Russian Grip on EU Nuclear Power

Report by Patricia Lorenz

May 4, 2022

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Foreword

The Vienna Ombudsoffice for Environmental Protection (Wiener Umweltanwaltschaft - WUA) is very proud to present this report. The current events lead the WUA to commission this report on the severe dependence of nuclear industry from fuel and service provided by the Russian State atomic energy corporation Rosatom, which has been founded in 2007 by President Putin and is under direct control of the Kremlin.

This proves the idea of achieving energy supply security with nuclear energy a fatal mistake, because some type of nuclear fuel and maintenance for VVER reactors are irreplaceable. The ethical consequences of continued cooperation are undeterminable. The report also analysed options for ordering fuel, services and new reactors from non-Russian companies as replacements, however, short-term solutions proved to be impossible, even the long-term prospect is burdened with a high number of insecurities.

Phasing-out this high-risk energy production is the only reasonable action to take.

David Reinberger

Vienna Ombudsoffice for Environmental Protection (Wiener Umweltanwaltschaft)

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While the volume compared to gas and oil is certainly smaller, the Russian nuclear export business is a factor in its foreign policy and part of the Russian war machine; the heavy reliance on uranium and nuclear fuel made this possible.

However, with the war continuing and war crimes a fact, on April 7 the European Parliament agreed on another resolution, demanding a full embargo on imports of oil, coal, nuclear fuel and gas from Russia, believing that the Russian industry and experts, namely Rosatom, can be replaced by Western ones.

However, this might not be the case, as this report shows:

Rosatom became the leader of the USD 500 billion global nuclear energy market, building 37% of all new reactors in the world, eclipsing the United States' meagre 7% share. However, claims about the status and progress of the new nuclear power plant project should be taken with a grain of salt, as an analysis by an independent Russian expert has shown.

Rosatom/TVEL is the supplier of nuclear fuel for the VVER reactor series. They use different fuel to that of Western design nuclear power plants, thus creating severe dependency for those countries still operating the nuclear power plants they built in Communist times. The situation for VVER-440 units is different from the larger and newer VVER-1000 series, because no Western supplier can provide fuel for the smaller plants. For countries operating only VVER-440 plants, Slovakia and Hungary, about half of their domestic power generation is at risk.

Some countries (Ukraine, Bulgaria, Czech Republic) already started switching to Western suppliers, but Westinghouse is the only one already supplying VVER-1000 fuel assemblies. On top of likely technical problems with the replacement fuel which have occurred in the past decades it is clear, that Westinghouse will not be able to handle the large number of new customers asking for fuel – Westinghouse will first need to create new production capacities. Short-term solutions are not likely while some EU leaders started calling for an embargo also on nuclear fuel from Russian state companies.

Less known but of key importance are the many companies active in nuclear services. Among them is Škoda JS, a former Czech nuclear company, which in 2004 was bought by OMZ, the Russian heavy machinery manufacturer, itself owned by Gazprombank, a private bank owned by Russian gas monopoly Gazprom. Škoda JS is indispensable for keep the nuclear power plants Temelin, Dukovany, Mochovce, Bohunice, Paks and Kozloduj operating. The Czech government and the Czech utility ČEZ are desperately trying to find a solution, including nationalization, also connections to FSB were reported.

The report also gives an overview of the possible alternative vendors for new reactors, which are very limited. On top of the usual construction time and costs overruns, both the French EPR and the US AP-1000 have encountered several design failures. The South

Korean APR-1400 is not recognized as a Gen III+ reactor in Europe, Chinese reactors are already excluded for security reasons in UK and the Czech Republic.

Introduction

This report maps out the situation the nuclear industry finds itself in since Russia invaded Ukraine. When compared to gas and oil from Russia, where discussions on sanctions, boycotts, terms of payment started right away, nuclear power has managed somewhat to stay out of the limelight.

Regarding the gas supply, Germany and Austria in particular, and to a lesser extent Italy, were quickly blamed by other EU member states for their refusal to cancel their gas delivery contracts. Reluctantly, the most dependent countries made clear that they are not going to sanction Russian gas. Currently the oil embargo is on the agenda and nuclear fuel might be next. The economic difficulties might become even worse. According to Gabriel Felbermayr, Director of the Austrian Institute of Economic Research (WIFO) in Vienna, a new Iron Curtain may fall between Russia and the rest of Europe; the resulting "ice age" could last ten years, at least."[1]

Nuclear power so far managed to avoid Western embargoes for manifold reasons. Among those many reasons is certainly the heavy reliance on uranium and nuclear fuel. Scientists from the Colorado School of Mines pointed out: "As Western nations look for ways to reduce their reliance on Russian oil and gas, another aspect of the Ukraine crisis has received less attention: Most of the 32 countries that use nuclear power rely on Russia for some part of their nuclear fuel supply chain."[2]

While the volume compared to gas and oil is certainly smaller, the Russian nuclear export business is a factor in its foreign policy and part of the Russian war machine. In an open letter[3], a coalition of Ukrainian NGOs called upon the US and EU leaders: "Russia is using its nuclear company as one of the tools in the ongoing war. At this very moment it is important to impose tough sanctions against Russia, which will halt its ability to continue waging a brutal war on Ukraine and threaten international security."

However, when the European Commission came out with its REPowerEU strategy for weaning the EU off Russian gas on 8 March, nuclear was strangely absent. The IAEA Director General also seemed surprised: "We are disappointed that very little is said about nuclear in the communication, given that it consistently produces around one quarter of electricity in the EU," said Grossi. "Ignoring the EU's main source of highly dispatchable, low-carbon and non-weather dependent energy raises questions about whether the proposed measures are realistic."[4] Thanks to this misleading policy some countries will have to face very tough decision soon, as this report shows.

