

THE GLOBAL NUCLEAR MARKET

The global nuclear material market, which includes uranium ore extraction, enrichment, and construction of power plants, has become a topic of increasing concern in recent years. In particular, the dependence of this market on authoritarian regimes such as Russia has raised several risks and implications.

1. Introduction

Many countries seek to reduce greenhouse gas emissions and transition to more sustainable energy sources, including nuclear power. Nowadays, nuclear power generates approximately 10 % of the world's electricity and one-third of global low-carbon electricity, with 440 nuclear reactors operating in 30 countries and 54 reactors under construction in 19 countries, including four building their first nuclear reactors. Unlike variable renewable energy sources such as solar and wind, which require backup power during output gaps, nuclear power plants can provide a continuous and reliable supply of energy.¹

The increasing demand for electricity, particularly in developing countries, has also driven the demand for nuclear power. Besides, in the future, the world's growing population and increasing industrialization are expected to drive a significant rise in electricity consumption in the coming decades. In addition to this incremental demand, the USA and EU will face the challenge of renewing much of their existing generating capacity during the same period.

Nuclear power offers low actual generation cost, price stability, on-site fuel, contribution to clean air and low CO₂ objectives, and good voltage support for grid stability. These attributes are becoming increasingly recognized as important for long-term reliability and security of supply, particularly as dependence on intermittent sources grows.²

The nuclear power landscape has changed since the Fukushima disaster in 2011, with many countries re-evaluating their energy policies and safety regulations. However, it is still possible for nuclear power to play a role in the future energy mix, particularly as newer technologies are developed that offer better safety and smaller-scale options.³ For example, small modular reactors (SMRs) are being developed to provide nuclear power on a smaller scale, which may be more suitable for certain communities or industries. These SMRs have a lower potential for accidents, as they use passive safety features and require less human intervention than larger reactors. In addition, new fuel cycles and reactor designs are being explored that could offer greater security and sustainability.⁴

However, nuclear power has its risks and challenges, including the issue of nuclear waste disposal, the potential for accidents or sabotage, and the link between nuclear power and nuclear weapons. Any decision to return to the

¹ Jawerth, Nicole. "What is Clean Energy Transition and How Does Nuclear Power Fit In?" IAEA. [Link](#).

² "World Energy Needs and Nuclear Power." World Nuclear Association. October 2022. [Link](#).

³ Paillere, Henri, and Jeffrey Donovan. "Nuclear Power 10 Years After Fukushima: The Long Road Back." IAEA. March 11, 2021. [Link](#).

⁴ Liou, Joanne. "What are Small Modular Reactors (SMRs)?" IAEA. November 4, 2021. [Link](#).

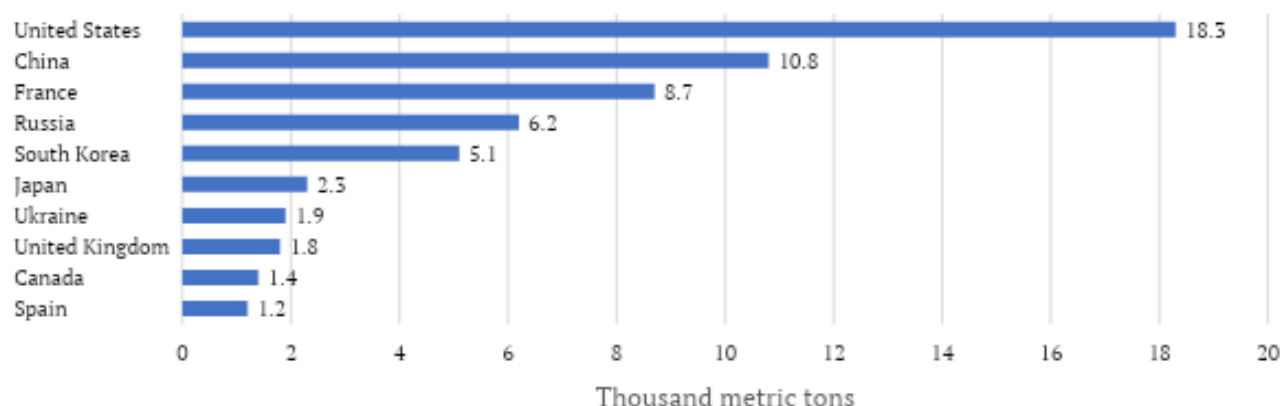
atomic age must be made with careful consideration of these risks and by strict safety regulations and international agreements.

