 10 years to complete, not the four years forecast. Reliable costs for them have not been published but are certain to be high.

There was then a sharp fall in home orders for China, with only a few placed in the period 2011–2016 after the Fukushima disaster. Ordering then resumed at two to four reactors per year. Two of the three Chinese vendors, China General Nuclear (CGN) and China National Nuclear Corporation, both previously licensed to Areva, began to develop a design, Hualong One, that they claim would meet the safety standards in Europe and the United States. China's State Nuclear Power Technology Corporation indigenized the AP1000 under license to Westinghouse, calling reactors using its version CAP1000. It also scaled up the design to 1,500 MW in the CAP1400 design, claiming the design is its own intellectual property. From 2015 onward, most new orders used either the Hualong One or CAP1000 design. There have also been six orders for Russian imports to add to four previous imports from Russia.

From about 2014 onward, China began efforts to win reactor export orders. It appeared to have won orders in Turkey (CAP1000/CAP1400) and the UK (CGN HPR1000), and it planned to carry out the construction for two reactors in Romania using Canadian technology, but those projects all collapsed. Its only exports have been six units to Pakistan, four dating back to before 2011. Little has been published about the factors that led to these orders for Pakistan, but the conspicuous failure to win export orders elsewhere suggests special political factors were involved in Pakistan.

China is increasingly dominating world nuclear statistics and is likely to overtake France in the next couple of years to become the country with the second largest nuclear capacity in the world (behind the United States). In May 2025, it had 57 operating reactors, and it accounts for nearly half (28) of the reactors under construction in the world in 2025. However, in terms of its contribution to China's electricity supply, in 2023 nuclear was less than 5 percent, and the reactors under construction are likely only to cover demand growth. New low carbon generating capacity in China is dominated by renewables. It was reported that, in April 2025, the capacity of renewables plants in China had reached 1,400 GW, compared to 56.5 GW of nuclear capacity.

China is now explicitly excluded from bidding by the potential nuclear markets in Europe, so it seems likely the Chinese nuclear industry will continue to rely mainly on its home market. Whether China judges it worthwhile to try to win the few orders likely to be placed in the developing world remains to be seen.

Russia / Russia, via its vendor Rosatom, was the first country to offer modern reactors with a core-catcher with its AES–91 design (sold to China). In 2006, it launched its AES-2006 design, which it claimed met all the European safety standards at the time. There were ambitious targets for orders for the home market, but by 2025 only four new reactors using the AES–2006 design had been completed, with two under construction and a further two using its successor, VVER–TOI, under construction. Rosatom was much more successful in export markets, accounting for the majority of world nuclear export orders from 2010 onwards. This includes eight orders from China and six from India. However, Rosatom's most impressive achievement probably was its exports to countries with little or no existing nuclear capacity. These included reactor sales to Bangladesh (two), Belarus (two), Egypt (four), Iran (one), and Turkey (four). Some other prospective orders never materialized; for example, to Jordan and Vietnam.

The factors behind this export success appear to have been Russia's offer to finance the purchase and the possibility of it taking an ownership stake in the power company (as in Turkey). Also, Rosatom is willing to sell to markets like Iran that would have been politically infeasible for other suppliers.

Rosatom has been relatively unsuccessful in Europe, apart from its orders to Belarus. An order for Finland, Hanhikivi, was abandoned in 2021 before construction started, following Russia's invasion of Ukraine, and an order for Hungary, Paks 2, placed in 2014 was only expected to start construction in 2025. Plans to submit the Russian design for evaluation by the UK safety regulator in 2015 were not proceeded with. The Russian invasion of Ukraine means Rosatom is likely to be excluded from European markets for the foreseeable future.

Russia's most recent export order was placed nearly a decade ago, and it currently has few export prospects. Several factors may explain this. One is a shortage of human and financial resources. Rosatom is reportedly struggling to recruit sufficiently skilled workers, and the strain on its financial institutions of providing loans, typically $5 billion per reactor, may be telling. Also, it may have exhausted the stock of new reactor markets. Its exports have often been to countries that have long aspired to own nuclear power plants, like Egypt and Turkey, but had never been able to place orders, often for reasons of finance. As with China, many markets will be closed to Russian exports, and it seems unlikely that Rosatom will win large numbers of nuclear exports.

