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Nuclear energy's revival is still modest outside of China

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Confidential

Key points

Thirteen years after the Fukushima disaster, the world is returning to nuclear power: China has embarked on building a vast fleet of plants to become the world's second-largest nuclear power producer, just behind the United States and ahead of France. In the rest of the world, new nuclear plants are springing up, while in Japan and the United States reactors shut down after accidents or for economic reasons are being reopened. As a result of the energy crisis in 2021 and the war in Ukraine, as well as the need to reduce carbon emissions, several countries that had decided to abandon the atom are reconsidering their decision.

Outside of China, however, the recovery remains tentative: the number of new power plants inaugurated or under construction is still far from the levels of the nuclear boom years of the 1970s and 1980s. Requiring billions of dollars in investment and sometimes taking more than a decade to build, nuclear power remains a major financial challenge in most countries around the world. The industry also faces fierce competition from renewable energy, with new capacity installations exceeding the most optimistic forecasts year after year.

The nuclear industry is hoping to revive its fortunes thanks to small modular reactors (SMRs). But despite the enthusiasm of American tech giants (Google, Amazon, Microsoft, etc.), faced with the power needs of their artificial intelligence models, the commercial development of SMRs remains hypothetical. Only one recently developed model is currently in operation, in China. As for the Western players, they have yet to demonstrate their technological maturity and find commercial outlets.

Russia and China will therefore continue to dominate the market for new reactors in the coming years. These two players, which are increasing the number of projects on their own soil, are also taking advantage of the unlearning of the nuclear industry in the United States and France to win export contracts. However, Russia may suffer the consequences of Western sanctions, which are disrupting its industry, while a number of challengers, such as KHNP, are emerging.

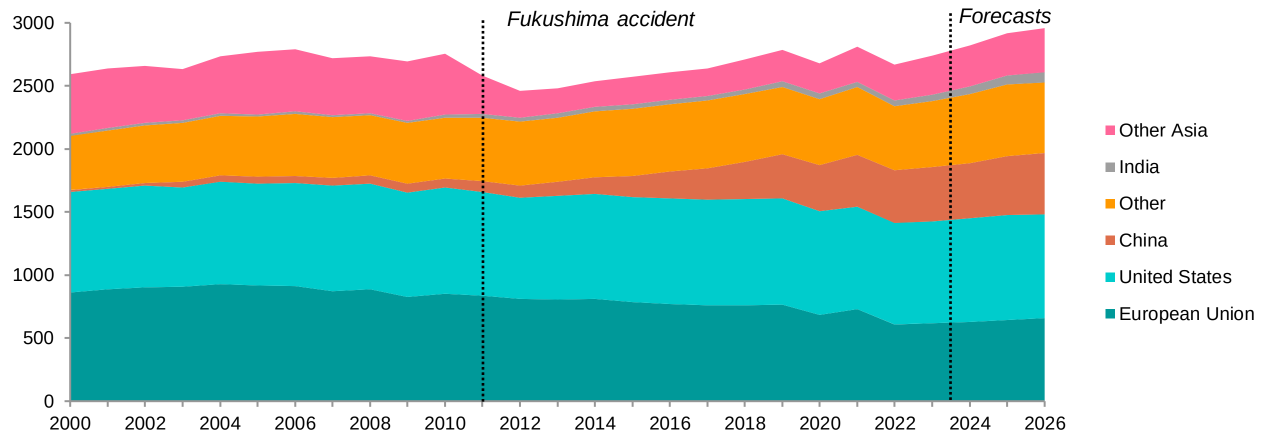
The return of nuclear power is not without consequences for the uranium market: despite rising projections, uranium production may struggle to keep pace with rising demand. Given the concentration of supply in the hands of a handful of players, securing their supply is also likely to prompt governments to turn to other markets, particularly for the production of enriched uranium, a process largely controlled by Russia.

1. Nuclear power had returned to pre-Fukushima levels, thanks to China

Since its development in the 1950s, civil nuclear power has grown rapidly, driven by the most advanced economies. From less than 2% in 1970, nuclear power's share of global electricity production reached **more than 17% in the mid-1990s**[1], before gradually declining in the early 2000s, due to the development of other energies (gas, renewables), the closure of reactors that had not been replaced, and the growing share of non-nuclear countries in global demand. **In March 2011, the Fukushima nuclear accident brought the industry to a sandstill and several countries decided to abandon nuclear power as too risky**. Global nuclear power generation fell from 2,629 TWh in 2010 to 2,346 TWh in 2012 . [2]

According to the International Energy Agency (IEA), **global nuclear power generation returned to its pre-Fukushima level of 2,788 TWh in 2019**, and is expected to reach a record 2,820 TWh in 2024 (figure 1). **This increase is almost entirely due to the growth of the Chinese fleet**, which has more than offset plant closures elsewhere in the world, mainly in the European Union. From an insignificant 17 TWh in 2000, Chinese production has increased sixfold between 2010 (74 TWh) and 2023 (433 TWh)[3], and the country now has 56 reactors in operation.

Figure 1: Nuclear power generation by region (TWh, 2006-2026)



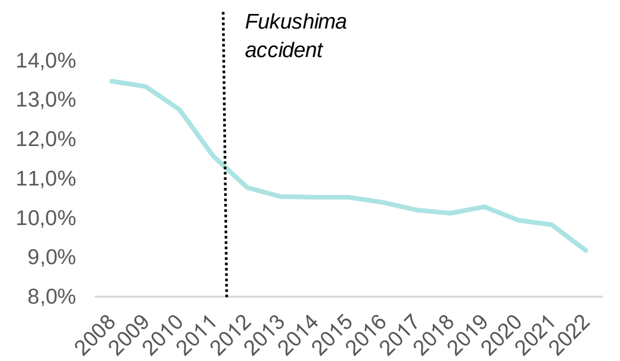
Source: IEA

Several factors explain this recent comeback. The global energy crisis - exacerbated by the outbreak of war in Ukraine - has highlighted the growing dependence of governments on fossil fuel imports, against a backdrop of the race to achieve carbon neutrality. **Nuclear power therefore appears to be a source of electricity that can meet the needs of both energy security and energy transition**: unlike solar and wind power, it can produce electricity continuously. What's more, as memories of the Chernobyl (1986) and Fukushima disasters fade, public opinion is less and less hostile to this technology.

However**, nuclear power's share of global electricity generation is steadily declining; after falling below 10% in 2020, its share reached 9.2% in 2022** (figure 2) and is expected to remain stable at its current level (9%) until 2050[4], according to the IEA. Other energy sources have grown faster: first natural gas, and more recently solar and wind power.

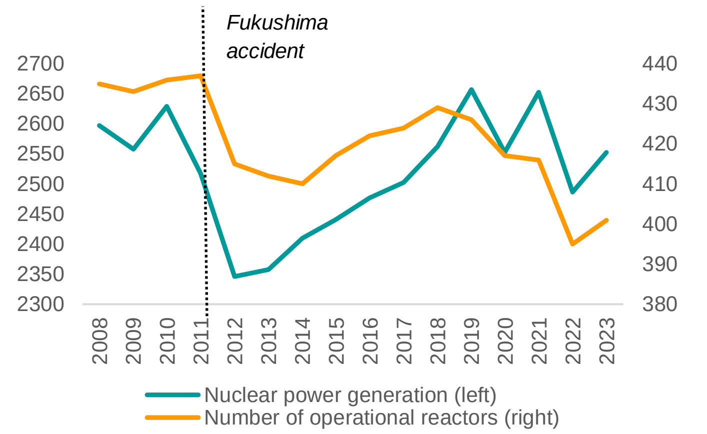
[1] IEA, Electricity *Information*
[2] IAEA, Trend in Electricity Supplied
[3] IEA, *Electricity 2024, Analysis and forecast to 2026*, January 2024
[4] AEF, *Comment expliquer le "grand come back" du nucléaire*, December 2023

Figure 2: Share of nuclear power in world electricity generation (in %)



Source: IEA

Figure 3: Nuclear electricity generation (left, in TWh) and operating reactors (right)

