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# PRESENT STATUS AND FUTURE PLANS FOR THE NUCLEAR SECTOR IN UKRAINE

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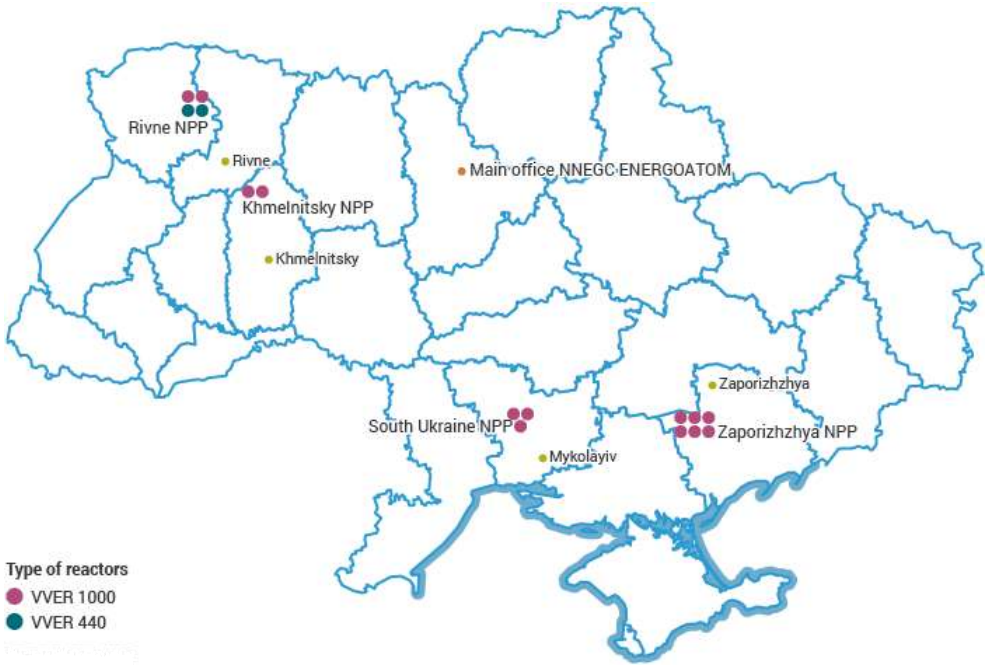
## Ukraine's nuclear power plant fleet

Nuclear power plays a huge role in Ukraine's energy system (Figure 1), accounting for over 50 per cent of electricity supply. The majority of the country's reactors were built in the Soviet era and all use the Russian VVER design, although the capacities differ. Twelve of the 15 units installed at four sites located across the country were constructed before independence in 1991, and since then three further units have been built by Ukraine itself. The two oldest units use the VVER-400 design with a capacity of 400 MW, while the remainder use the newer VVER-1000 design, with a capacity of 1,000 MW. A total of 13.8 GW of installed capacity therefore exists in Ukraine, although it is not all operational at present because of the continuing war. The Zaporizhzhia nuclear power plant is currently in Russian-held territory and is being managed by Energoatom staff under Russian control, but despite the Ukrainian involvement there are serious concerns about the state of the plant and the safety risks due to the continuing conflict. As a result, 6,000 MW of capacity is currently not producing power for the Ukrainian grid. Of the remaining capacity, 7,800 MW is currently producing electricity.

**Figure 1: Location of nuclear power plants in Ukraine**




Source: Energoatom

As Table 1 shows, a number of the units at the four nuclear power plants have already seen their lives considerably extended. The original Soviet plants were mostly put into operation in the 1980s with a 30-year design life, and all but one of the plants built in this era have now seen their lives extended by at least 10, and sometimes 20, years. As a result, the plants at Khmelnitsky and Rivne will be operational late into this decade and beyond. Construction of two more units at the Khmelnitsky plant began in the 1980s but was paused after the accident at Chernobyl and has not yet been recommenced despite negotiations with various potential contractors.