However, with the war continuing and war crimes a fact, on April 7 the European Parliament agreed on another resolution, demanding a full embargo on imports of oil, coal, nuclear fuel and gas from Russia, believing that the Russian industry and experts, namely Rosatom, can be replaced by Western ones:

> 17. Calls for an immediate full embargo on Russian imports of oil, coal, nuclear fuel, and gas, for Nordstream 1 and 2 to

1 Kleine Zeitung, April 22, 2022.
2 https://theconversation.com/russias-energy-clout-doesnt-just-come-from-oil-and-gas-its-also-a-key-nuclear-supplier-179444 (Accessed April 14, 2022).
3 https://en.ecoaction.org.ua/on-russian-nuclear-industry.html.
4 Energy Monitor, 24 March 2022: https://www.energymonitor.ai/sectors/power/will-the-ukraine-war-change-europes-thinking-on-nuclear (Accessed April 3, 2022).

> be completely abandoned, and for a plan to continue ensuring the EU's security of energy supply in the short-term to be presented; […]
>
> 19. Urges the Member States to terminate collaboration with Russian companies on existing and new nuclear projects, including in Finland, Hungary and Bulgaria, where Russian experts can be replaced by Western ones, and to phase out the use of Rosatom services; calls for an end to scientific cooperation with Russian energy companies, such as Rosatom, and other relevant Russian scientific entities; demands that sanctions on Belarus mirror those introduced against Russia in order to close any loopholes allowing Putin to use Lukashenka's aid to circumvent sanctions;

The task of this report is to provide a first assessment of whether it is possible to replace Russian nuclear services in the near-term. This report is probably the first to gather a comprehensive picture of the Russian nuclear industry's deliveries, supplies and services for the European nuclear industry, and provides one example of a mutual dependency.

Can the manufacturer Rosatom and its subsidiary TVEL be easily replaced? What about the rest of the Russian *matryoshka* unveiling Rosatom's numerous subsidiaries in Russia as well as less visible ones, such as the "Czech" but actually Russian-owned Škoda JS which itself partly owns the Nuclear Research Institute Řež?

The first step is the manufacturing and construction of new reactors. This might be the clearest phase: Business of this size and importance cannot take place any longer, therefore Rosatom will not construct any of its VVER in Europe for years, or rather decades, to come. Some countries had already taken the decision to ban Russian (and Chinese) reactors construction, notably the Czech Republic, with Finland following weeks after the invasion. Only Hungary has tried to hold on to its order. In theory, of course, reactors can be ordered from other countries, although Rosatom was seen as the market leader in this field.

What is much clearer is the dependence on Rosatom's nuclear fuel manufacturer TVEL, which, after switching back and forth to other fuel suppliers, still supplies most countries operating VVER. Those with VVER-440 reactors are fully dependent on Russian fuel.

Less well-known is that not only nuclear fuel, but also reactor maintenance is in Russian hands. The report also devotes a large chapter to services and maintenance in the field. At first glance the VVER market leader is the well-known Czech company Škoda JS, but it is actually Russian-owned, and hardly replaceable for Czech Republic, Slovakia, Bulgaria and Hungary. Unsurprisingly, Hinkley Point C and other European Pressurised Reactor (EPR) projects might also be affected.

In combination with the shocking picture of Russian troops shelling and threatening Ukrainian nuclear power plants and the fact that most Soviet-built nuclear power plants in CEE countries have already reached the end of their original life-time, a well-prepared phase out of nuclear power would be the economically and politically most sustainable answer.

1. Russian Nuclear Companies

The nuclear sector is exposed to high risks all over the world because the industry is heavily dependent on Russian-mined uranium, VVER-fuel supplies, servicing and maintenance of nuclear power plants and new-build plans.

The EU's latest sanctions on Russia do not (yet) include the nuclear sector, but new-build projects, pushed back for years and relatively advanced in the planning or preparation stages, have already been, or may be cancelled, while sooner or later others could turn out to be very problematic, in one way or another.

At the centre of this is Rosatom and, of great importance for CEE countries, the former Czech company Škoda JS and the technical support organisation (TSO) Řež ÚJV.

1.1 Rosatom – The nuclear giant

Rosatom Holding, with around 300 companies, was created by Vladimir Putin in 2007. It is an economic as well as political power to reckon with. As the Czech nuclear regulator SUJB's chairwoman Dana Drábová said in 2021: "Rosatom is a company under Kreml control."[5]

This is also confirmed by Rosatom's development programme, which had to be approved by the Russian President. Putin approved a rise in funding under the programme, known as the Development of Equipment, Technologies and Scientific Research in the Nuclear Industry, from Rb 349.5 billion (USD 4.77 billion) to Rb 552.7 billion, of which Rb 119 billion are expected to be allocated from the Russian federal budget.[6]

According to Rosatom's website, the corporation includes about 300 enterprises and organisations employing a total workforce of more than 290,000.[7]

The Rosatom 2020 Annual Report on market shares:

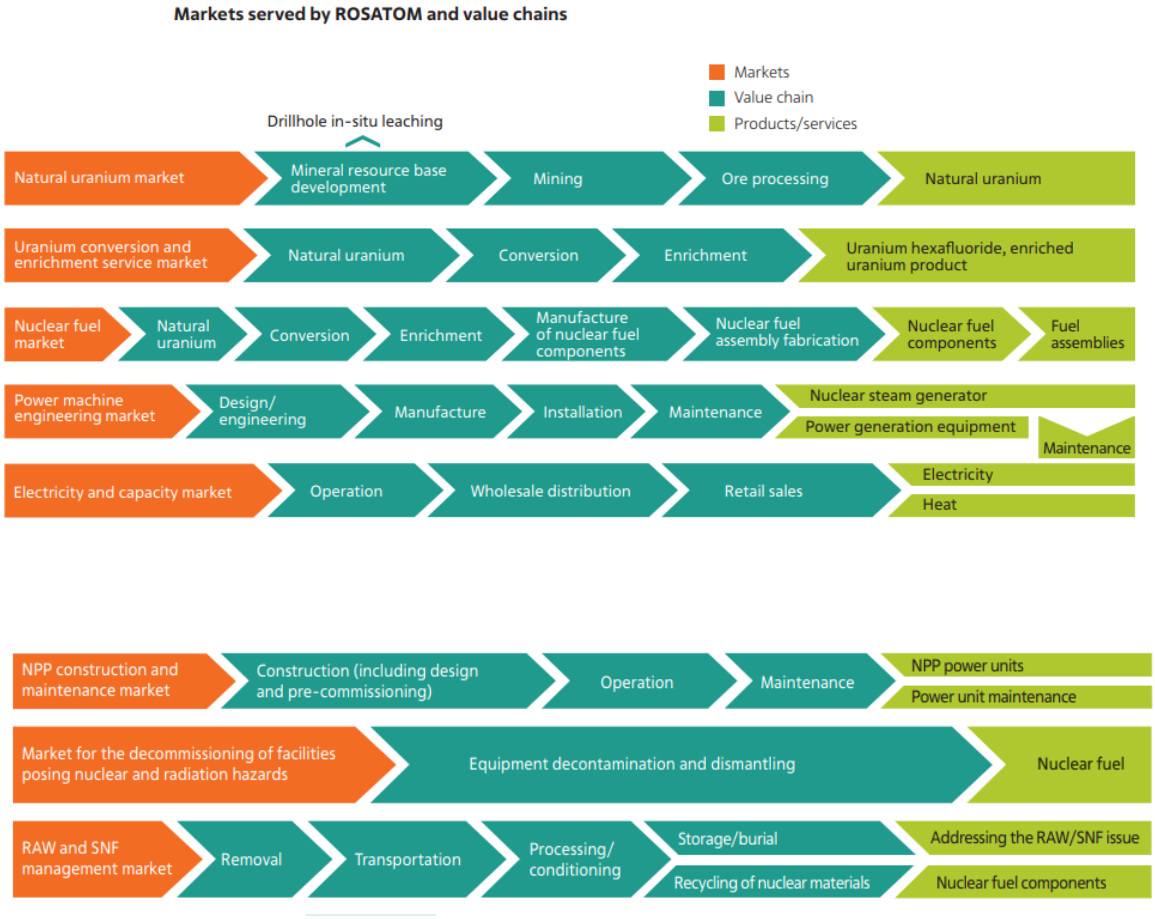
In 2020, ROSATOM ranked:

- First in the world in terms of the number of NPP power units in the portfolio of foreign projects (36 power units, including power unit No. 1 of the Belarusian NPP);
- First on the global uranium enrichment market (36%);
- Second in the world in terms of uranium production (15% of the market);
- Third on the global nuclear fuel market (17%).

The following scheme shows that through its subsidiaries Rosatom covers the complete "nuclear fuel cycle" of the nuclear industry, from mining to burial:

[5] iDNES.cz podcast, April 27, 2021.
[6] Platts Nucleonics Week August 19, 2021.
7 https://rosatom.ru/en/about-us/.

Figure 1: Markets served by ROSATOM and value chains[8]



Its political importance can be easily demonstrated by the following "staffing decisions": In 2016, Russian President Vladimir Putin appointed Rosatom Director General Sergey Kirienko as the First Deputy Head of the Presidential Administration with immediate effect. Before becoming the head of Rosatom, Kirienko led the Russian Federal Atomic Energy Agency for two years.[9] Currently, he is the Chairman of the Supervisory Board of Rosatom.

Rosatom became the leader of the USD 500 billion global nuclear energy market, building 37% of all new reactors in the world, eclipsing the United States' meagre 7% share.[10] However, claims about the status and progress of the new nuclear power plant

[8] Rosatom 2020 Annual Report.
[9] WNA, https://www.world-nuclear-news.org/Articles/Kirienko-leaves-Rosatom-to-join-Presidential-Admin#:~:text=Russian%20President%20Vladimir%20Putin%20has%20appointed%20Rosatom%20director-general,minister%20of%20economic%20development%20and%20trade%20since%202010. (Accessed April 17, 2022).
[10] https://thebulletin.org/2015/10/russian-nuclear-power-convenience-at-what-cost/ (Accessed April 2, 2022).

project should be taken with a grain of salt, as an analysis by an independent Russian expert has shown.[11]

At the time, the Russian side also offered interesting incentives. One was financing in the form of loans, as applied for the Hungarian nuclear power plant Paks II, where Russia covered 80% of the (assumed) construction costs with a loan. To enter the market even more convincingly, Rosatom offered Turkey the BOO (build-own-operate) option: providing uranium fuel, running the reactors, and taking back the generated nuclear waste to Russia. However, similar offers were not made for projects such as Dukovany in 2020, with the funding having dried up.

BOO Akkuyu

Turkey, a country with no nuclear power plants and no nuclear experience, ordered four units from Russia. Turkey had no nuclear safety regulator, nor any nuclear legislation. There the BOO model seemed to make sense, however, the drawback is complete dependence on Russia during construction and operation. The project is progressing only slowly.