REACTOR LIFE EXTENSION

Given the length of time from nuclear project inception to first power—typically 20 or more years—the main factor in determining the world's nuclear capacity up to 2050 will be the extent to which the existing stock of reactors can be extended beyond their design life, which is usually assumed to be 40 years. Life-extension is much cheaper than building new capacity and less problematic in terms of public consent. However, operations and maintenance (O&M) costs tend to rise significantly over time as systems reach the end of their life and must be replaced. There is also the cost of any safety upgrades the national nuclear regulator might require.

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About 60 percent of the world's nuclear capacity is in three countries: the United States (26 percent), France (17 percent), and China (15 percent). Nearly all of China's capacity is less than 20 years old, so life-extension is not an issue there for the next two decades. The United States and France are a different story.

US / As of 2023, the United States had 94 reactors in operation, accounting for 18.5 percent of US generation. Twenty-seven commercial reactors have been closed. Apart from the two new reactors at Vogtle, all the operating reactors were ordered before 1975. More than 100 orders and all those placed after 1974 were cancelled between 1974 and 1981. So, apart from Vogtle, the designs in operation date from the early 1970s or earlier, well before the Three Mile Island accident and the design changes it induced.

In the United States, reactors have a fixed license period of 40 years and must close at the end of that period unless the NRC grants a life-extension. By 2030, 84 of the 94 operating reactors will have reached 40 years, and 45 will be more than 50 years old.

Beginning in 1998, the NRC began to accept applications to extend licenses by 20 years. Nearly all the operating reactors have been life-extended. In 2018, the NRC began to accept applications to extend life from 60 to 80 years. Eight reactors have completed this process successfully and seven more are under consideration by the NRC.

There has been considerable publicity about the proposals to reopen two of the closed reactors, Three Mile Island 1 and Palisades. Fourteen reactors have closed since the lifetime extension option became available in 1998, including nine that had already had their lives extended. However, only four of those have closed since 2018, including Three Mile Island 1 (2019) and Palisades (2022), and reopening reactors shut down for seven or more years might not be feasible. So, reopening closed reactors is unlikely to be an important factor in the United States or elsewhere.

Life-extension in the United States has not required plant upgrades. Owners need only demonstrate the reactors still meet the safety standards in place when they were first licensed, plus the relatively small number of mandatory upgrades applied to all reactors. As a result, life extensions require only paper studies and are achieved at low cost. Despite this, reactors in US states with competitive electricity markets are only surviving because of large state subsidies despite them nearly all being amortized long ago. The lifespan of US reactors is likely to depend more on their economics and on the willingness of state or federal authorities to provide subsidies than on their ability to be licensed.

France / In 2024, France's 56 reactors accounted for 67 percent of French generation. That percentage is high, but below France's normal level of 75 percent or more. The decrease was because a generic fault—stress corrosion cracking of pipework—required lengthy closures of many reactors to carry out inspections and repair work.

As in most European countries, France's reactors have a rolling license period that is renewed after each maintenance and refueling shutdown. Unlike US reactors, there is no fixed age at which the reactors must be closed. Nevertheless, every 10 years they must undergo a mandatory, in-depth "Periodic Safety Review" to determine what measures will be needed to allow the reactor to remain in operation for a further 10 years. This will determine what upgrades and replacements are required.

By 2024, half of France's reactors had reached 40 years of operation. By 2030, all but eight will have reached 40 years. By 2038, the first-built French reactors will reach 60 years of operation. So, if life extension beyond 60 years is not approved by the French nuclear regulator, then French nuclear capacity will fall sharply. France plans to order six new reactors (one every 18 months) using the EPR2 design, but since the first of these is not expected to be completed before 2038, this program will do no more than somewhat slow the reduction in nuclear capacity if life-extension beyond 60 years is not allowed.

When EDF announced its intention to life-extend its French reactors in 2014, it committed to upgrade them to as near current safety and security standards as possible. As a result, the process has proved expensive, with EDF spending about €5 billion ($5.9 billion) per year to replace worn parts (e.g., steam generators) and install upgrades. It was not until 2021, three years after the oldest reactors reached 40 years of operation, that the French safety regulator Agence Securité Nucléaire published the full list of upgrades that would be required for the oldest set of reactors. Some upgrades were relatively straightforward and easy to implement, although not necessarily cheap to carry out; for example, upgrades to the backup diesel generators. However, other issues proved more problematic; for example, designing retrofitted core-catchers and strengthening the shell to withstand aircraft impact. The majority of the more complex upgrades have not been carried out yet, and their cost will remain very uncertain until the work is done.

Life-extending a reactor by 20–40 years means giving a whole new operating life to an old design that would not be considered if it were offered as a new reactor.