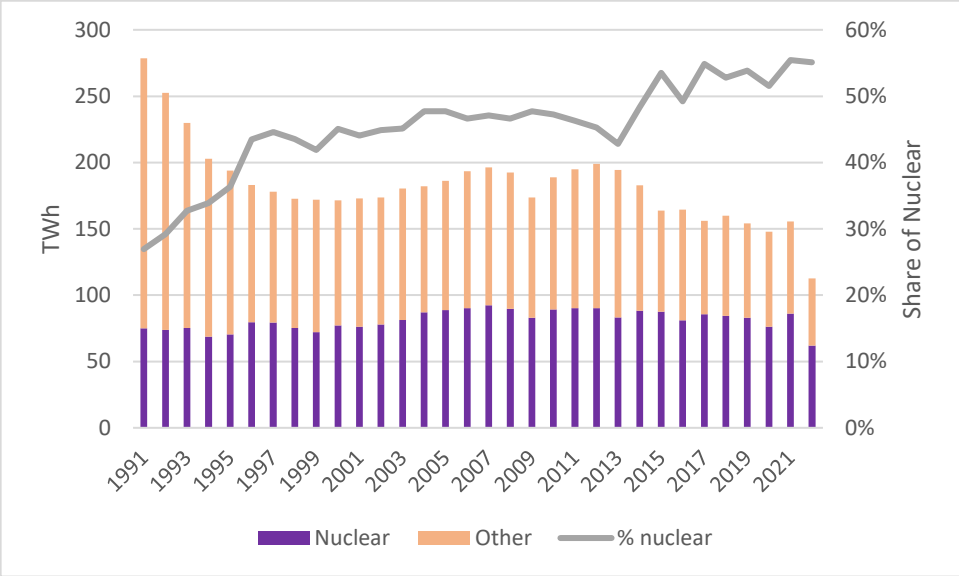
**Table 1: Ukraine's nuclear power plants**

| | Design | Capacity (MW) | Commissioned | Initial retirement | Extension | Current status |
|---|---|---|---|---|---|---|
| **Zaporizhzhia** | | | | | | |
| Unit 1 | VVER 1000/320 | 1,000 | 1984 | 2015 | 2025 | Under Russian control |
| Unit 2 | VVER 1000/320 | 1,000 | 1985 | 2016 | 2026 | Under Russian control |
| Unit 3 | VVER 1000/320 | 1,000 | 1986 | 2017 | | Under Russian control |
| Unit 4 | VVER 1000/320 | 1,000 | 1987 | 2018 | 2028 | Under Russian control |
| Unit 5 | VVER 1000/320 | 1,000 | 1989 | 2028 | 2030 | Under Russian control |
| Unit 6 | VVER 1000/320 | 1,000 | 1995 | 2025 | | Under Russian control |
| **Khmelnitsky** | | | | | | |
| Unit 1 | VVER 1000 | 1,000 | 1987 | 2018 | 2028 | Operating |
| Unit 2 | VVER 1000 | 1,000 | 2005 | 2036 | | Operating |
| **Rivne** | | | | | | |
| Unit 1 | VVER 400 | 400 | 1980 | 2010 | 2030 | Operating |
| Unit 2 | VVER 400 | 400 | 1981 | 2011 | 2031 | Operating |
| Unit 3 | VVER 1000 | 1,000 | 1986 | 2017 | 2037 | Operating |
| Unit 4 | VVER 1000 | 1,000 | 2006 | 2036 | | Operating |
| **South Ukraine** | | | | | | |
| Unit 1 | VVER 1000 | 1,000 | 1983 | 2013 | 2033 | Operating |
| Unit 2 | VVER 1000 | 1,000 | 1985 | 2015 | 2025 | Operating |
| Unit 3 | VVER 1000 | 1,000 | 1989 | 2020 | 2030 | Operating |
| | | | | | | |
| **Total capacity** | | **13,800** | | | | |
| **Total operating capacity** | | **7,800** | | | | |
| | | | | | | |
| *Under construction: Khmelnitsky* | | | | | | |
| *Unit 3* | *VVER 1000* | *1,000* | | | | *75% complete* |
| *Unit 4* | *VVER 1000* | *1,000* | | | | *28% complete* |

Sources: World Nuclear Association, Energoatom.