2. Uranium

Uranium is a naturally occurring element found in rocks and soil, and the largest producers of uranium ore are Kazakhstan, Namibia, and Canada. These three countries account for around two-thirds of the world's uranium production, with Kazakhstan being the largest producer – 45 % of the world supply.⁵ Moreover, as for 2021, Russia is one of these countries that mines uranium; this state is responsible for 5% of the world supply and ranks 6th in the world's production of uranium, while its resources account for 8 % of the world share.⁶

It is projected that uranium demand from the world's nuclear reactors will increase to 79.4 thousand metric tons of elemental uranium (MTU) in 2030 and 112.3 thousand MTU in 2040. As of 2021, it was estimated that global uranium demand from nuclear reactors was 62.5 thousand MTU.⁷ The leading uranium-consuming countries are the United States, China, France, Russia, and South Korea.⁸

Figure 1. Uranium consumption worldwide in 2020 by countries



Source: Statista⁹

⁵ Uranium Mining Overview. World Nuclear Association. June 2022. [Link](#).

⁶ World Uranium Mining Production. World Nuclear Association. July 2022. [Link](#).

⁷ Wulandari, Fitri. "Uranium price forecast: Can it continue to recoup losses?" Capital. December 7, 2022. [Link](#).

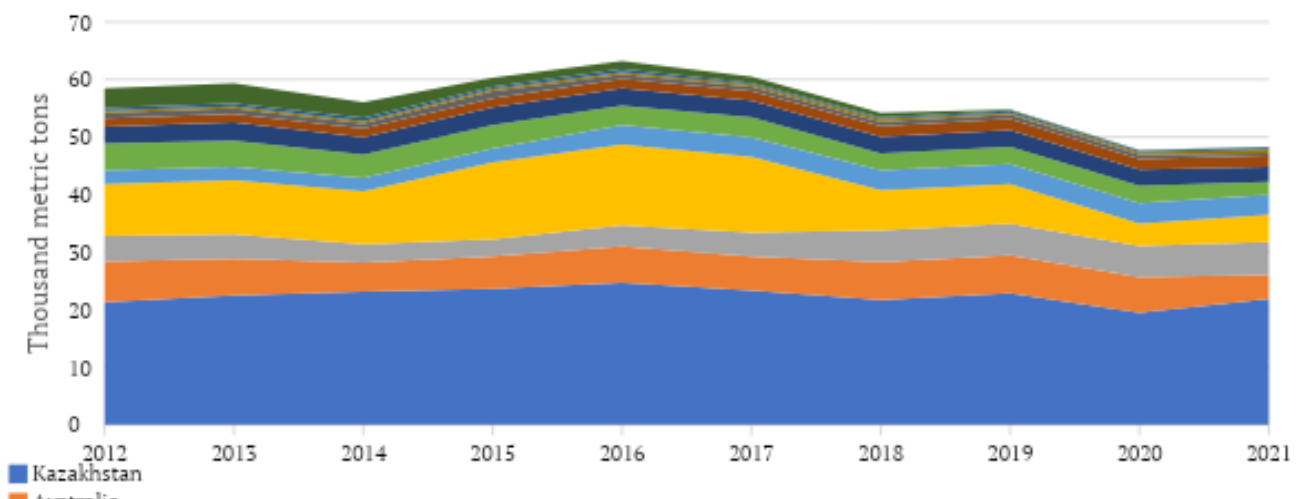
⁸ Garside M. "Leading uranium consuming countries worldwide 2020." Statista. March 20, 2023. [Link](#).