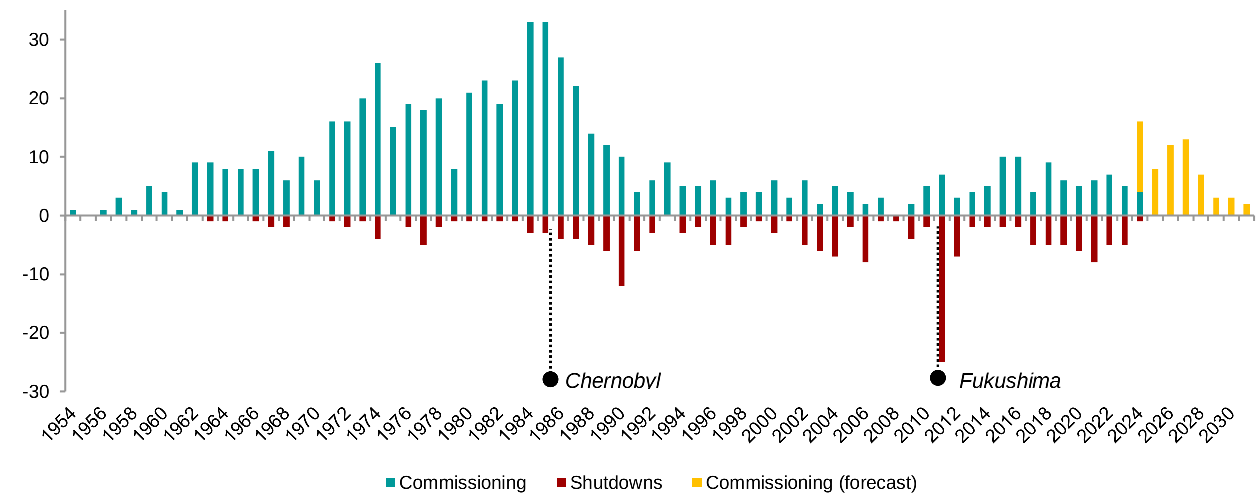


Source : IAEA

2. The upturn is expected to continue at least until the end of the decade

Five reactors will have reached commercial operation by 2024, and two more are expected to do so by the end of the year. This confirms the upturn of recent years, although it is still far from the very optimistic forecasts of the World Nuclear Report (sixteen new reactors expected worldwide, figure 4). This upturn will continue until the end of the decade: between 2024 and 2031, some 60 commercial reactors with a total installed capacity of 64 GW are expected to be built worldwide, adding to the approximately 371 GW already in operation at the end of 2023 (IAEA)[5]. **The global nuclear fleet will thus grow by more than 17% over the next seven years.** However, the rate of construction is still **well below the records set in the 1970s and 1980s**, when the 1973 oil crisis prompted the United States and several European countries to speed up their new-build programmes, while the USSR was also developing its civil nuclear fleet.

Figure 4: Reactor starts and stops (units per year)



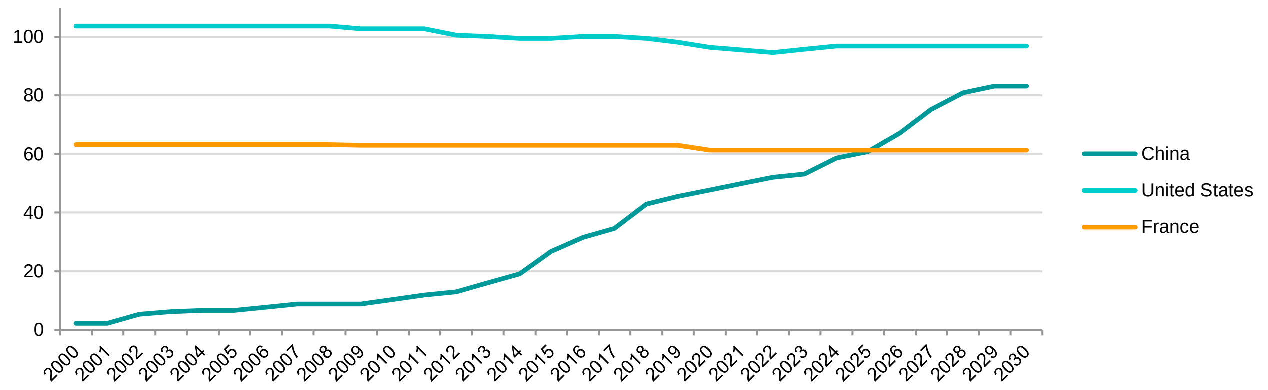
Source: World Nuclear Report data, GSA visualisation

[5] IAEA Releases Nuclear Power Data and Operating Experience for 2023, International Atomic Energy Agency, 20 August 2024

2.1. China will continue to drive global nuclear growth

As in the past decade, **China will play a dominant role in the future growth of its nuclear power plants**: it will build **28 new reactors, representing 45% of the total** expected deliveries by 2030. **Its installed capacity will then reach 83 GW, putting it on a par with the United States** (93 GW of projected capacity) – and enabling it to dethrone the world's current number two, France (figure 5).

Figure 5: China's installed nuclear power capacity to 2030, in GW



Source: World Nuclear Report data, GSA analysis

China's unprecedented appetite for nuclear power is driven primarily by its **desire to move away from "all-coal" power generation**, both to meet its international commitments to **reduce** CO_2 emissions and to tackle the pollution peaks affecting its cities. It is also anticipating the massive electrification of many sectors, such as land transport. **However, China does not want to replace coal (for which it is autonomous[6]) with natural gas**, which would risk making it dependent on the United States, the world's largest exporter of LNG exporter.

In December 2011, China's National Energy Administration (NEA) initially set **a target of installing up to 300 GW of nuclear power in one to two decades**. But there are a number of obstacles to this goal, not least dependence on foreign suppliers: at that time, the majority of the country's operating reactors still came from the United States, China, France or Canada. In addition, the Fukushima accident prompted the authorities to suspend approvals for the construction of new power plants and to launch a safety inspection of the existing fleet.

The Thirteenth Five-Year Plan (2016-2020), which for the first time limited the share of coal in the energy mix, therefore set a more realistic target: 58 GW by 2020. This target was not met, but the next five-year plan (2021-2025) raised it again, to 70 GW by the end of 2025. Again, Beijing will be slightly behind its targets. **In the meantime, China has secured its technological autonomy**: all the reactors currently under construction in the country are made in China: CAP1000 and CAP1400 (derived from Westinghouse's AP1000), and above all Hualong One (or HPR1000), the first reactor designed entirely in China. The construction of two CFR-600 fast neutron reactors, expected by 2026 - a few years behind the original schedule - will finally enable the country to "close the fuel cycle": these so-called fast breeder reactors will allow spent fuel from conventional power plants to be reprocessed and reused. With the exception of uranium ore imports, China is therefore well on the way to controlling the entire fuel cycle, from enrichment to reprocessing and conversion.

2.2. In the United States, will the AI craze and subsidies last?

In recent months, the revival of the nuclear sector has become a **major issue in the debate about the development of the US electricity mix**. Nuclear power's share of national electricity production has hovered

[6] Coal: despite record demand from Asia, the beginnings of a decline, Global Sovereign Advisory, April 2024

around 20% since the late 1980s, and the decline of coal has mainly benefited natural gas and, more recently, renewable energies.

2.2.1 Big Tech warms up to the atom

But the **growing needs of the tech giants, accentuated by their massive investments in artificial intelligence** (AI,which requires energy-hungry supercomputers and datacentres), are sparking renewed interest in nuclear power. Estimates of the increase in electricity requirements for these infrastructures by 2030 range from +170% according to McKinsey[7] to over 300% according to Goldman Sachs[8]. According to Goldman Sachs, ***data centres* will account for 11.7% of total US electricity consumption by that date, up from 3.7% in 2023**.

While the development of AI has caused their carbon emissions to soar, moving them further away from their '*net zero'* commitments, the tech giants have so far relied on renewables, via solar and wind power purchase agreements. But the intermittent nature of these sources, and the long lead times required to connect them to the electricity grid, have led them to turn to nuclear power. On 20 September 2024**, Microsoft signed a 20-year power purchase agreement with Constellation Energy that will enable the restart of the Three Mile Island nuclear power plant in Pennsylvania**. Although a number of administrative steps remain to be completed, this contract is symbolic: the plant was the site of the country's worst serious nuclear incident in 1979 (involving reactor No. 2, which will remain closed).

The other GAFAMs are not to be outdone. After acquiring a cloud hosting centre connected to a nuclear power station in March, **Amazon** announced three agreements on 16 October 2024: two purchase agreements with grid operators for electricity to be generated from small modular reactors (SMRs, see below), and a direct investment, of an unknown amount, in X-Energy, which is developing an SMR[9] . After announcing its interest in fusion (theoretically safer than fission, but not yet commercially available) and SMRs[10] (see below), on 3 October 2024 **Google** made its interest in buying conventional nuclear power official[11] and, on 14 October 2024, announced the signing of a *power purchase agreement* (PPA) with the start-up Kairos Power. The agreement covers 500 MW until 2035, which should be equivalent to the production of six or seven units of Kairos Power's small SMR (75 MW). **Apple** has discreetly added nuclear power to the list of energies it considers "clean"[12] **. Meta**'s scientific director**,** Yann LeCun, has spoken of the benefits of locating its AI infrastructure near nuclear power stations[13]. Finally, **OpenAI** has made no announcements, but has presented its plans to build several 5GW *datacentres* to the federal government, while its chief executive Sam Altman is trying to build a "coalition" to invest in the infrastructure, including energy, needed for AI[14]. He is also a lead investor in start-ups **Helion Energy** (fusion) and **Oklo** (SMR).