The importance of these power plants to the Ukrainian energy system cannot be overstated, as they produce more than 50 per cent of the electricity consumed in the country and have taken an increasingly important role over the past few years as the country has sought to reduce its consumption of gas in order to bring its purchases of Russian energy to an end. Figure 2 shows how electricity demand has fallen since the Russian annexation of Crimea and the occupation of the Donbass and Luhansk regions in 2014 and fell even further in 2022 as the current war commenced. However, during this period the importance of nuclear has increased, despite the recent loss of control over the Zaporizhzhia plant, reaching a high of 55 per cent of total electricity output in 2022.

**Figure 2: Ukrainian power supply by source since 1991**




Source: Energy Institute Statistical Review of World Energy, 2023.

**Ukraine as an example of diversification in the nuclear fuel cycle**

Given the importance of nuclear power in Ukraine, combined with the country's difficult relationship with Russia throughout the period since 1991, it is not surprising that the country has been actively seeking to break its dependence on Russia in all spheres of the nuclear supply chain. Rosatom, and its subsidiary TVEL, play a critical role in the global nuclear industry, as Russia has exported its technology both within the former Soviet Bloc and now further afield. Russian reactors are currently operating in 11 countries across the world; Ukraine and its neighbours such as Belarus and Armenia, European countries such as Bulgaria, Czechia, Slovakia, Hungary, and Finland, and global actors such as Iran, India, and China.[1]

Ukraine holds the largest number of Russian-made reactors, though, and historically was also reliant on Russian supplies of equipment, fuel, and expertise to maintain its industry. One of Rosatom's major competitive advantages is that it has traditionally supplied an all-inclusive package for nuclear energy, or a one-stop shop, which has been helpful to its customers but which has bound them into a long-term strategic relationship with Russia.[2]

Russia's competitive position is based on the fact that, although it is a relatively small player in the mining of uranium, it plays an outsize role in other parts of the nuclear fuel supply chain, accounting for 40 per cent of global conversion services (which turn uranium oxide in uranium hexafluoride) and 46 per cent of global enrichment capacity (which converts the uranium hexafluoride into enriched uranium oxide with a higher share of U-235).[3] Rosatom, via TVEL, has also dominated in the fabrication of the fuel rods which are used in its VVER reactors. The configuration of the fuel assemblies for the VVERs differs from other international reactors, and for many years no other companies had any incentive to produce fuel that could vie with Rosatom's supply, which was often offered at low cost to undermine any potential competition.

[1] Bowen, M., and Dabar, P. (2022), *Reducing Russian Involvement in Western Nuclear Power Markets,* New York: Centre for Global Energy Policy, Columbia University
[2] Szulecki, K., and Overland, I. (2023), 'Russian nuclear energy diplomacy and its implications for energy security in the context of the war in Ukraine', *Nature Energy*, 8, 413–421.
[3] World Nuclear Association, 'World uranium mining production', https://world-nuclear.org/information-library/nuclear-fuel-cycle/mining-of-uranium/world-uranium-mining-production.aspx.

Furthermore, Rosatom not only has a very strong position in the front end of the nuclear fuel cycle, but also offers services at the back end which few, if any, of its competitors can match. It owns and operates one of the only uranium recycling plants in the world,[4] and offers a disposal and storage service which allows its customers to manage this difficult process at the end of a fuel rod's useful life. For example, Krasnoyarsk in Siberia is home to the Mining and Chemical Complex, where Rosatom can offer the ability to handle spent fuel at many different stages within one huge facility.[5] This places it in a unique position to maintain a strategic relationship with its customers throughout the life of their nuclear assets and beyond.

Ukraine has worked hard to disentangle itself from this Russian-dominated supply chain over the past two decades, and its efforts have accelerated since 2014. It is valuable to explore how it has made progress and whether this can provide an example for other countries looking to diversify their nuclear fuel supplies.

In terms of manufacturing, two important companies are located in Ukraine. The first is Energomashspetstal, which manufactures castings and forgings used in large reactor pressure vessels. It is potentially a source of significant competitive advantage for Ukraine but is currently owned by Rosatom and is located in Kramatorsk in the Donetsk region, under Ukrainian control at present but close to the front line of the war with Russia. As such, its operations are limited at present and its future unsure. More positively, JSC Turboatom is a world-class turbine manufacturer and has constructed more than half the turbines currently in operation in Ukraine's power sector. Importantly, it is now cooperating with US company Westinghouse on the uprating of 13 of the VVER-1000 units in Ukraine and hopes to develop the ability to carry out similar operations across Europe. Furthermore, Turboatom has also been involved in building 190 casks for Ukraine's new Central Spent Fuel Storage Facility (see later discussion).