⁹ Uranium market worldwide. Statista. [Link](#).

While nuclear power generation is the primary source of uranium demand, the utilization of uranium in the military and defense sectors remains notable. Worldwide, military stockpiles contain seven times the yearly production of uranium, with the United States and Russia holding the largest arsenals.¹⁰

Russia's war against Ukraine provoked the EU to pass sanctions against products of all kinds, including fossil fuels, but nuclear fuel is still left out. The reason for this resistance is the high level of the European Union's dependency. As of 2021, the EU imported 2,538 tons of raw uranium from Russia, almost 20 % of all the EU imports. Another trading partner is Kazakhstan (the share of the EU uranium import is 23 %) where uranium mining is controlled by the Russian state-owned company Rosatom.¹¹

Figure 2. Production volume of uranium by countries



Source: World Nuclear Association¹²

3. Enrichment

As uranium extracted from the ore is not suitable for use in nuclear reactors or weapons in its natural form, it needs to be enriched with the uranium-235 isotope. The primary fuel enrichment facilities of commercial importance are in France, Germany, Russia, the Netherlands, the United Kingdom, and the United States.¹³

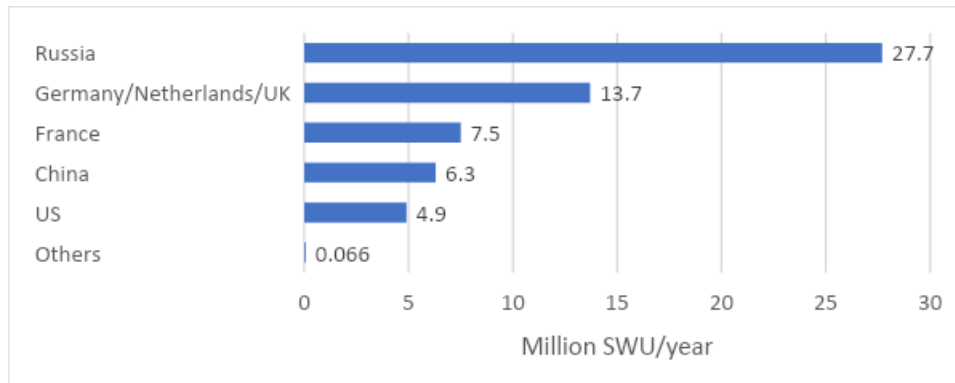
¹⁰ Reddy, Rohan. "Uranium Market Primed for Growth." Global X. February 9, 2021. [Link](#).

¹¹ "Russia's €200m nuclear exports untouched by EU sanctions." euobserver. October 7, 2022. [Link](#).

¹² World Uranium Mining Production. World Nuclear Association. July 2022. [Link](#).

¹³ Nuclear Fuel. NEI. [Link](#).

Figure 3. World enrichment capacity in 2022



Source: World Nuclear Association¹⁴

In the 1990s, Russia and the U.S. signed an agreement on the disposition of highly enriched uranium (HEU) extracted from Russian nuclear weapons. Under the terms of the deal, Russia undertook to down-blend 500 tons of HEU, enough to build 20 thousand nuclear warheads, over 20 years. The two sides agreed that the resulting low-enriched uranium (LEU) would be used as fuel by nuclear power plants in the United States.¹⁵

As a result, the U.S. has become dependent on Russia's HEU, and as of 2021, it imported 14 % of its enriched uranium for nuclear fuel from Russia.¹⁶ With the outbreak of the Russian full-scale invasion of Ukraine, the U.S. decided to allocate \$4.3 billion to create facilities for uranium enrichment to reduce their dependence on Russia.¹⁷

Once enriched, the uranium is transformed into a powder and compressed into fuel pellets. These pellets are loaded into closed metal tubes called fuel assemblies by the fuel fabricator and are utilized in nuclear reactors.¹⁸ Most nuclear power plants are in the U.S., France, and China (this country has had the highest increase of operational reactor units – 42 – in the last 10 years; now, the country has 54 units, and 24 more are under construction), Russia, and South Korea.¹⁹

Russia has a decent number of clients to sell fuel. Rosatom supplies nuclear fuel to 73 power reactors operating in 13 countries, including Bulgaria, the Czech Republic, Finland, Slovakia (these countries solely rely on Russia's fuel), China,²⁰ etc.