2.2.2 Biden-era subsidies played a crucial role in the sector's revival

The return to favour of nuclear power in the United States can also be explained by the increase in support from the Biden administration. The **Civil Nuclear Credit Program**, which is part of the Bipartisan Infrastructure Law (BIL), adopted in 2019, **has made it possible to postpone the closure of two reactors in California, scheduled for 2024 and 2025, and should benefit other sites**. At the same time, the Inflation Reduction Act (IRA, 2022) introduced **specific subsidies for nuclear electricity: $15/MWh for existing plants, and $25/MWh** (or a tax credit of 30% of the investment) **for new plants**. Even more than the Microsoft contract, this aid played a crucial role in the revival of *Three Mile Island*: the plant closed in 2019 because it was no longer competitive with wind power and natural gas[15]. Finally, Holtec is to receive a loan under the IRA to

[7] How data centres and the energy sector can sate AI's hunger for power, McKinsey, 17 September 2024
[8] AI is poised to drive 160% increase in data center power demand, Goldman Sachs, 14 May 2024
[9] Amazon signs agreements for innovative nuclear energy projects to address growing energy demands, Amazon press release, 16 October 2024
[10] Google Could Use Small Nuclear Reactors to Power Data Centers, Power Magazine, 24 September 2024
[11] Google considers sourcing from nuclear power plants, says CEO Pichai, Nikkei, 3 October 2024
[12] Apple 2030 - A Plan as Innovative as our Products, Apple, consulted on 09 October 2024
[13] Is nuclear energy the zero-carbon answer to powering AI?, Financial Times, 3 October 2024
[14] Altman Infrastructure Plan Aims to Spend Tens of Billions in US, Bloomberg, 4 September 2024
[15] Microsoft's Three Mile Island Deal Signals a Broader Nuclear Comeback, Wired, 24 September 2024

restart the Palisades plant in Michigan. At least two other reactors could be restarted quickly, according to the US administration[16].

2.2.3 Headwinds

But there are a number of pitfalls to avoid. **The tech and AI giants need to meet their energy needs very quickly**. There are only a handful of nuclear power stations that can be restracted quickly, and it takes years to build new units: construction of Vogtle-3 and Vogtle-4 began in... 2009. The commercial launch date for the first SMRs remains highly hypothetical. What's more, tech's long-term energy requirements are uncertain: AI computer models and processors are evolving rapidly. Their energy efficiency is therefore likely to improve significantly, while some of the calculations will be decentralised to users' devices, reducing the need for supercomputers.

As elsewhere in the world, the **revival of nuclear power will also have to compete with the record installation of renewable capacity**: the Energy Information Administration (IEA)[17] estimates that wind, solar and hydroelectric power will generate more than 20% more electricity in 2025 than in 2023[18] . New solar capacity alone (123 TWh) is expected to exceed the expected demand growth (107 TWh).

Finally, while a **Donald Trump** victory in the November 2024 presidential election could call into question subsidies linked to the BIL or the IRA, the Republican candidate says he is in favour of reviving nuclear power.

2.3. In Europe, nuclear is no longer a taboo, but a true recovery has yet to materialise

Western Europe is the market where nuclear power has declined the most after Fukushima: **installed capacity fell by 22% between 2010 and 2024 (-27 GW), mainly due to the closure of the German fleet** (-18 GW), a process that started in 2002, accelerated after Fukushima and ended in 2023. Belgium was due to follow suit, while France legislated in 2014 to reduce the share of nuclear power in its electricity mix to 50% by 2025. **But the energy crisis, followed by the war in Ukraine, reversed the trend.** Belgium has postponed its nuclear phase-out by ten years and France has abandoned any reduction, instead announcing six new generation pressurised water reactors (EPR2) - not yet financed - with the potential for eight more. The Czech Republic, Bulgaria, Hungary and Sweden have also announced projects. In total, **two nuclear reactors are currently under construction in the EU** (Flamanville in France and Mochovce-4 in Slovakia); **a further twelve are planned and financed, most of them by the end of 2030** (**+13.5 GW**); and a further 45 are planned in the longer term (+28.3 GW)[19], with no firm commitments. Outside the EU, the UK is expected to start up the two Hinkley Point reactors in 2030-2031.

The return of nuclear power could be accelerated by the possible **restart of part Germany's nuclear fleet**. This scenario is no longer so unlikely: in the run-up to the parliamentary elections in September 2025, the **CDU/CSU** (conservatives) are campaigning on this issue, while the **AfD** (far right) has historically been pro-nuclear. Even the **FDP**, a member of the "green-yellow-red" coalition that oversaw the last power plant shutdowns, called at the end of 2023 for a halt to the dismantling of these plants, in order to keep open the possibility of reopening them[20]. According to a study carried out in July 2023 by Radiant Energy Group[21], **it is technicall possibler to quickly restart at least eight reactors (around 10 GW)**: the dismantling of these units, the last to be shut down, has not yet begun and their main equipment is still operational. However, the operators of at least five of these reactors have since obtained dismantling authorisations from the Länder concerned. **In order to stop the dismantling of these plants, which will take until 2035-2040 depending on the site, those in favour of restarting German nuclear power plants will need to win a majority in the Bundestag in 2025 and in the Länder concerned**, in elections to be held between 2026 and 2028.

[16] US looks to resurrect more nuclear reactors, White House advisor says, Reuters, 8 October 2024
[17] Solar and battery storage to make up 81% of new U.S. electric-generating capacity in 2024, Energy Information Administration, 15 February 2024
[18] EIA: U.S. energy transition to speed forward through 2025, Institute for Energy Economics and Financial Analysis, January 2024
[19] Nuclear Power in the European Union, World Nuclear Association, 13 August 2024
[20] Allemagne: les libéraux remittent en cause l'arrêt du nucléaire, Le Point, 1er September 2023
[21] Restart of Germany's nuclear reactors: can it be done?, Radiant Energy Group, July 2023

2.4. In the rest of Asia, the recovery remains modest

2.4.1 Japan returns to the atom, but stops short of ordering new plants

More than a decade after the Fukushima disaster, **Japan is firmly committed to revitalising its nuclear fleet**. Of the 54 reactors in operation at the time of the disaster - all of which were shut down afterwards - **twelve have already been restarted** (representing around 11 GW of capacity) and **thirteen others are in various stages of restart** (12.6 GW), in addition to **two reactors under construction**, each with a capacity of 1.3 GW. As a result, the nuclear fleet produced 81 TWh of electricity in 2023: 50% more than in 2022, but almost four times less than in 2010.

Japan has not started to build any new reactors: the two projects currently underway were started before Fukushima. **But each new administration proves to be more pro-nuclear than the last**. While the Abe and Shuga governments limited the use of nuclear power as much as possible, in February 2023 Fumio Kishida's government decided to maximise its use as part of the country's "green transformation" strategy[22]. The Ishiba Executive, formed in October, has emphasised this shift by calling for the reopening of as many reactors as possible[23]. While electricity consumption has been declining for several years, and forecasts have regularly been revised downwards, the executive is now counting on a significant upturn, thanks in particular to **a large number of projects for semiconductor factories and *data centres* linked to AI**[24] . The powerful Ministry of Economy, Trade and Industry (METI) therefore intends to write the revival of nuclear power into the marble of Japan's 7th Strategic Energy Plan, currently being drawn up .[25]

2.4.2 In India, nuclear will grow strongly, but will cover a small share of the country's needs

India has so far largely missed its nuclear development targets: the capacity of the 23 reactors of the **Nuclear Power Corporation of India Ltd** (NPCIL, which has a monopoly on building and operating nuclear power plants) does not exceed 8 gigawatts, compared with... 63 GW envisaged in the Twelfth Development Plan of 2012. The state-owned group is set to almost triple its installed capacity by 2032 **with eight additional reactors (6.8 GW),** half supplied by Russia's Rosatom and the other half of Indian design. It has also started serial construction **of 10 additional reactors** of 700 MW each. Construction of the two front-runners, Kaiga 5 and 6, has begun[26] , although the target of completing all ten by 2030[27] seems optimistic.