1.2 Nuclear industry key companies owned by Rosatom

A full list is available on Rosatom's website: https://rosatom.ru/en/all-enterprises. Most of the information listed in the following interview stems from the Rosatom website but was confirmed by other sources; only key companies are included.

Atomenergomash (AEM)

AEM delivers reactor islands, turbine islands and owns the well-know OKB Gidropress. AEM is involved in constructing reactors at the following sites in Russia: Kurskaya NPP, Leningradskaya NPP, Novovoronezhkaya NPP. Abroad, AEM is involved in new construction and modernisation: Astravets / Belarussia, Akkuyu / Turkey, Kudankulam / India, Tianwan / China, Hanhikivi / Finland, Temelín NPP, Paks II / Hungary, Kozloduy / Bulgaria, Bushehr / Iran, Mochovce /Slovakia and Metsamor / Armenia.

JSC Atomenergoprom (AEP)

The group comprises around 50 nuclear industry enterprises. Atomenergoprom (AEP) provides the full production cycle of nuclear power engineering — from uranium production to nuclear power plant construction and energy generation. AEP companies already includes large enterprises such as Rosenergoatom Concern (#2 in the world by nuclear electricity generation), TVEL (17% of the world nuclear fuel market), and TENEX.

Atomstroyexport (ASE, Engineering Division of Rosatom), JSC

Atomstroyexport (Engineering Division of Rosatom) unites the leading companies of the nuclear industry, namely: JSC Atomstroyexport. ASE is involved in the following NPP projects:

[11] Ecodefense, Vladimir Slivyak, Dreams and Reality of Russian Reactor Export. https://ecdru.files.wordpress.com/2019/03/rosatom-report2019.pdf.

Astravets/ Belarus, Hanhikivi/ Finland, Akkuyu/ Turkey, Paks II/ Hungary, El-Dabaa/ Egypt/, Kudankulam/ India, Rooppur/ Bangladesh, Tianwan/ China, Xudapu / China and Kursk in Russia.

Mayak Production Association

Mayak in Ozersk, in the Chelyabinsk Region, is infamous. Mayak produced plutonium as early as the 1940s and later became known worldwide for several accidents and radioactive contaminations. Spent fuel reprocessing is a service offered at the Mayak facilities, also to Western countries' utilities.

Nukem

The well-known market leader in storage and transport containers for the nuclear industry, the German company Nukem Technologies GmbH, has only one shareholder: ASE Group ('Atomstroyexport'). In October 2019, Nukem was integrated into TVEL/Rosatom[12]. It provides services related to the management of radioactive waste and spent nuclear fuel (SNF), as well as the decommissioning of hazardous nuclear and radiological facilities. AEA is handling projects such as three projects in Bulgaria: Construction of Dry Storage Facility for Spent Fuel at Kozloduy Nuclear Power Plant, Construction of a Near-Surface Repository for Low Level and Short-Lived Intermediate Level Waste in Bulgaria, Design for Dismantling of Equipment in the Controlled Areas of Kozloduy Nuclear Power Plant Units 1 to 4. In Austria, Nukem has three projects with the Nuclear Engineering Seibersdorf GmbH, and a total of 22 countries have contracts for Nukem's casks and services. At the Ignalina NPP site, it is responsible for the RBMK-1500 SNF storage facility and conditioning and storage facilities. Nukem is constructing the conditioning centre at the Bohunice site in Slovakia, and at Chernobyl. In France, Nukem is decommissioning Brennilis NPP, and NPP Philippsburg 1 in Germany.[13] More information on the projects can easily be found on the company's website.[14]

OKB Gidropress

OKB Gidropress is the designer of the VVER reactors, of which 21 NPP were built in a number of countries (Russia, Ukraine, Armenia, Finland, Bulgaria, Hungary, Czech Republic, Slovakia, China and India), and 22 WWER-440 units. As the plant designer, Gidropress plays a key role in modernisations and life-time extensions.

Project Centre ITER

Russia is involved in the international ITER project.

TENEX

Uranium products, including conversion and enrichment of uranium, also for Western PWR (Pressurised Water Reactors).

TITAN-2

The TITAN-2 Holding represents a group of Russian companies involved in constructing nuclear power facilities. Organisations within the Holding perform the whole cycle of

[12] https://www.nukemtechnologies.de/news/nukem-wird-teil-des-back-end-bereichs-von-rosatom (Accessed April 29,2022).
[13] https://rosatom.ru/en/rosatom-group/back-end/nukem-technologies-gmbh/.
[14] https://www.nukemtechnologies.de/en/projects.

works, from development of basic design documentation to facility commissioning. It is the General Contractor responsible for construction of new units at the Leningrad NPP/Russia, as well as the Main Contractor for Hanhikivi-1 NPP in Finland and Akkuyu NPP in Turkey.

TVEL Fuel Company of ROSATOM

The TVEL Fuel Company of Rosatom incorporates enterprises for the fabrication of nuclear fuel, conversion and enrichment of uranium, production of gas centrifuges, as well as research and design organisations. More information on fuel production can be found in the chapter on Nuclear Fuel and TVEL´s website: http://www.tvel.ru/en/.

1.2.1 TVEL´s four enrichment and conversion companies

1. Angarsk Electrolysis Chemical Complex

Angarsk, Irkutsk Region

Uranium enrichment since 1957; a host facility for the International Uranium Enrichment Centre (IUEC) operating under the auspices of the IAEA.