¹⁴ Uranium Enrichment. World Nuclear Association. October 2022. [Link](#).

¹⁵ "Looking Back: The U.S. –Russian Uranium Deal: Results and Lessons." Arms Control Association. [Link](#).

¹⁶ Philip, Lizzie. "Why the US needs Russian uranium?" The Verge. August 9, 2022. [Link](#).

¹⁷ Natter, Ari. "US Seeks \$4.3 Billion for Uranium to Wean Off Russia Supply." Bloomberg. June 7, 2022. [Link](#).

¹⁸ Nuclear Fuel. NEI. [Link](#).

¹⁹ Buchholz, Katharina. "The Countries With the Most Nuclear Reactors." Statista. October 18, 2022. [Link](#).

²⁰ "Fuel load for Chinese fast reactor dispatched from Russia." World Nuclear News. January 4, 2023. [Link](#).

Moreover, some countries rely on Russia because of the storage of spent nuclear fuel it has; one of them is Germany.²¹ France was also among those countries, but the full-scale invasion changed it, and the contact between Rosatom and Orano was closed. The French company is not considering signing a new contract with the Russian nuclear giant.²²

4. Technology

Rosatom, a Russian state-owned corporation, has a significant share of the global market for constructing power plants. This further exacerbates the global dependence on Russia.²³ As of the end of 2021, Rosatom has built 42 reactors in various countries in the world, including Armenia, Bulgaria, Slovakia, Ukraine, Finland, the Czech Republic,²⁴ and 15 more are under construction, including India²⁵ and Bangladesh.^{26,27} Besides, it recently signed an agreement to build nuclear reactors in Hungary²⁸ and one power plant in Turkey²⁹ and Egypt³⁰ each. Moreover, there are plans to build a second NPP in Belarus by Rosatom without resolving the problems with the first one.³¹ As of December 2022, together with fuel supplies, Rosatom had a 10-year portfolio of overseas orders worth \$200 billion.³²

The dependence on Russia is the highest in eastern and central Europe, where Russia designed 19 nuclear power plants. Bulgaria, the Czech Republic, Hungary, Slovakia, and Finland rely on Russian technologies and services and the fuel elements provided by Rosatom.³³ In addition, Russia has been using its nuclear energy sector to increase its influence and assertiveness on the global stage. It has done this by using financial instruments, such as loans, investments, and partnerships, to expand its nuclear exports and secure energy deals with other countries.

One notable example is Russia's partnership with Hungary on expanding the Paks Nuclear Power Plant. Russia offered Hungary a loan of €10 billion to finance the construction of two new reactors and a five-year grace period, meaning that Hungary will start paying off the loan in 2031 (originally, the state was supposed to start loan

²¹ "Russia Has Once Again Become the Solution to Germany's Nuclear Problem." High North News. January 21, 2020. [Link](#).

²² "Russia owns the only plant in the world capable of reprocessing spent uranium." Le Monde. December 3, 2022. [Link](#).

²³ Mufson, Steve. "The U.S. imports uranium from Russia. What if sanctions end that?" The Washington Post. January 21, 2023. [Link](#).

²⁴ Foltynova, Kristyna. "Russia's Stranglehold On The World's Nuclear Power Cycle." Radio Free Europe. Radio Liberty. September 1, 2022. [Link](#).

²⁵ "Rosatom begins construction of the sixth power unit of the Kudankulam NPP in India." December 21, 2021. [Link](#).

²⁶ Zami, Md. Tahmid. "FEATURE – Bangladesh puts energy hopes in first nuclear power plant, despite delay." Reuters. January 5, 2023. [Link](#).