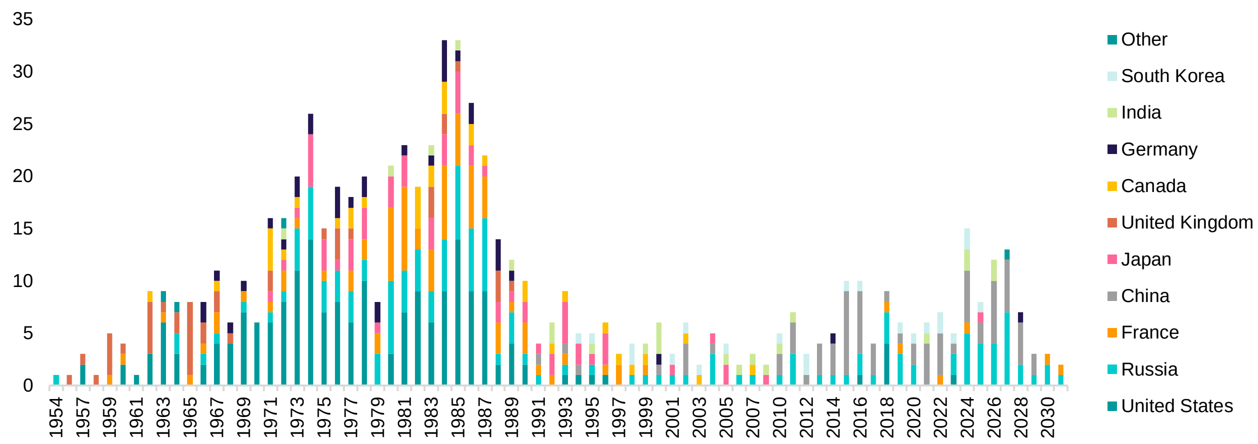
However, nuclear power will continue to provide only a tiny proportion of the country's electricity needs: at best 21.8 GW in 2032, compared with peak demand expected to reach 334 GW in 2030[28]. To make up for this shortfall, NPCIL has recently sought to engage the private sector. It has proposed a public-private partnership with major groups (Tata Power, Adani, Vedanta, Reliance Industries, etc.) to finance power plants to the tune of USD 26 billion[29] . The executive has also proposed joint venture projects between NPICL and industrial groups to build 220 MW SMRs[30]. These announcements have not yet been implemented.

[22] Promotion or Regulation? Blurred Lines in Japan's Nuclear Energy Policy, Nippon.com, 15 February 2024
[23] New Economy Minister Calls For 'As Many Reactor Restarts As Possible', Nucnet, 2 October 2024
[24] Japan's 7th Strategic Energy Plan: Toward merging Carbon Neutral and the Circular Economy approaches, Mistubishi Research Institute, 23 August 2024
[25] Is the Plan to Build New Nuclear Power Plants as Part of GX Efforts Realistic?, Renewable Energy Institute, 15 August 2024
[26] Kaiga steam generator arrives on site, World Nuclear News, 7 August 2024
[27] India goes for "fleet mode" construction, Nuclear Engineering International, 23 October 2019
[28] Report On Optimal Generation Capacity Mix For 2029-30, Central Electricity Authority, 2023
[29] Exclusive: India seeks $26 billion of private nuclear power investments, Reuters, 21 February 2024
[30] It's time for India to unleash private investment in nuclear energy, Nikkei Asia, 29 August 2024

3. A solid Sino-Russian duopoly in new reactor supplies

Dominated for several decades by Western manufacturers - mainly American, French and, to a lesser extent, Canadian - **the construction of nuclear reactors, on both domestic and export markets, is now subject to a veritable Russian-Chinese duopoly**.

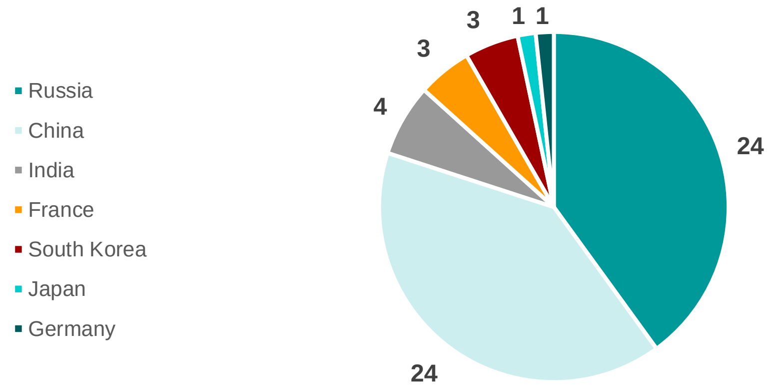
Figure 6: Deliveries of new reactors, by nationality of supplier



Source: World Nuclear Report data, GSA visualisation

This situation is set to continue in the years ahead: of the sixty or so commercial reactors scheduled for delivery worldwide between 2024 and 2031, **24 will be supplied by Russia** - mainly through Rosatom - **and as many by the various Chinese nuclear players** (CGN, CNNC and SPIC).

Figure 7: Deliveries of new reactors, 2024-2031, by nationality of supplier



Source: World Nuclear Report data, GSA visualisation

3.1. Now self-sufficient, China turns to exports

Although Beijing is still partly dependent on the American company Westinghouse for the construction of some power plants (see above), the entry into service of the *Hualong One* in 2021 illustrates the country's emancipation in the field of nuclear energy: this pressurised water reactor is considered to be the **first third-generation Chinese reactor entirely of Chinese design**, even if some instrumentation and control components are still supplied by Areva (France) and Siemens (Germany).

This model is the cornerstone of Beijing's civil nuclear ambitions: since it was first commissioned, five more have been delivered and eleven more are under construction in China. This volume allows CGN and CNNC, who jointly developed the model, to take advantage of **economies of scale** to limit delivery times and construction costs. The unit cost of a 1GW reactor is estimated to be between USD 3 and 3.5 billion[31]. This 'serialisation' means that China can now look forward to export contracts: the first two were commissioned in Pakistan in 2021 and 2022, and a third has been commissioned by CNNC in 2023[32]. Hualong One's commercial prospects in other parts of the world remain to be seen: in Saudi Arabia, where competition with the United States will be fierce; in Argentina, where the election of Javier Milei could jeopardise the completion of the Atucha III contract[33] ; in Turkey, and so on.

3.2. Will sanctions challenge Russian dominance?

A major player in the nuclear power industry since the 1970s, the Russian state-owned group **Rosatom has weathered the post-Fukushima storm better than its Western rivals**: it has maintained a relatively buoyant order book, thanks to contracts in Russia, Belarus, China and India. In particular, the group has won major contracts outside its traditional sphere of influence, sometimes in the face of strong international competition: it won the mega-contracts for El Dabaa in Egypt and Akkuyu in Turkey (four reactors each), as well as the Roopur contract in Bangladesh.

At home and abroad, Rosatom's power plants all use variants of the third-generation VVER-1200 reactor, which also allows the state-owned group to exploit economies of scale: their cost is estimated at around USD 3 billion, comparable to China's Hualong One[34,35].

But the **Western sanctions that have hit Russia since its invasion of Ukraine in February 2022 could jeopardise the Russian nuclear export model**. So far, Rosatom has only had one contract cancelled (Hanhikivi 1, in Finland[36]) and has been able to complete its European contracts signed before the war. In Slovakia, Mohcovce-3 came into service in 2023 and Mohcovce 4 is under construction. Hungary has not called into question the contract to extend its Paks power station; work is due to start in 2025. However, **Rosatom has not signed any new firm contracts abroad since February 2022, and Western sanctions are disrupting some emblematic projects, such as Akkuyu**, where Siemens' refusal to supply certain equipment has delayed the project by at least a year and forced Rosatom to turn to Chinese suppliers[37] .

Above all, the conflict has undermined one of the keys to Rosatom's success: its ability to offer contracts including the supply of nuclear fuel on a long-term basis and on favourable terms, thanks to its dominance in the enrichment market (see chapter 5.2.2). However, the **Russian-Ukrainian conflict has prompted several countries with Rosatom reactors to turn urgently to other fuel suppliers** (Westinghouse, Orano, Urenco, etc.): Ukraine of course, but also Bulgaria, Finland, the Czech Republic, Slovakia, etc. The EU has launched two programmes, led by Westinghouse (APIS, 2023) and Framatome (SAVE, 2024), to develop alternative supply chains for Russian fuel[38].