2. Siberian Chemical Combine

Seversk, Tomsk region

The facility supplies Russia's low-enriched uranium fuel and enriches reprocessed uranium for foreign customers. It is one of the largest sites that stores low and intermediate level nuclear waste from reprocessing, with more than 30 million cubic metres.[15]

3. Production Association Electrochemical Plant

JSC PA ECP, Zelenogorsk, Krasnoyarsk territory

The company produces low-enriched uranium.

4. Urals Electrochemical Integrated Plant

JSC UEIP, Novouralsk, Sverdlovsk region

The company provides uranium enrichment.

1.3 Gazprom and OMZ – owner of Škoda JS and Řež ÚJV

Less well-known are the many companies active in nuclear services. Among them is Škoda JS, a former Czech nuclear company, which in 2004 was bought by OMZ, the Russian heavy machinery manufacturer, itself owned by Gazprombank, a private bank owned by Russian gas monopoly Gazprom. A look at the board of directors[16] shows many Russian names with some also on the Škoda JS board of directors[17] and thus under direct control of Russian capital. OMZ is also linked to Gazprombank (managing fonds)

[15] https://www.world-nuclear.org/information-library/country-profiles/countries-o-s/russia-nuclear-fuel-cycle.aspx (Accessed, April 29, 2022).
[16] http://www.omz.ru/en/company/direction/.
[17] https://www.koda-js.cz/struktura-spolecnosti/.

and has already been placed under sanctions.[18] At the same time, Škoda JS owns 17.39% of the Research institute and TSO ÚJV Řež.

The amount of highly specialised and unique information and data gained over decades working in all fields of nuclear infrastructure is enormous, as the following overview shows.

Škoda JS is currently responsible for maintenance of both NPPs (units at Bohunice, and Mochovce-1 and 2), and the construction of Mochovce-3 and 4 where it serves as the main contractor Škoda JS is also contracted for maintenance of the two Czech NPPs Dukovany and Temelín. Škoda JS is already responsible for Paks 1-4 (maintenance and modernisation, including inspections of the reactor pressure vessel at units 2, 3 and 4) and has signed contracts with MVM ERBE within a framework contract for the Paks 2 units for document evaluations, and inspections of the primary circuits.

On top of this, through Škoda JS the Russian nuclear giant owns about 20% of the nuclear research institution ÚJV Řež which is also a TSO. That means they enjoy access to sensitive safety documentation on reactors in both countries.

Russian hand in EPR (European Pressurised Reactor) - NPP Hinkley Point C / UK

Since July 2018, Škoda JS has had a contract with France's Framatome to manufacture two sets of EPR reactor pressure vessel internals (core basket, heavy reflector and the upper internals) for the two units currently under construction at Hinkley Point C, as well as for the two other EPR reactors in the EU: for the one recently completed in Olkiluoto (Finland) and for the still much delayed Flamanville-3 (France).

2. Nuclear fuel by Rosatom / TVEL

Created by Putin in 2007, state company Rosatom now produces nearly 20 percent of the world's nuclear fuel — providing an important revenue stream for Moscow, just like fossil fuels. According to its 2020 Annual Report, Rosatom produced over 1,000 tons of heavy metal (tHM) of nuclear fuel and 7,100 tons of uranium.[19]

TVEL is the supplier of nuclear fuel for the VVER reactor series. They use different fuel to that of Western design nuclear power plants, thus creating severe dependency for those countries still operating the nuclear power plants they built in Communist times. The situation for VVER-440 units is different from the larger and newer VVER-1000 series, because no Western supplier can provide fuel for the smaller plants.

The EURATOM Supply Agency (ESA) in its 2019 and 2020 Annual reports already warned against the continued dependence of VVER reactors operators on a single foreign supplier for nuclear fuel. This remains a matter of concern and is considered a significant vulnerability, in stark contrast with the situation elsewhere."[20]

Table 1: VVER units in the EU (16) and Ukraine (15)

Country	Nuclear power plant	Type of unit
Bulgaria	Kozloduj 5 & 6	VVER-1000

[18] https://www.reuters.com/article/ukraine-crisis-russia-usa-sanctions-corr-idUSL8N1BD4CB.
[19] Rosatom Annual Report 2020.
[20] ESA 2019, https://euratom-supply.ec.europa.eu/publications/esa-annual-reports_en.

Czech Republic	Dukovany 1-4	VVER-440
	Temelín 1 & 2	VVER-1000
Finland	Loviisa 1 & 2	VVER-440
	Hanhikivi 1 (under construction)	VVER – 1200
Hungary	Paks 1 – 4	VVER – 440
	Paks 5&6 (under construction)	VVER – 1200
Slovakia	Bohunice 3&4	VVER-440
	Mochovce 1&2	VVER- 440
	Mochovce 3&4 (under construction)	VVER-440
Ukraine	Khmelnitsky 1&2	VVER-1000
	Rivne 1&2	VVER-440
	Rivne 3&4	VVER-1000
	South Ukraine 1-3	VVER-1000
	Zaporishskaja 1-6	VVER-1000

2.1 VVER 1000 fuel

The issue of Russia being the sole nuclear fuel supplier for the VVER reactors, also in EU countries, has been a topic for decades, and in particular the issue of whether the TVEL fuel can be replaced with fuel made by Western companies; information on why fuel deliveries were substituted by other suppliers cannot always be fully verified. In addition to technical issues, economic, political, and geostrategic interests may have played a role.

Westinghouse was also only delivering fuel for VVER-1000, not for VVER-440, although with one exception, when from 2001-2004 fuel for delivered for Loviisa reactors in Finland.