²⁷ Reducing Russian Involvement in Western Nuclear Power Markets. Energy Policy. Columbia. May 23, 2022. [Link](#).

²⁸ "Russia to build two nuclear reactors in Hungary." CNN. August 27, 2022. [Link](#).

²⁹ "Russia's Rosatom signs new construction contract for Turkish nuclear plant." Reuters. July 30, 2022. [Link](#).

³⁰ Oirere, Shem. "Egypt Issues Second Permit for \$30B Nuclear Power Plant Work." ENR. April 12, 2023. [Link](#).

³¹ "Belarus hints at building a second nuclear power plant without resolving problems at its first." BELLONA. February 23, 2023. [Link](#).

³² Stricker, Andrea, and Anthony Ruggiero. "Ending global reliance on Russia's nuclear energy sector." FDD. February 3, 2023. [Link](#).

³³ Liemienov, Oleksandr. "Why do Western countries hesitate with imposing sanction on Rosatom." ZN,UA. Березень 23, 2023. [Link](#).

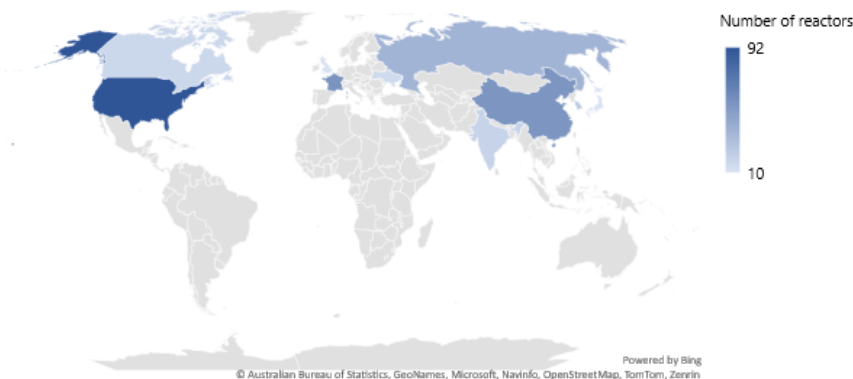
payments in 2026)³⁴. This deal could be considered an attempt to deepen its influence in the region and increase its foothold in the European energy market.

As a result, Russia used it during the Russian-Ukrainian war, and despite pressures from other EU states anxious to target Russia's nuclear exports with sanctions, in August 2022, the government in Hungary decided to move ahead with the construction of two more Russian nuclear reactors that have been planned for several years.³⁵ However, recently, there was information about the possibility of enlarging the French role in refurbishing its nuclear program. As a result, it could eventually replace Russia at Hungary's only atomic power plant.³⁶

At the same time, Finland was more proactive in comparison to Hungary, and the state halted plans to build a Russian nuclear power plant in this Nordic country³⁷ in part due to the war against Ukraine, which has worsened the risks for the project.³⁸

Another prominent example is the collaboration of Turkey and Russia, where the latter country transferred \$20 billion to finance the Akkuyu Nuclear Power Plant in July 2022. Upon completion in 2026, this NPP will generate approximately 35 billion kWh of electricity each year, which is equivalent to about 10 % of Turkey's electricity requirements. Rosatom has agreed to be responsible for the design, construction, operation, maintenance, and decommissioning of the power plant under a long-term contract.³⁹ These actions from Russia only increase its leverage over Turkey, especially in terms of significant control over Turkey's energy sector, and allow it to expand its influence in the region.

Figure 4. Number of operational reactor units by country in 2022



Source: Statista⁴⁰

³⁴ "CORRECTED – Hungary gets 5-year payment delay on Russian-led nuclear plant project." Reuters. April 29, 2021. [Link](#).

³⁵ "Europe's energy crisis: Russia gets approval to build two reactors in Hungary." euronews. August 29, 2022. [Link](#).

³⁶ Jan van der Made. "Is Hungary shifting the focus of its nuclear sector from Russia to France?" rfi. March 24, 2023. [Link](#).