From a mining perspective, Ukraine is estimated to be the 11th largest producer of uranium in the world, although in 2022 its production fell sharply from 455 tonnes to only 100 tonnes (in comparison, the largest producer, Kazakhstan, produced 21,227 tonnes).[6] Historically, Ukraine's state-owned uranium miner VostGOK has produced as much as 30 per cent of the country's domestic needs, but the Ukrainian authorities have now set a target for the country to be self-sufficient by 2027. This aggressive goal is based on maintaining output at two existing mines and opening a further two by 2026, in tandem with the renovation of two sulphuric acid plants where the uranium is extracted from ore.[7]

Perhaps most importantly, though, the entire output of Ukraine's uranium mines has been committed to Canadian company Cameco in a back-to back deal which will then see the Canadian company convert it into uranium hexafluoride and provide Ukraine with enough converted uranium to meet its entire needs, topping it up with Canadian-sourced supply as necessary.[8] This agreement will run from 2024 to 2035 under a contract combining fixed and market prices and will allow Ukraine to completely stop relying on Russian conversion facilities.[9]

Moving on through the front end of the cycle, the Ukrainian authorities have agreed to extend an agreement for enrichment services with UK company Urenco.[10] Urenco will take the converted uranium hexafluoride from Cameco and provide the enriched uranium needed for fuel assembly. The company has been working with Energoatom since 2009, but the contract has now been extended until 2035 with an option for a further extension to 2043 in a deal that was supported by the UK government.[11]

The final part of the fuel cycle involves the manufacture of the fuel assemblies for use in Ukraine's VVER reactors, and here Energoatom's growing partnership with Westinghouse has come to full fruition. The relationship started as early as 2005, when the Ukrainian authorities first planned to break the monopoly of Russian fuel supply to the VVER-type nuclear plants, and Energoatom implemented a Ukraine Nuclear Fuel Qualification Project to seek alternative vendors.[12] An initial contract for a three-year trial was signed with Westinghouse in 2008, but controversially came to an end when Energoatom claimed that the fuel had flaws. Instead, a long-term contract was signed with TVEL, with Ukraine spending $500–600 million per year on fuel.

[4] https://www.lemonde.fr/en/energies/article/2022/12/03/russia-owns-the-only-plant-in-the-world-capable-of-reprocessing-spent-uranium_6006479_98.html#:~:text=Once%20the%20spent%20fuel%20assemblies,95%25)%20is%20sent%20to.
[5] https://www.iaea.org/newscenter/news/under-one-roof-russias-integrated-strategy-for-spent-fuel-management.
[6] https://world-nuclear.org/information-library/nuclear-fuel-cycle/mining-of-uranium/world-uranium-mining-production.aspx.
[7] https://www.world-nuclear-news.org/Articles/Ukraine-pushes-for-domestic-uranium-supply.
[8] https://www.world-nuclear-news.org/Articles/Energoatom-sends-first-uranium-mined-in-Ukraine-to#:~:text=Energoatom%20President%20Petro%20Kotin%20said,natural%20uranium%20hexafluoride%20(UF6).
[9] https://www.reuters.com/world/ukraines-nuclear-deal-with-canadas-cameco-carries-big-risks-rewards-2023-05-05/.
[10] https://www.energoatom.com.ua/app-eng/eng-2811232.html.
[11] https://www.theengineer.co.uk/content/news/ukraine-s-nuclear-operator-signs-long-term-enrichment-contract-with-urenco/.
[12] https://world-nuclear.org/information-library/country-profiles/countries-t-z/ukraine.aspx.

The 2014 annexation of Crimea dramatically changed the political and commercial landscape, and the contract with Westinghouse was renewed through to 2020. By 2018 Westinghouse was supplying around 30 per cent of Ukraine's VVER fuel, and the contract was extended to 2025, by which time it was expected that the US company would be supplying seven of the country's 15 reactors.