One interesting result thrown up by research for this report is that TVEL is not only continuously improving the fuel assemblies for its VVER series, but is also designing specific fuels for individual plants which could later be used by other plants; for Paks in Hungary, fuel with characteristics other than those for Loviisa (enrichment level) was recently loaded in the core. In 2019, Dukovany started operating on modified RK3 Plus VVER fuel.[21] This constitutes an additional problem when it comes to non-Russian companies supplying VVER reactors with assemblies.

It was reported in 2016 that TVEL intends to standardise the construction of its VVER-1000 fuels for use in all VVER plants.[22]

[21] Nuclear Fuels, August 12, 2019.
[22] https://oenergetice.cz/elektrarny-cr/cez-nakoupi-pro-temelin-opet-americke-jaderne-palivo (Accessed April 29, 2022).

2.2 First Westinghouse fuel for VVER-1000 in 2000

Czech Republic

An attempt to rid power generation from its dependence on fuel deliveries from Moscow has already been made. When, following the Velvet Revolution in the Czech Republic, the decision was taken to complete the VVER-1000 Temelín reactors, the intention was to achieve a Western safety standard and Western fuel supply. Therefore, the US company Westinghouse helped to finish the plants and promised to develop the necessary fuel. When Temelín unit 1 went into operation in 2000, Westinghouse had developed nuclear fuel for this special East-West engineering cooperation, Temelín 1 & 2. Later this fuel turned out to be inadequate.

Ukraine

With its fleet of 13 VVER-1000 units, Ukraine has consistently led the way in trying to diversify its TVEL fuel and demonstrates the realistic options available.

Development of the first Westinghouse VVER-1000 fuel for delivery to Ukraine started in 2001. Westinghouse had earlier designed and delivered VVER fuel to the Temelín nuclear power station in the Czech Republic, but without having considered the mixed core conditions. Developing VVER-1000 fuel for mixed cores presented an additional challenge, especially since compatibility data on the resident fuel was not easily accessible to Westinghouse. Westinghouse shipped the fuel in 2005 and it was loaded in South Ukraine 3 the same year.[4] Later it turned out that the US nuclear fuel assemblies did not fulfil the requirements and revealed mechanical scratches and rub marks, grid damage, and that the fuel rods were not sufficiently stable. Bent fuel rods pose a safety risk if they cannot be moved properly in and out of the reactor core. The State Nuclear Regulatory Inspectorate of Ukraine (SNRIU) did not approve loading of any subsequent Westinghouse fuel assemblies of this design. Both the Czech Republic and Ukraine reverted to TVEL fuel deliveries, but after the 2014 annexation of Crimea, Ukraine re-started its fuel diversification. A constant issue is the difficulty of accessing the required technical data and information which are owned by TVEL, Rosatom and Škoda. Meanwhile, Westinghouse has been able to deliver an improved design – the Robust Westinghouse Fuel Assembly (RWFA). The first reload batch of this design was inserted in NPP South Ukraine 3 in March 2015. In 2014, Energoatom, the operator of all Ukrainian NPPs, extended the fuel contract to also include assemblies for the Zaporishskaja plant. When the Russian army occupied the NPP Zaporishskaja in March 2022, observers claimed they had taken with them fuel samples both fresh and spent.

As hinted earlier, another issue is political influence and the fact that the Russian fuel assemblies are cheaper. This might have played a role in a surprising U-turn in Ukraine, when it was reported that the Russian state-owned nuclear fuel company TVEL will supply fuel to eight out of 15 Ukrainian reactors between 2021 and 2025, as announced by the Ukrainian state-owned nuclear power generator Energoatom on January 10. TVEL supplies fuel to nine reactors, while the remaining six use Westinghouse fuel. Energoatom disclosed the plans after revelations that the company, without a public announcement, had signed an agreement with TVEL in September 2018 to extend Russian fuel supplies for five years through 2025. Foreign Minister Pavlo Klimkin, who said he was not aware of the agreement, has urged Energoatom to explain the continued dependence on the Russian supplier. "I believe those who were involved in this decision-making at least owe an exhaustive explanation to Ukrainian society," Klimkin wrote on

his Facebook page December 21. Ukraine accuses Russia of waging a war against the country following annexation of the Black Sea peninsula of Crimea in March 2014 and continued military support for separatists in parts of the Donetsk and Luhansk regions in eastern Ukraine.[23] A 2021 report said that the Rivne nuclear power plant received its first-ever shipment of fuel assemblies from Westinghouse on July 21.[24] On February 23, 2022, Rosatom completed a fuel delivery for NPP Rivne.[25] Rivne-3 will begin loading Westinghouse assemblies in early 2022 after inspecting the shipment, and it is expected to take four years to completely phase out TVEL fuel for the unit; in 2025 Rivne-3 will operate entirely on American nuclear fuel.

Table 2: TVEL fuel in Ukraine as of April 2022

Ukraine	Khmelnitsky 1&2	VVER-1000 *TVEL*
	Rivne 1&2	VVER-440 *TVEL*
	Rivne 3&4	VVER-1000 WEC unit 3, TVEL unit 4
	South Ukraine 1-3	VVER-1000 1 TVEL, 2 & 3 units WEC
	Zaporishskaja 1-6	VVER-1000 4 WEC, 2 units TVEL

However, Ukraine also intends to receive VVER 440-fuel from the US company. In 2021, a contract was signed between Energoatom and Westinghouse for the development and delivery of licensing documentation for fuel assemblies fitting VVER-440 reactors. The first reload of Westinghouse fuel in a Ukrainian VVER-440 nuclear fuel is expected at Rovno-2 in 2024, according to Energoatom. However, it was already expected for 2022.