3.3. KHNP looks for growth, Framatome and Westinghouse must still recover

While the Russian-Chinese dominance of the nuclear reactor construction market is unlikely to be challenged in the short term, **Korea Hydro & Nuclear Power (KHNP)** could emerge as a rival. The South Korean group has built sixteen of the twenty-eight power plants in its home country, and is due to deliver four new reactors by 2033. **This revival in domestic orders has enabled KHNP to win its first export contracts**: it supplied the four reactors for the Barakah power plant (5.6 GW) in the United Arab Emirates, which will come on stream between 2020 and 2024. Since then, KHNP has been targeting Europe, where it faces competition from

[31] Nuclear Power in China, World Nuclear Association, 14 August 2024
[32] Hualong One exports new nuclear unit to Pakistan, Xinhua News, 16 July 2023
[33] Más cerca de Estados Unidos: Milei buscaría cancelar el proyecto de Atucha III con financimiento chino, Politica Argentina, 5 April 2024
[34] Russian nuclear power: Convenience at what cost? Bulletin of the Atomic Scientists, 2015
[35] Case Study of the VVER Project at Tianwan, China, Nuclear Energy Agency, 2014
[36] Finnish group ditches Russian-built nuclear plant plan, Reuters, 2 May 2022
[37] Turkish nuclear plant delayed by withheld Siemens parts, China to supplyReuters, 11 September 2024
[38] A new Euratom project will help diversify nuclear fuel supply, European Commission, June 2024

Westinghouse. The US group has launched legal proceedings against the contracts awarded to KHNP in Poland in 2023 and in the Czech Republic in July 2024, arguing that the Korean group uses its technologies and that it must obtain approval and a licence from the US government before exporting them.

As for the former Western nuclear leaders, Framatome and Westinghouse, they will have to regain their competitiveness, after one industrial failure after another. **The commissioning, in 2018 and 2019, of the two EPR reactors in Taishan (China) signalled the revival of the French nuclear power industry**, which had not built a nuclear power station since Civaux (France) in... 1999. The project was relatively well managed: the two units were delivered at a cost of around €12.5 billion, "only" 60% over the original budget[39], and one year behind schedule. The project, led by EDF (which took over Areva NP, now Framatome, in 2018) with two Chinese partners, CGN (51%) and Yudean (30%), validated the EPR technology, even though the operator had to shut down reactor no. 1 for several months on two occasions due to fuel sheath fractures and corrosion problems . [40]

Despite this success, **the EDF-Framatome tandem does not seem to have benefited from a learning curve for the EPR reactors launched later**. Olkiluoto-3 (Finland) was delivered in 2023, nine years late, while Flamanville (France) is due to reach that milestone this year, twelve years after the planned date. For both EPR projects, Framatome was faced with **colossal budget overruns**: Olkiluoto cost around €11 billion, compared with the €3.2 billion initially announced[41] . Flamanville cost even more: €13.2 billion, and even €19.1 billion according to the French Court of Auditors, i.e. 4 to 6 times more than the original budget. **These cost overruns were partly offset by the French government** through recapitalisations of Framatome (€2 billion) and EDF (€5.1 billion between 2017 and 2022). However, the problems experienced at Olkiluoto and Flamanville have been repeated in the UK, where the two Hinkley Point reactors, which started up in 2018, are due to be delivered between 2029 and 2031, four years late, and at a cost estimated at between €36.2 and €39.7 billion, compared with the €21 billion forecast.

The **US nuclear industry faces the same problem of loss of expertise**: before the delivery of Vogtle-3 and Vogtle-4 in 2023 and 2024, it had not delivered a new unit to the United States since 1996, with Westinghouse contenting itself with contracts in China. These two reactors were commissioned seven years late and cost around USD 30 billion, almost 75% more than expected[42]. This project was the cause of Westinghouse's bankruptcy in 2017. These setbacks were blamed on a poor choice of construction partners and the inability of a subcontractor**, Shaw**, to ensure the serial in series of certain components of the AP1000 reactors[43]**. Westinghouse has no current projects, but its order book could fill up**: it is expected to win a contract to build four reactors in China[44], is awaiting confirmation of a contract to build Poland's first power station[45], and could replace KHNP in Slovakia[46]. In the longer term, it hopes to build up to nine reactors in Ukraine[47].

4. An true revival will require a financial or technological breakthrough

4.1. Nuclear power has become one of the most expensive sources of electricity

How much does a megawatt-hour (MWh) of nuclear-generated electricity cost? There is no single answer to this question: **the levelized cost of electricity** (LCOE, i.e. taking into account all the costs over the entire life cycle of the plant) from **a new nuclear power plant depends on many parameters: financing, construction costs, structure of the electricity market**, etc.

[39] La filière EPR : rapport thématique, Cour des comptes, 2020
[40] Delays, extra costs, setbacks: key dates for the EPR reactors, AFP, 2 September 2024
[41] The World Nuclear Industry Status Report, 2019
[42] Georgia nuclear rebirth arrives 7 years late, $17B over cost, AP 25 May 2023
[43] How two cutting-edge U.S. nuclear projects bankrupted Westinghouse, Reuters, 2 May 2017
[44] The US' Westinghouse will supply four nuclear reactors for two projects in China, Enerdata, 2 September 2024
[45] Westinghouse and Bechtel Welcome Investment in Poland's First Nuclear Power Plant, Westinghouse press release, 24 September 2024
[46] Westinghouse Protests Czechia Nuclear Tender Decision, Westinghouse press release, 2 August 2024
[47] Westinghouse Congratulates Energoatom on Start of AP1000® Work at Khmelnytskyi NPP, Westinghouse press release, 15 April 2024

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4.1.1 Nuclear electricity prices are CAPEX-driven

The investment required to build a nuclear power plant runs into billions of dollars, and the work is spread over several years. **The capital expenditure (CAPEX) required for construction therefore represents a significant proportion of the final LCOE**, while the operating expenditure (OPEX: fuel, personnel, maintenance, etc.) are low: the opposite of a thermal power plant, where the purchase of fuel will represents the bulk of the costs over the lifetime of the plant.

The weight of the CAPEX is therefore a decisive factor in explaining the difference in the final LCOE in different markets: it is low in countries such as Russia, China and South Korea, due to lower labour costs and a strong base of expertise; conversely, in the United States and Europe, high salaries and the costs incurred by the "re-learning" of nuclear sites (training, delays, defective parts) accentuate the CAPEX. According to estimates by the Nuclear Energy Agency (NEA, an OECD subsidiary), the final LCOE varies from one country to country.

Table 1: Share of CAPEX and OPEX in the LCOE of nuclear electricity, USD/MWh

	CAPEX	OPEX, including:		LCOE	CAPEX weighting
		Operation and maintenance	Fuel		
United States	50.32	11.6	9.33	71.25	71%
France	47.51	14.26	9.33	71.1	67%
China	29.6	26.42	10	66.01	45%
Russia	26.88	10.15	4.99	42.02	64%
Japan	46.92	25.84	13.92	86.67	54%
South Korea	25.54	18.44	9.33	53.3	48%
India	32.89	5.43	9.33	47.64	69%
Slovakia	82.8	9.71	9.33	101.84	81%

Source: NEA. Figures for the average discount rate (7%)

The importance of the cost of capital also means that **financing conditions have a strong influence on the cost of the project, and therefore on the final LCOE**: according to the NEA models, the discount *rate*, i.e. the cost of short-term borrowing (itself linked to central bank policy rates), leads to significant differences in the LCOE (table 2).

Table 2: Evolution of the LCOE, in USD/MWh, according to different discount rates

Discount rate:	3%	7%	11%
United States	43.9	71.25	108.85
France	45.27	71.1	106.61
China	49.92	66.01	88.13
Russia	27.41	42.02	62.11
Japan	61.16	86.67	121.73
South Korea	39.42	53.3	72.39
India	29.77	47.64	72.22
Slovakia	57.61	101.84	162.75

Source : NEA

4.1.2 Rising costs everywhere except China

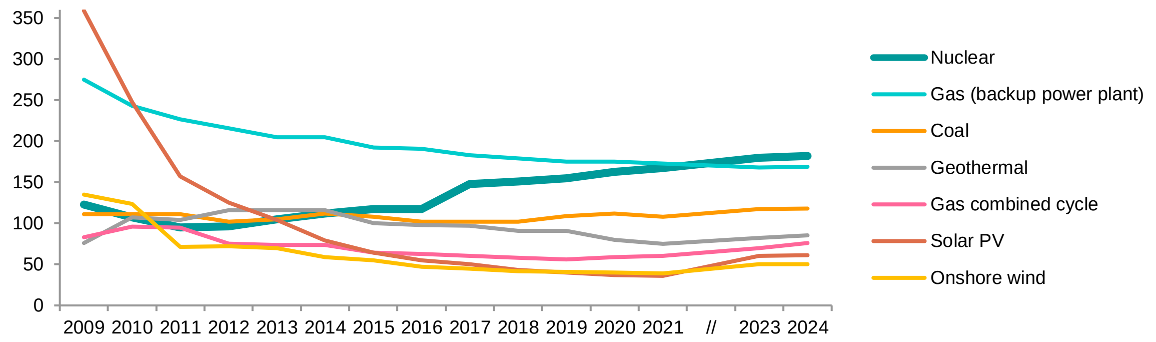
According to the NEA, the cost of new nuclear power plants **has risen considerably in OECD countries**: from just over \$2 million/MWh in 2010 to over \$5.5 million/MWh in 2020, a figure that should fall to \$5 million/MWh by 2025-2030, according to its forecasts[48]. The agency attributes this inflation to the difficult 're-

[48] Projected costs of generating electricity, 2020 Edition, p 146, Nuclear Energy Agency, 2020

learning' of the nuclear industry in many countries that have not built a power station for decades: training, supply chains, etc. Another factor is the increase in safety standards following the Fukushima disaster.