³⁷ Milne, Richard. "Finnish group abandons plans for Russia-backed nuclear power plant." Financial Times. May 2, 2022. [Link](#).

³⁸ "Finland ends deal with Russian corporation Rosatom for nuclear power plant." Business Standard. May 2, 2022. [Link](#).

³⁹ "Russia transfers billions of dollars to Turkey for \$20B nuclear plant." Daily Sabah. July 29, 2022. [Link](#).

⁴⁰ Buchholz, Katharina. "The Countries With the Most Nuclear Reactors." Statista. October 18, 2022. [Link](#).

5. Getting rid of Russia

There are countries that have been trying to reduce their dependence on Russia. One of them is the U.S. which considers that the best way to confront Chinese and Russia's influence on the nuclear market is to collaborate with its allies such as France, the UK, Canada, Japan, etc., and put appealing financial deals. The list of American allies could be expanded to emerging markets, for example, African countries, as several states have declared their need for reliable zero-carbon energy that SMRs can produce. Still, their current rigid structures cannot support large LWRs.

In this respect, the increasing need for advanced reactors in both established and developing markets presents the United States with a chance to export novel nuclear technologies and reclaim its position as a global leader and enter into long-term diplomatic and financial agreements and replace Russia and, to a lesser extent, China. There have been successful cases of international co-financing at both the government and private sector levels, such as US-Japan and US-Republic of Korea (ROK). For example, according to the agreement, the U.S. companies sold equipment, technology, and fuel to Japan; in turn, Japan spent at least \$150 million on US license fees and nuclear fuel services.⁴¹

Unfortunately, the EU is reluctant to make bold moves. There were suggestions to introduce some trade restrictions with regard to nuclear energy in the 10th package of sanctions against Russia in February. Still, eventually, that was not done due to Hungary's position who promised to veto such a package. The next attempt was in April when Poland and Baltic states explicitly suggested introducing nuclear restrictions in the 11th package. It was not approved yet. President Zelenskyi discussed the issue during the latest visit to Kyiv of Ursula von der Leyen, the president of the European Commission, on May 9.

The current structure of the uranium market is not considered optimal for the developed world because this market is heavily concentrated, with a few countries controlling most of the world's uranium production (Kazakhstan, Canada, Australia, Uzbekistan, and Russia). This concentration creates concerns over supply security, making the uranium market and trade routes susceptible to disruption. For example, Kazakhstan and Uzbekistan are geopolitically vulnerable. Russia could block the transit of uranium through its territory and even use its regionally active military forces to interfere with nearby air or maritime trade. As a result, this could disrupt the global supply chain and affect uranium availability and price.⁴²

6. Proliferation

The proliferation of nuclear weapons is a significant risk to international peace and security. Several nations currently do not possess nuclear weapons but have the potential to create them. One of these countries is Iran. It is known this state has already produced uranium particles that were enriched up to 83.7 % purity at its Fordo fuel

⁴¹ Gordon, Jennifer T. "International co-financing of nuclear reactors between the United States and its allies." Atlantic Council. January 9, 2020. [Link](#).

⁴² "Opinion: Nuclear Energy Security: Sleep Walking into the Next Energy Crisis?" Global Risk Insights. [Link](#).

enrichment plant south of Tehran,⁴³ and this amount is enough to build “several” nuclear weapons.⁴⁴ The risk of other nations creating nuclear weapons is of concern for many reasons.