On top of likely technical problems, it is clear that Westinghouse will not be able to handle the large number of new customers asking for fuel – Westinghouse will first need to create new production capacities.

Bulgaria switching to Westinghouse fuel

Bulgaria has two VVER-1000 units operating at the Kozloduj sites. Bulgaria started preparing for the switch three years ago.

According to experts in Bulgaria, the new supply by Westinghouse will come through, but the necessary tests took 2-3 years and the new fuel still needs a permit for commissioning. In early 2021 a contract was signed between the Bulgarian government and Westinghouse for a safety assessment of Westinghouse nuclear fuel as a supplement to Russian-sourced fuel for the 1,000-MW Kozloduy-5.[26] However, TVEL is contracted to supply Kozloduy-5 and -6 until 2025.[8]

[23] Nuclear Fuels January 28, 2019.
[24] Nuclear Fuels July 26, 2021.
[25] NIW, March 25, 2022.
[26] Nuclear Fuels February 8, 2021.

2.3 VVER-440 fuel

There is currently no alternative fuel supplier on the market. Although a well-known fact, the respective countries have chosen to ignore this problem, even claiming that nuclear energy is a domestic energy source ensuring a reliable energy supply. [27] The EC, namely the ESA even financed a project: "EURATOM has allocated funding to support diversification of the nuclear fuel supply for the VVER units operating within the EU. Earlier this year, a consortium of Westinghouse and eight European partners was awarded more than €2 million ($2.2 million as of 14 July 2015) by EURATOM for a programme to qualify a second supplier."[28]

Westinghouse has already been delivering fuel to the Loviisa NPP 440 units, however, not even Finland intends to resume the Westinghouse fuel supply. Technical issues include not only the fact that Westinghouse does not produce this fuel, but that there is no one type of VVER-440 fuel which could be used to supply all the reactors of this type (all 4 Slovak reactors, all 4 reactors in Hungary), and the Russian Rosatom company TVEL has developed specialised fuel for the individual reactors. The fuel and the core configuration and other key tasks are in the hands of TVEL, Škoda JS and Řež.

Countries operating VVER-440 units in the EU and Ukraine have also announced a growing interest in qualifying a second supplier. Back in 1998, BNFL (British Nuclear Fuel Limited) delivered lead test assemblies to unit 2 at Finland's Loviisa plant. The assemblies were manufactured in the fuel facility in Springfields, UK, and the purpose of the programme was to qualify a second supplier for Loviisa, as well as for Paks in Hungary. After successful completion of the operation of the LTAs, in December 1999 BNFL was awarded a contract to supply reload deliveries to Loviisa and a total of seven reload batches were delivered between 2001 and 2007. Shortly before the contract award, Springfields was incorporated into Westinghouse fuel operations after BNFL was acquired by Westinghouse. Westinghouse decided that the reload fuel would be assembled by ENUSA in Spain instead of at Springfields. Following some unsuccessful fuel tenders in 2006 and 2007, Westinghouse decided to exit the VVER-440 business. Lately, the increased importance of diversified fuel supply has resulted in discussions with different utilities about re-entering the market with an upgraded Westinghouse fuel design, including more advanced materials, as well as improved mechanical features. The EURATOM programme has allocated funding to support diversification of the nuclear fuel supply for the VVER units operating within the EU. Earlier this year, a consortium of Westinghouse and eight European partners was awarded more than €2 million ($2.2 million as of 14 July 2015) by EURATOM for a programme to qualify a second supplier. The programme will mainly focus on establishing the methods and methodology required to licence a VVER-440 fuel design. The consortium includes partners with expertise in different technical disciplines and the countries operating VVER440 within the EU are represented (see box). As part of the programme, steps will be taken to update the design previously delivered to Loviisa, and to create a state-of-the-art design.[29]

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[27] MPO, Ministry of Trade and Industry: Czech State Energy Concept 2015. https://www.mpo.cz/assets/dokumenty/52841/60959/636207/priloha006.pdf. p. 44, where nuclear fuel is categorized as primary domestic source.
[28] Nuclear Engineering International NEI, September 2015.
[29] Ibid.

Both Paks and Loviisa are being supplied by TVEL with a newly modified second-generation VVER-440 fuel, although these fuels are not identical. The fuel for Paks enables an increase in the coolant volume inside the reactor core and optimisation of the hydro-uranium ratio. TVEL also decreased the amount of fuel bundles loaded in the reactor core. Loviisa has the same number of fuel assemblies, but a lower uranium enrichment level was developed.[30] In late 2020, TVEL loaded 18 fuel bundles of a modified design of VVER-440 fuel into the 500-MW Paks-3 in Hungary during last month's recent refuelling outage at the unit.[31]

TVEL confirmed this being the company's strategy in December 2020: "We are actively engaged in the development of new models and modifications of VVER-440 fuel for power plants in Europe. The projects of the new fuels for the Loviisa plant in Finland, Dukovany plant in the Czech Republic, [and] Mochovce and Bohunice plants in Slovakia are currently at various stages of implementation. Despite the same reactor model, these projects are quite different technically and conceptually."[32] Two more VVER-440 units are also depending on TVEL supply, Metsamor in Armenia.

Westinghouse may develop VVER-440 fuel

In 2021, a contract was signed between Energoatom and Westinghouse for the development and delivery of licensing documentation for fuel assemblies fitting VVER-440 reactors. The first reload of Westinghouse fuel in a Ukrainian VVER-440 nuclear fuel is expected at Rovno-2 in 2024, according to Energoatom. This, of course, may change due to the current war situation; with respect to other VVER-440 operators, it the question of whether it is commercially viable for Westinghouse to produce fuel for a few VVER-440 reactors needing fuel with different characteristics.