In the United States, the LCOE for nuclear power calculated by Lazard is now USD 184/MWh, cup from USD 123/MWh in 2009. According to the bank, **nuclear power is the source of electricity whose cost have risen the most, making it the most expensive source of electricity** (figure 8), **due to a rise in key interest rates**, but also because Lazard's figures are based on the construction of the Vogtle-3 and Vogtle-4 reactors, delivered in 2023 and 2024 with significant additional costs . [49]

Graph 8: Levelized cost of electricity (LCOE) in the United States, in USD/MWh



Source: Lazard Levelized Cost of Energy, June 2024 version

There is no history of nuclear LCOE for the European market, but **the major budgetary overruns of the latest plants delivered (Olkiluoto-3, Flamanville, Hinkley Point) suggest inflation similar to, or even higher than, that in the United States.** The LCOE calculated by the NEA for France (table 2) is almost identical to that for the United States.

With an estimated LCOE of USD 66/MWh, **China has so far managed to avoid any increase in the cost of nuclear power**, and the large number of new builds planned should enable it to avoid any nuclear "unlearning" and to maintain this level until 2050: at that time, the IEA forecasts a virtually unchanged LCOE of USD 65/MWh[50]. The market structure is also very different in China, where the purchase price of nuclear-generated electricity, which has remained unchanged since 2013, makes it possible to de-risk investments and thus reduce the cost of credit by guaranteeing operators' future revenues.

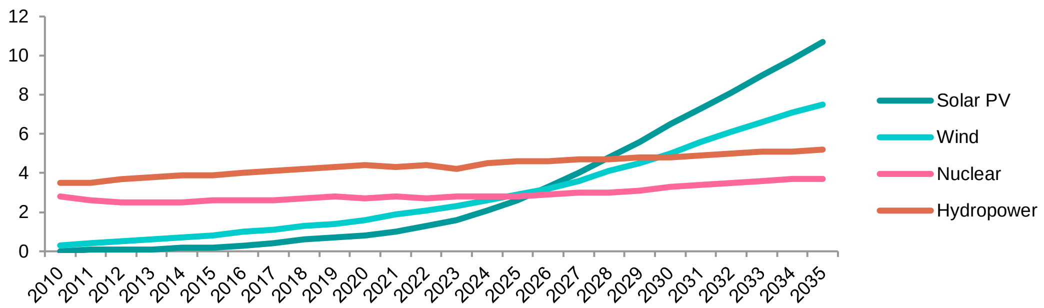
Whatever the market under consideration, however, **extending the operating life of a nuclear power plant** means that the cost of electricity is very competitive. As it construction has already been amortised, the only costs are those of operating it and, if necessary, upgrading the reactor. In all the countries included in its estimates (United States, France, Switzerland and Sweden), **the NEA evaluates the LCOE of such a plant at around USD 30/MWh, a level comparable to that of renewable energies in these markets**. Globally**, many operators are looking to extend the life of their power plants**. In the United States, six reactors have had their operating lives extended to 80 years (from the initial 40)[51] by the Nuclear Regulatory Commission (NRC), and several dozen more are expected to follow[52]. Russia has also extended the lifespan of at least 24 reactors[53], and the debate is also underway in France - where almost half the reactors are over 40 years old[54] - and in other countries. The profitability of these extensions also explains the **re-commissioning of closed power plants** in Japan, the United States and perhaps soon in Germany (see above).

[49] The World Nuclear Industry Status Report, 2023
[50] Staggering rise of clean energy in China a wake-up call to Australia - including on nuclear, Renew Economy, 30 April 2024
[51] License Renewal and Long-Term Operation (LTO) of Nuclear Power Plants, Jensen Hughes, 10 October 2024
[52] Nuclear Power in the USA, World Nuclear Association, 27 August 2024
[53] Russian Federation Nuclear Power Profile, IAEA, 2021
[54] Nucléaire : une nouvelle concertation publique sur la prolongation de la durée de vie des réacteurs, Le Monde, 18 January 2024

4.1.3 The tidal wave of renewables may hamper the growth of nuclear

Records for the installation of new renewable capacity, particularly solar PV, around the world are likely to challenge plans to revive nuclear power. The IEA estimates that **5,500 GW of additional renewable capacity (solar, wind, hydro) will be added globally by 2030[55], compared with around 45 GW of new nuclear capacity.** By then, the IEA estimates that the world will be producing about 16,000 TWh of renewable electricity a year, almost double the 2023 level. Again, the share of nuclear power will remain low: around 3,300 TWh (figure 9).

Figure 9: projected annual electricity generation, by source, in thousands of TWh/year



Source: IEA

The development of renewables is all the more worrying for the nuclear sector as **costs continue to fall**, at least for solar energy: the price of photovoltaic modules fell by a further 45% between September 2023 and September 2024[56] , including for the most efficient models.

Comparing the costs of nuclear and renewable electricity is complicated by the heterogeneity of nuclear LCOEs around the world. However, NEA data for a number of markets (table 3) shows that the **LCOE of renewables is generally much lower than that of nuclear**, and sometimes even **competitive with that of plants whose lifetime has been extended**. According to Lazard, the LCOE of solar and wind power in the United States is three to four times lower than that of nuclear power, respectively.

Table 3: Comparative LCOEs for nuclear, wind and solar power, USD/MWh

	Onshore wind	Offshore wind	Solar PV (power plant)	Nuclear (new power station)	Nuclear (life extension)
France	56.08	89.82	33.94	71.1	30.65
China	58.43	81.86	50.78	66.01	N/A
United States	39.02	65.62	34.59	71.25	33.25

Source : NEA

For the time being, nuclear power still has the advantage of being able to deliver electricity continuously, unlike the intermittent nature of renewables. **But the development of batteriy energy storage (BESS), which can smooth out this intermittency, could call this argument into question**: here too, costs are falling rapidly and installations are exceeding all forecasts year after year. BloombergNEF now estimates the cumulative storage capacity installed by 2030 at 1.87 TWh[57] . Assuming that these batteries perform one complete charge-discharge cycle per day, BESS would deliver **682 TWh of electricity per year to the world's power grids** by 2030.

[55] Renewables 2024, analysis and forecast to 2030, International Energy Agency, October 2024
[56] PVXchange Price Index, September 2024
[57] World's energy storage capacity forecast to exceed a terawatt-hour by 2030, Energy Storage News, 18 October 2023

4.2. SMRs, the industry's newest hope, remain largely unproven

Faced with the difficult financial and technical equation of traditional reactors, start-ups and established manufacturers are opting for small modular *reactors* (SMRs), which the IAEA defines as **advanced reactors with an electrical output of less than 300 MW**, small enough that their components and sub-systems can be manufactured in a factory and transported to the final installation site.

On paper, SMRs offer a number of advantages. Mass production should enable economies of scale, reduce construction times and simplify site logistics. Smaller, they can be installed as close to demand as possible, limiting grid connection costs. Modular, they can be installed progressively, as demand dictates. Finally, most of the proposed designs are supposed to be intrinsically safer than traditional reactors: passive heat removal, low-pressure operation, self-containment of the core in the event of an incident, etc.[58]

The SMR niche is therefore booming: the IAEA has identified more than **80 models under development by 2022**[59] . In the United States alone, at least four start-ups are working on SMR design, in addition to the established players. In France, the Nuclear Safety Authority (ASN) is monitoring the dossiers of nine start-ups and NuWard, a subsidiary of the EDF group. In detail, however, **the emergence of commercially viable SMRs is still a long way off**. The first example of China's Linglong One (or ACP-100), with a capacity of 125 MW, is due to become operational on the island of Hainan in 2026[60], but its designer, CNNC, does not communicate much about its economic parameters, and with good reason: with a unit cost announced at 700 million USD, its cost per MW of installed capacity is more than twice that of a *Hualong One*. As for the five operational models listed by the World Nuclear Association[61] , most are adaptations of older designs, which do not benefit from the latest developments in terms of safety or modularity. The Chinese CNP-300, operational since 1990 in China and 2000 in Pakistan, is derived from designs dating from the 1970s, intended for Chinese nuclear submarines. The Indian PHWR-220 dates from the 1980s, while the Russian EGP-6, dating from the 1970s, is in the process of being abandoned. The KLT-40 and RITM-200, designed to equip Russian icebreakers, are recent designs. The RITM-200 two floating power stations, deployed from 2019 onwards off Arctic towns not connected to the national grid.