However, the Russian invasion in February 2022 changed the picture completely, with Ukraine accelerating plans to move completely away from Russian nuclear fuel. By June 2023 an agreement had been signed with Westinghouse that all of Ukraine's fuel would come from the US company's fabrication plant in Vasteras in Sweden.[13] Energoatom has confirmed that a number of steps have been taken to ensure that both VVER-440 and -1000 units can operate on the new fuel, including the purchase of new monitoring equipment, transport facilities, and loading equipment, as well as training for Energoatom specialists. A dummy fuel assembly has been trialled, and Energoatom CEO Petro Kotin has now claimed that 'Ukraine once again demonstrated to European states ways to overcome Russian influence in the nuclear industry.'[14]

One final element of Ukraine's nuclear diversification has been in the back end of the cycle, as in December 2023 it opened the Central Spent Fuel Storage Facility, which is now used for storing spent fuel from the three nuclear plants which remain under Ukrainian control. Energoatom, which used to spend around $200 million per year for use of Russian storage facilities, is now able to save this cost as well as reduce a critical and strategic dependence on Russia. The plant was built in partnership with the US company Holtec International and has now entered a three-year trial period. According to local press reports, 13 containers of fuel have already been placed at the facility, and a security analysis will now be prepared as part of an application for full industrial operation.[15]

Overall, then, Ukraine has taken significant steps to diversify away from Russian influence in its nuclear supply chain. With new contracts signed for conversion, enrichment, and fuel fabrication, a planned increase in domestic mining of uranium, and the opening of a new waste storage position, it would appear that Ukraine has demonstrated that it is possible to change the boundaries of this complex value chain with high barriers to entry. It would be wrong to be complacent, though. The potential increase in uranium output is yet to be proved, and Russia continues to exert influence across the European nuclear supply chain, which could have implications for Ukraine in a crisis situation.[16] Nevertheless, the country finds itself in a much more comfortable position than a decade ago.

**Future plans for expansion using international technology**

Ukraine's energy strategy sees nuclear continuing to have a vital role in the country's energy system, both as a source of domestic energy and as a potential source of zero-carbon power exports to Europe. It could also form the basis of a green energy regeneration in Ukraine, providing the zero-carbon electricity to support the production of hydrogen and other green products for export to the EU. To support this plan, the government plans for nuclear capacity to be expanded to 24 GW by 2040, and agreements to facilitate this have been signed. In September 2021, Energoatom and Westinghouse signed an initial agreement for the construction of four US-designed AP1000 reactors to be located at existing sites in Ukraine, as well as the completion of the two units under construction at Khelmnitsky. This agreement was then upgraded in June 2022 to increase the number of AP1000 reactors to be built to nine, and in January 2023 the Ukrainian government also approved the go-ahead for a proposal to construct two brand new reactors at Khelmnitsky.

In addition, Energoatom plans to work with Holtec on the construction of a number of small modular reactors (SMRs) around the country, mainly to replace existing reactors as they come to the end of their lives, and the Ukrainian company has also signed a memorandum of understanding with NuScale to explore the possibility of deploying their SMR plants. This deal was further enhanced at COP27 by an announcement that a US consortium will collaborate with Ukraine on a plan to use SMRs to produce hydrogen and ammonia.[17] While completion of all these plans will of course be dependent on the conclusion of the war in a manner which allows for future investment, they nevertheless demonstrate the clear potential for nuclear power to play a vital role in the rebuilding of the Ukrainian economy over the next two to three decades.

[13] https://www.reuters.com/business/energy/ukraine-signs-deal-with-westinghouse-end-russian-nuclear-fuel-needs-2022-06-03/.
[14] https://www.energoatom.com.ua/app-eng/eng-2712233.html.
[15] Nucnet (2023), 'Kyiv "removes dependence on Russia" with commissioning of central spent fuel storage facility', 20 December.
[16] Dolzikova, D. (2023), 'Catch-235: Western dependence on Russian nuclear supplies is hard to shake', Royal United Services Institute Commentary.
[17] https://world-nuclear-news.org/Articles/USA-Ukraine-announce-cooperation-on-clean-fuels-fr.