The creation of nuclear weapons by some nations could lead to a destabilization of the global power structure. The possession of nuclear weapons is often considered a significant factor in a nation's international status, and any shift in the balance of power caused by the acquisition of nuclear weapons by more nations could lead to concerns about security and the potential for conflict. Furthermore, the proliferation of nuclear weapons could increase the likelihood of nuclear war which would have catastrophic consequences for the world. We all remember the horrific atomic bombings of Hiroshima and Nagasaki and what horrible long-term consequences they brought Japan.⁴⁵

Even the mere threat of nuclear war can lead to tensions and fear among nations which could result in diplomatic and economic instability. When Russia launched the full-scale invasion of Ukraine, it started threatening both Ukraine and the western world with the usage of tactical nuclear weapons.⁴⁶ Moreover, in February 2023, Russia suspended its participation in its last major nuclear arms treaty with the U.S., making it harder to control nuclear weapons.⁴⁷ Consequently, the creation of nuclear weapons by additional nations such as Iran would increase the risk of these weapons being used against other countries, especially Iraq, Saudi Arabia, Yemen, Syria, Livan, and Bahreyn.⁴⁸

Moreover, the creation of nuclear weapons by other nations that don't possess them yet could increase the risk of nuclear materials falling into the hands of non-state actors, such as terrorist organizations. The creation of nuclear weapons requires the acquisition and use of nuclear materials, which can be difficult to secure. If a nation were to create nuclear weapons, there is a risk that these materials could be stolen or sold to non-state actors, increasing the risk of nuclear terrorism.⁴⁹

To mitigate the risk of nuclear weapon creation by nations that currently do not possess them, the international community has implemented several measures. These measures include diplomatic efforts, economic sanctions, and non-proliferation agreements – one of them is the Nuclear Non-Proliferation Treaty (NPT), which was established in 1970.^{50,51} However, some countries (for example, North Korea) have chosen to develop nuclear weapons despite international pressure. Respectively, the international community needs to continue to work together to prevent the proliferation of nuclear weapons, to maintain international peace and security. It requires ongoing international cooperation, diplomacy, and enforcement of international agreements and regulations.

⁴³ McCausland, Phil, and Dan De Luce. “Iran enriching uranium to near weapons-grade levels, nuclear watchdog warns.” NBC News. March 8, 2023. [Link](#).

⁴⁴ “Iran has enough enriched uranium to build ‘several’ nuclear weapons, US says.” PBS. January 26, 2023. [Link](#).

⁴⁵ “Bombing of Hiroshima and Nagasaki.” HISTORY. November 18, 2009. [Link](#).

⁴⁶ Watson, Eleanor. “What are tactical nuclear weapons and how might Putin use them?” CBS News. October 12, 2022. [Link](#).

⁴⁷ “Is nuclear war more likely after Russia's suspension of the New START treaty?” nature. March 7, 2023. [Link](#).

⁴⁸ Khotyn, Rostyslav. “Not only Ukraine. What other wars and conflicts is Iran involved into?” Radio Svoboda. November 3, 2022. [Link](#).

⁴⁹ Suh, Elisabeth, and Miriam Katharina Heß. “Nuclear Terrorism.” DGAP. September 8, 2021. [Link](#).

⁵⁰ “Disarmament, Non-Proliferation and Arms Export Control.” European Union External Action. August 16, 2022. [Link](#).

⁵¹ “Treaty on the Non-Proliferation of Nuclear Weapons (NPT).” United Nations. [Link](#).

7. Ukraine

Ukraine has 15 operable nuclear reactors at four working plants, generating about half of its electricity. Previously, the country depended on Russia for nuclear services and fuel. At the beginning of June 2022, Ukraine signed a deal for Westinghouse's nuclear power company to supply fuel to all its atomic power stations to end the country's reliance on Russian supplies. Moreover, it was agreed that Westinghouse would construct nine new nuclear units (much more than was planned before, as there was an agreement to build five power units) and establish an engineering center in the country.⁵² In January 2023, a decision was made to start the construction of 2 AP1000 power units of the American company Westinghouse at the Khmelnytskyi NPP. It's planned that the construction of both blocks will be finished by 2032.⁵³

In addition, during the discussion in Ukraine House Davos within the framework of the World Economic Forum in Davos, which was held in January 2023, it was stated that Ukraine is in the process of launching pilot projects of low-power reactors.⁵⁴ In March 2023, Ukrainian Energoatom and Rolls-Royce signed memorandums of understanding (MoUs) to explore the deployment of its small modular reactor (SMR).⁵⁵ According to the statement of energy minister Herman Haluschenko, Ukraine is considering ambitious plans to build up to 20 SMRs to replace thermal generation units destroyed during the Russian-Ukrainian war.⁵⁶ In April, a similar agreement was signed with Holtec International, who has a SMR model (SMR-160), too. Moreover, some participation of Ukraine in the production cycle is also being discussed.