Western SMR players also need to demonstrate the viability of their projects. US start-up NuScale was the first and so far the only company to receive Nuclear Regulatory Commission certification for its US600 model power plant (a combinaison of twelve 50 MW reactors) in 2023. A few months later, however, it cancelled its flagship project in Utah, after the projected cost had risen from USD58/MWh to USD89/MWh[62]. All the other US players (Holtec, Kairos, X-Energy, Westinghouse, etc.) are in various stages of pre-certification[63]. In France, NuWard announced in July 2024 that it was reviewing its project, which it considered too technically complex. Jimmy Energy has submitted an application to the ASN for a 10 MW mini-centre to supply heat only to an industrial customer.

In France, the ASN has reminded new entrants of their obligations regarding spent fuel management, and has asked them not to avoid the "*technical, societal and systemic issues"* raised by their projects. Installations close to factories or urban centres raise many questions about safety, as well as political and social acceptability. **SMRs may therefore not be the guarantee for a revival of the nuclear industry**.

[58] What are small modular reactors (SMRs), International Atomic Energy Agency, 13 September 2023
[59] Advances in Small Modular Reactor Technology Developments, IAEA, 2022
[60] Main control room of Linglong-1, world's first commercial onshore SMR completes construction, Global Times, 22 May 2024
[61] Small Nuclear Power Reactors, World Nuclear Association, February 2024
[62] Cancelled NuScale contract weighs heavy on new nuclear, Reuters, 10 January 2024
[63] SMR Pre-Application Activities, US Nuclear Regulatory Commission, consulted on 16 October 2024

5. The uranium market may be headed for a reshaping

5.1. Uranium ore: supply struggles to keep up with demand

5.1.1 A future increase in demand

The return to favour of nuclear energy offers new prospects for the uranium market (an essential fuel for nuclear production), which is set to grow over the next decade. According to the World Nuclear Association, **demand for uranium will increase by 28% between 2023 (65,650 tonnes) and 2030 (83,840 tonnes)**. In its baseline scenario, and the organisation estimates that demand could even double by 2040[64]. But these growth projections, which depend on the realisation of the announced investments, will depend on the actual expansion of the global plant fleet. The future increase in demand could eventually lead to a supply crisis.

5.1.2 Uranium production: an uncertain outlook

Uranium is both an abundant and widespread resource, present in the Earth's crust in many parts of the world. In 2020, identified resources amounted to almost **8 million tonnes**, with conventional deposits in around fifty countries[65] , mainly in Australia (28% of resources in 2021), Kazakhstan (13%) and Canada (10%)[66] **. Uranium mining, which is limited to about fifteen countries, is much more concentrated: Kazakhstan produced 43% of the world's uranium in 2022**, far ahead of Canada (14.9%), Namibia (11.4%) and Australia (9.2%) (figure 10). Kazakhstan's hegemony in this market is due to the geology of its deposits, which can be mined cheaply and very profitably using a technique known as *in-situ* leaching. This advantage has enabled the state-owned nuclear company, **Kazatomprom**, to become one of the most prolific and competitive uranium producers in the world.

Uranium global production nevertheless **fell by 25% between 2016** (63,207 tonnes) **and 2020** (47,731 tonnes)[67]. Falling demand, against a backdrop of oversupply and stagnating prices, led major producers (notably Kazakhstan and Canada) to voluntarily reduce their output, while a number of plants were closed due to lack of profitability. Now that the nuclear revival and the explosion in demand **led to a five-fold increase in uranium prices since 2016**, production is picking up again. From 65,000 tonnes in 2023**, production of uranium U-308** (uranium trioxide, a chemical form commonly used to represent uranium extracted from mines) **is expected reach more than 75,000 tonnes in 2030, driven by new mining investments** (figure 11). High uranium prices have encouraged miners to restart their operations: **more than 10 mines have reopened in the United States, Australia and Canada since 2022**[68].

However, the expected increase in uranium production could prove insufficient to meet the growth in demand**. This shortfall could lead to supply shortages, while the depletion of reserves in the main deposits is expected to lead to a decline in production from existing mines from 2030 onwards, without the projects currently underway being able to offset their decline**[69]. This is all the more true given that new mines will take between 8 and 15 years to come on stream, according to the World Nuclear Association. Moreover, some producers may not be able to meet their production targets: in August 2024, the giant Kazatomprom announced that it was reducing its production target for the following year by 17%[70].

[64] World Nuclear Association, *The Nuclear Fuel Report, Global Scenarios for Demand and Supply Availability 2023-2040*, May 2024
[65] Vie publique, *Uranium: a strategic resource*, August 2023
[66] Nuclear Energy Agency, *Uranium 2022, Resources, Production and Demand*, 2023
[67] World Nuclear Association, *World uranium mining production*, last updated in May 2024
[68] Financial Times, *US uranium miners resurrected by nuclear revival and Ukraine war*, March 2024
[69] RGN, *Towards a doubling of uranium requirements by 2040*, September 2023
[70] Financial Times, *World's largest uranium producer slashes production target*, August 2024

Figure 10: Uranium production by country (in tonnes, 2013-2022)

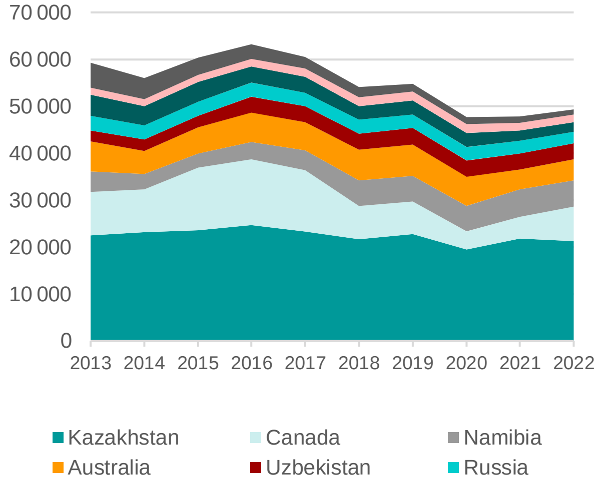
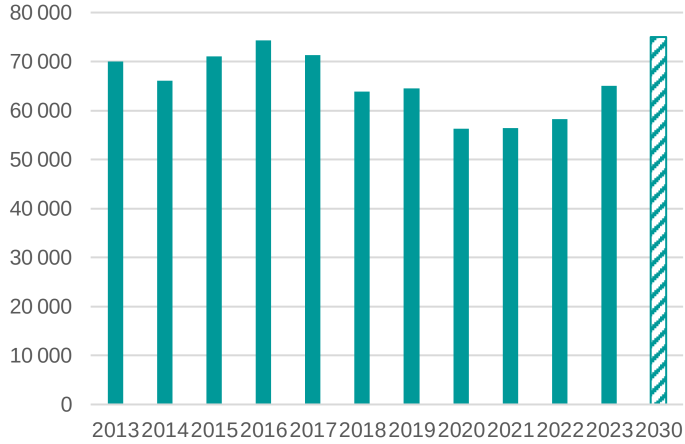


Figure 11: World production of uranium 308 and outlook to 2030 (in tonnes of U308, 2013-2030)



Source: World Nuclear Association, UxC

5.1.3 A rush to secure supply in the context of market rebalancing

Rising demand for uranium, which is benefiting mining countries, is prompting consumer countries to secure their supplies. A number of political and economic factors, including the outbreak of war in Ukraine and the coup d'état in Niger in July 2023 (4% of production in 2022), **have led governments to reorganise and diversify their supplies, against a backdrop of geopolitical tensions**.

Despite the recent rapprochement between Western chancelleries and Kazakhstan, whose uranium accounts for a large proportion of US and European supplies, **Kazatomprom warned in September 2024 that the war in Ukraine was complicating its uranium deliveries to its Western partners**[71] . For the Kazakh giant, Western sanctions against Moscow have created a number of technical and financial obstacles, as one of its main export routes to Europe and the United States runs through Russia. As a result, Kazakh uranium exports to Asian markets - and China in particular - are less costly and could increase, against a backdrop of booming Chinese demand. **At the same time, Kazakhstan's mining industry remains directly linked to Russia**: Rosatom holds stakes in 5 of Kazatomprom's 14 deposits, receiving 20% of their output. At the end of 2022, the Russian company also acquired a 49% stake in Kazakhstan's Budenovskoye deposit, which is set to become the world's largest source of uranium[72]. **In October 2024, Kazatomprom also announced the signing of a supply contract with China's CNNC**[73] , which already has several mining contracts with local operators - and this despite the fact that 65% of China's imports already come from Kazakhstan.

With Kazakh uranium exports to the West set to decline, Western countries are looking to diversify their supplies. Mining prospecting has been revived in Eastern Europe, and ambitious projects have been launched: in the Saskatchewan region, in Canada, the start-up **NextGen Energy** is behind a huge uranium extraction project, due to come on stream in 2029, that could eventually contribute more than a quarter of the world's supply[74] .