Life extension issues / Life-extending a reactor by 20–40 years effectively means giving a whole new operating life to an old design that would not be considered if it were offered for a new reactor. In other words, life-extended nuclear power plants would not come close to meeting the standards required for new reactors. This raises several important safety questions: How comfortable, for example, would the public feel if much of the aircraft fleet were operating long after the end of its design life? The promise by EDF to upgrade the plants to as near current standards as possible raises the question, how near is that? If it is not that near, the promise is empty.

Another issue is that significant parts of the plant will not be accessible to determine their condition because of the level of radioactivity. So, the condition of those areas can only be estimated by extrapolation from the condition of similar materials; for example, those recovered from retired reactors.

There is also the issue of O&M costs of life-extended reactors. The evidence from the United States is that a high proportion of operating reactors have only been able to remain in service because of substantial subsidies from state governments or because they are in regulated states where they are not required to be economically competitive.

CONCLUSION

Despite a major public relations push in the media and with policymakers for new nuclear, the anticipated nuclear revival will not happen because of the fundamentals of the technology in terms of cost, construction time, and reliability. Commercial financiers will remain very reluctant to fund these projects if any of the risk falls on them. Nuclear projects also take far too long before a return on investment can begin to be earned, typically more than 15 years from investment decision to first power.

SMRs will not meet their goals. For the technologies to succeed, it will not be enough for them to be cheaper than large reactors; they will have to compete with other low-carbon options such as renewables and energy efficiency measures. Gen IV designs may come along in the future, but experience suggests they are unlikely to progress to commercially available designs. Large reactor designs appear to be obsolescent. The ideas that were claimed would solve past problems were tried and failed in the previous attempted renaissance, and no new ideas to improve large reactors are emerging.

Life extension will keep nuclear capacity going for some time, although if there is an incident or accident that exposes the gap between past and current safety standards or if there is a serious equipment failure from undetected deterioration of components, the situation may change. A bigger challenge is that the older reactors get, the higher the O&M costs will tend to be. Already in the United States, life-extended reactors that are fully amortized and need only cover their O&M costs from market revenue are struggling to compete with the cheapest option, natural gas dual-cycle generation. As renewables and storage technologies continue to get cheaper, the economics of old nuclear plants will come under increased scrutiny in countries where reactors must compete in the wholesale electricity market.

Few utilities are prepared to risk their own money on new nuclear projects. In the past, investing in nuclear was not a financial risk to them because whatever costs were incurred could be passed on to consumers through regulated rates. Now, utilities that must compete in wholesale markets would be risking a large amount of their own money if they were to build new nuclear plants. New nuclear programs will have to rely on government finance, ownership, and government-imposed power purchase agreements so they are fully insulated from the wholesale electricity market. The record of utilities with nuclear experience in appraising nuclear technologies is far from good, but governments do not have the skills necessary to meet the requirements imposed by managing nuclear projects.

The mystery is why the nuclear industry retains any credibility. Throughout its history, nuclear proponents have made rosy claims about the safety and economics of the next generation of nuclear projects, but they have all gone unfulfilled. In the early years of nuclear development, claims that processes such as learning by doing, technology change, standardization, economies of scale, and economies of number would result in improved performance had an intuitive credibility. However, after repeated failures to produce the forecasted results, why are renewed claims of this type being taken seriously now? Is it simple ignorance of the past, or are there other factors that make policymakers cling to a belief in nuclear?

Why are people unwilling to consider the reason that nuclear projects fail so often is the technology itself? Instead, they fall back on old, tired excuses such as unsympathetic regulators, delays caused by local protestors, and simply not getting the right "recipe" for building nuclear power plants. In March 2025, UK Prime Minister Keir Starmer claimed:

> For too long, blockers have had the upper hand in legal challenges—using our court processes to frustrate growth. We're putting an end to this challenge culture by taking on the NIMBYs and a broken system that has slowed down our progress as a nation.

Starmer has created a taskforce to streamline safety regulation, but he has offered no evidence that the delays and cost escalation suffered at Hinkley Point C are in any way attributable to opposition or obstructive regulation—and he cannot because there is none.

The problem is not so much that money will be wasted on large numbers of uneconomic facilities. Rather, it is the opportunity costs of the time and human resources that are consumed by nuclear power and not available to other, quicker, more cost-effective and less financially risky options. We appear now to be facing serious risks from climate change, and there will not be a second chance if we fail to tackle it because too many resources are being consumed by an option—new nuclear—that will not work. R

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