Despite having significant uranium reserves, Ukraine has not fully developed them. It ranked sixth in the world for uranium reserves in 2020, with 46 thousand tons.⁵⁷ However, in 2021, the country's uranium production only met around 40 % of its nuclear fuel needs, making it very dependent previously on Russia and now on the U.S. Before the full-scale invasion, there were plans to increase uranium production to fully meet the needs of its nuclear power units after 2026. Production at four Ukrainian uranium deposits was projected to increase to 1,265 tons in 2026 from 455 tons in 2021. Nonetheless, this production level is still much lower than what the country has in reserves,^{58,59} and, as of 2021, Ukraine comes 10th in worldwide uranium production.⁶⁰

⁵² "Ukraine signs deal with Westinghouse to end Russian nuclear fuel needs." Reuters. June 3, 2022. [Link](#).

⁵³ "The Cabinet of Ministers decided to start the construction of 2 AP1000 power units of the U.S. company Westinghouse at KhNPP – the head of the Ministry of Energy." Interfax. January 20, 2023. [Link](#).

⁵⁴ "The priorities of Ukraine's post-war energy industry will be the development of nuclear, 'green' generation and decentralization of the system – the deputy head of the Ministry of Energy." Interfax. January 19, 2023. [Link](#).

⁵⁵ "Finland, Sweden and Ukraine consider Rolls-Royce SMRs." World Nuclear News. March 21, 2023. [Link](#).

⁵⁶ Dalton, David. "Kyiv Considering SMRs To Replace Power Plants Destroyed During War." NUCNET. March 20, 2023. [Link](#).

⁵⁷ Garside M. "Countries with the largest uranium reserves worldwide 2020." Statista. October 24, 2022. [Link](#).

⁵⁸ "Ukraine aims to produce enough uranium for nuclear energy needs." Reuters. December 29, 2021. [Link](#).

⁵⁹ Nuclear Power in Ukraine. World Nuclear Association. January 2023. [Link](#).

⁶⁰ World Uranium Mining Production. World Nuclear Association. June 2022. [Link](#).

Besides, in the middle of March 2023, the minister of energy in Ukraine announced that Ukraine plans in three years to start a full cycle of nuclear fuel production in Ukraine, with a long-term goal of exporting to other countries. Such states as the Czech Republic, Slovakia, Finland, and Bulgaria have already indicated their desire to shift from using Russian nuclear fuel to Westinghouse's, and Ukraine might potentially supply nuclear fuel to these countries in the future.^{61,62}

Additionally, in March 2023, Ukraine reached strategic agreements on the use of Ukrainian uranium in the production of nuclear fuel. It was also arranged to sell uranium to Canada which is mined at the Ukrainian Eastern Mining and Enrichment Plant.⁶³

It means that during the post-war recovery, Ukraine should pay attention not only to nuclear power generation and export of atomic fuel but also to uranium mining and processing, as this niche is a very demanding one from the side of the Western World which looks for the substitute of Russian uranium. Ukraine could potentially fill the gap and benefit economically.

⁶¹ "Ukraine aims to produce nuclear fuel by 2026, exports to follow." March 17, 2023. [Link](#).

⁶² "Ukraine will produce nuclear fuel that will replace Russian fuel on the European market – Herman Halushchenko." Ministry of Energy of Ukraine. March 16, 2023. [Link](#).

⁶³ "Ukraine reached strategic agreements on the use of Ukrainian uranium in the production of nuclear fuel – Herman Halushchenko." Ministry of Energy of Ukraine. March 20, 2023. [Link](#).