Russia and China, whose domestic production is unable to meet their growing demand, are leading the charge into the uranium market. In **Niger**, **Rosatom could try to seize the assets of Orano**, which owns three uranium mining and processing sites, taking advantage of the fact that French interests is challenged since

[71] Financial Times, *World's largest uranium miner warns Ukraine war makes it harder to supply West*, September 2024
[72] Caspian Policy Center, *Rosatom in Central Asia: Russia Eager to be involved in Central Asian Energy*, October 2024
[73] Kazatomprom, *Notice of Extraordinary General Meeting of Shareholders of Kazatomprom*, October 2024
[74] Bloomberg, *Deadly and Wildly Profitable, Uranium Fever Breaks Out*, June 2024

the coup in 2023[75]. In early of 2024, **Somina** (Société des mines d'Azelik), which is majority-owned by China, also announced that it was resuming its activities, after a ten-year hiatus due to a lack of profitability[76]. Much of Namibia's uranium industry is also controlled by China: CNNC has controlled 68% of Namibia's Rössing mine since 2019, while CGN acquired the Husab mine in 2012[77].

5.1.4 The West attempts to end its reliance on Russian enriched uranium

5.1.5 From raw ore to reactor, a complex production process

The nuclear fuel cycle, prior to its use in power plants, is divided into a number of stages: **extraction, conversion, enrichment and assembly**. Once extracted from the mines, the ore, which generally has a low uranium content (1 to 5 kg per tonne), is converted into a concentrate called **yellow cake**, with a uranium content of about 75%. The yellow cake is not sufficiently pure, so it is converted into uranium hexafluoride, a gaseous form suitable for the enrichment process, an industrial process **that increases the amount of U-235 in uranium (to 3-5% for most commercial reactors[78]) so that it can be used as fuel.**

5.1.6 Moscow, a key player in enrichment

This complex and regulated process (because of its implications for nuclear proliferation) is mastered only by a few countries. **Although 12 countries[79] have enrichment capacity, only a handful of them really control this overcapacity market.** In 2020, with 27.7 million *separative work units* (SWU/year, the unit for measuring the amount of effort needed to increase U-235 and separate it from U-238) per year, **Russia had 46% of the world's enrichment capacity** (managed by Rosatom), compared with 12% for France (Orano), 10% for China (CNNC), 8% for the United States and 23% for the United Kingdom, Germany and the Netherlands, the latter four countries being members of the Urenco consortium[80] (Figures 12 and 13). Although other operators are developing enrichment capacity (INB in Brazil, JNFL in Japan, etc.), it remains extremely limited.

There are a number of reasons why Moscow - and more specifically Rosatom, through its subsidiaries TVEL and Tenex - dominates this activity: extensive infrastructure inherited from the Soviet Union, massive industrial capacity, advanced technology, long-term contracts with foreign operators, etc. And this Russian dominance extends across the entire enrichment value chain. **And this Russian pre-eminence extends to the entire enrichment value chain:** through its fast-breeder reactors at Seversk, **Moscow is the only country in the world with the capacity to recycle and reprocess "unloaded" uranium (URT) after it has been used.** No other country has mastered this technology. The few countries that have opted for reprocessing are therefore obliged to export their TRU to Russia, such as France. In 2018, French supplier EDF signed a contract with Tenex to take over some of its TRU, before Orano signed a similar commitment in 2020 (which has now been settled). And despite the conflict in Ukraine, EDF continues to export its TRU to Russia; to limit its dependence on Moscow, Paris is therefore considering building a TRU enrichment and conversion plant on French soil[81].

[75] Bloomberg, *Russia Is Said to Seek French-Held Uranium Assets in Niger*, June 2024
[76] Le Monde, *Au Niger, une entreprise chinoise va reprendre l'extraction d'uranium après dix ans d'interruption*, May 2024
[77] Carnegie Endowment, *To Secure Kazakhstan's Uranium, Chinese Players Were Compelled to Accommodate Local Partners*, March 2024
[78] Most commercial reactors use uranium enriched to less than 5%. Above 20%, the uranium is considered "highly enriched". This grade is used in some research reactors and in naval propulsion reactors. For military applications, the U-235 content generally exceeds 85%.
[79] USA, Russia, China, France, URENCO Consortium (Germany, Netherlands, UK), Japan, Brazil, Argentina, India, Pakistan, Iran, North Korea.
[80] World Nuclear Association, *Uranium Enrichment*, October 2022
[81] La Tribune, *Nucléaire : après la Russie, la France envisage " sérieusement " de construire un site de conversion et d'enrichissement de l'uranium de retraitement*, March 2024

Figure 12: Enrichment capacity by State (2020, in million SWU/year)

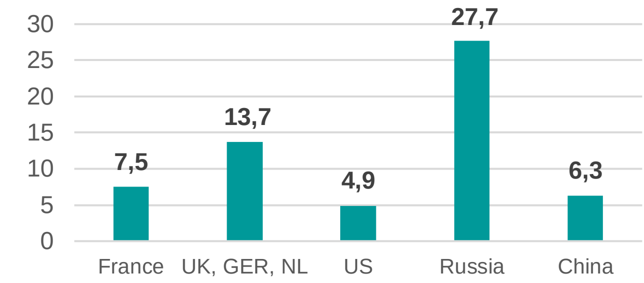
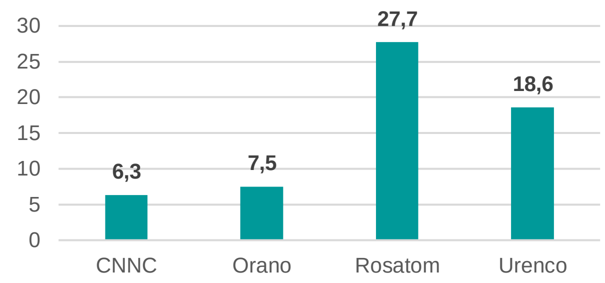


Figure 13: Enrichment capacity by operator (2020, in millions of SWU/year)



Source: World Nuclear Association

5.1.7 The West's efforts to free itself from Rosatom are facing several challenges

The outbreak of war in Ukraine has highlighted the continuing dependence of Western countries on the Russian enrichment cycle, and **they are now stepping up their efforts to free themselves from this dependence and increase their domestic production capacity.** In October 2024, Orano began work the expansion of its uranium enrichment plant, with the aim of increasing its production capacity by 30% from 2028[82]. A month earlier, the French company also announced the construction of an enrichment site in Tennessee, a project justified by the risk of a total or partial interruption in the supply of enriched uranium by Rosatom[83]. In 2023, the US company **Centrus** started the production of the medium enriched uranium (HALEU, between 5% and 20% U-235) needed for the new advanced reactors being developed in the United States, with the first delivery scheduled for November 2023[84]. Urenco also plans to increase capacity at its New Mexico plant by 15%.

In May 2024, the Biden administration also passed bipartisan legislation (enacted in August) **banning imports of Russian uranium products**, while at the same time releasing USD 2.72 billion to increase US enrichment capacity[85] . Recognising that implementation of the ban could disrupt US fleet operations and drive up prices, Washington plans to grant waivers until 2028 - a deadline that may prove insufficient given US producers' dependence on Russian supplies. **The implementation of this ban is part of multilateral efforts to establish a new uranium supply market free from Russian influence**: in December 2023, the United States, France, Canada, Japan and the United Kingdom pledged to collectively invest USD 4.2 billion to this end[86]. Several Western countries, including the United States and the United Kingdom[87]**, have also sanctioned certain Rosatom managers or subsidiaries for their involvement in the conflict in Ukraine**.

However, it will take several years to establish new supply chains for enriched uranium. **In September 2024, President Vladimir Putin said he was considering preemptively restricting his uranium exports[88]**. The reduction in Western imports of enriched uranium could also lead to a redirection of Russian flows towards other markets, thereby **circumventing the sanctions**.

[82] L'Usine nouvelle, *Orano launches work to extend Georges Besse II at Tricastin, a €1.7 billion project*, October 2024
[83] Orano, Project Ike Enrichment
[84] Bloomberg, *US Gets First Supply of Advanced Nuke Fuel for New Reactors*, November 2023
[85] US Department of Energy, *Biden-Harris Administration Enacts Law Banning Importation of Russian Uranium*, May 2024
[86] US Department of Energy, *At COP28, U.S., Canada, France, Japan, and UK Announce Plans to Mobilize $4.2 Billion for Reliable Global Nuclear Energy Supply Chain*, December 2023
[87] RUSI, *Power Plays, Developments in Russian Enriched Uranium Trade*, March 2024
[88] Reuters, *Putin says Russia should consider restricting uranium, titanium and nickel exports*, September 2024

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