Czech Republic

Since the beginning of the war in Ukraine, for the third time Czech Republic a nuclear fuel delivery has been flown into the Czech Republic. This was so urgent that, in the midst of the war in Ukraine, an exemption to the ban on flights for Russian aircraft into the airspace of the European Union had to be granted. ČEZ, the operator of both Temelín and Dukovany NPP explained that this was the last of the planned deliveries.[33] ČEZ also informed the public that Temelín currently has sufficient fuel stored for two years and Dukovany for three.

The nuclear fuel supplier for both NPPs is TVEL which belongs to the Russian state holding Rosatom. For Temelín, this contract expires in two years' time and ČEZ announced it will try to avoid renewing the contract with TVEL. For the construction of the new reactor, Rosatom has already been excluded for security reasons.[34]

TVEL has announced the start of tests of its 3rd generation fuel intended for VVER-440 reactors. The new fuel, which will be loaded in Dukovany in reload batch quantity in 2023, allows the reactor to operate with increased thermal capacity and to extend the

[30] World-nuclear-news.org, May 24, 2021.
[31] Nuclear Fuels December 28, 2020.
[32] Ibid.
[33] https://www.idnes.cz/ekonomika/domaci/rusko-jaderne-palivo-temelin-dukovany-dodavka-letadlo-zasoby-jaderne-elektrarny-cez.A220401_192525_ekonomika_hend.
[34] https://www.idnes.cz/ekonomika/domaci/rusko-jaderne-palivo-temelin-dukovany-dodavka-letadlo-zasoby-jaderne-elektrarny-cez.A220401_192525_ekonomika_hend.

fuel cycle at the plant, leading to better economic efficiency.[35] Nuclear Fuels reported in more detail: "The modification includes a higher uranium load and will enhance the efficiency of fuel usage (…). Increasing the mass of uranium in one fuel rod will allow a lower uranium enrichment level without reduction of thermal power generation in the reactor," the company said. It did not say how much uranium is contained in a rod of either the new or current design. Lower enrichment will also reduce the cost of the nuclear fuel production chain and facilitate handling of irradiated fuel, Rosatom said. (…) the company had developed different VVER-440 fuel cycle strategies for its customers in Hungary and Finland."[36]

This might already be reflected by Finland's NPP operator Fortum saying on March 25 at the Fortum AGM[37] that they intend to stay with TVEL (Rosatom company) as foreseen in the contracts until 2027 and 2030.

Finland

In March 2022, Fortum announced that although there are potential alternative suppliers of fuel for the NPP Loviisa they intend to continue with TVEL fuel for the two units as foreseen in the current contract until 2027 and 2030 respectively. According to TVEL, modified VVER-440 fuel for the Loviisa plant served to enhance the efficiency of fuel usage. It consisted of a higher uranium load in each fuel road, and a reduced level of uranium enrichment without a reduction of thermal power generation in the reactor.[38]

The company noted the project has involved the participation of a number of Russian nuclear industry enterprises, such as OKB Gidropress (part of Rosatom's machine-building division Atomenergomash), Bochvar Institute (TVEL's material science research facility), the Elemash Machine-building plant and the Kurchatov Institute national research centre. The new fuel passed a range of hydraulic, longevity and vibration tests at the site of OKB Gidropress research and experiment facility.

Finnish utility Fortum signed a contract with TVEL in March 2018 for the supply of the modified fuel for use at its twin VVER-440 Loviisa plant. It followed the signing in November 2017 of a similar contract between TVEL and MVM Paks for development of the new VVER-440 fuel for use in the Paks plant in Hungary.

Slovakia

Slovakia is a good example of total dependence. Currently, Slovakia's utility Slovenské elektrárne is the operator of four units of VVER-440 reactors, delivering over 50 % of Slovak power. This reactor type is operated with fuel which only the Russian company TVEL can deliver. Slovakia ignored the warning from EU institutions which kept enforcing alternative fuel suppliers. Instead, Slovakia continued with the construction of two additional VVER-440 units (Mochovce 3 & 4).

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[35] IAEA/NEA: Uranium 2020, Resources, Production and Demand, p. 9. https://oecd-nea.org/upload/docs/application/pdf/2020-12/7555_uranium_-_resources_production_and_demand_2020__web.pdf, p. 59.
[36] Nuclear Fuels May 31, 2021.
[37] https://www.fortum.com/files/answers-shareholders-questions-fortum-agm-2022/download?attachment.
[38] World-nuclear-news.org, May 24, 2021.

Therefore, three flights operated by the Volga Dnepr airlines, with special exceptions from the ban of Russian airspace, delivered fuel to Bratislava in the first days of the war on Ukraine. However, these batches may last only for another year. Compared to other countries, Slovakia is very silent when it comes to efforts to find other suppliers of nuclear fuel. The reasons might be that no alternative suppliers exist for those VVER 440 units, and the existing infrastructure for licensing new fuel – Nuclear Regulator and TSO – is not very capable. Consequently, it might prolong the time needed in order to use new fuel up to ten years. It is fair to assume that Slovakia is most likely lobbying the other member states and the EU Commission hard to keep fuel from Russia coming in, despite the ongoing war, war crimes and the crimes against humanity committed by the Russian army in Ukraine. This could turn Russia into a pariah state for years to come and lead to charges in the Hague – and result in a very difficult political situation for Slovakia.

TVEL is developing accident-tolerant fuel (ATF)

TVEL invested into developing accident-tolerant fuel (ATF). This type of fuel is a response to the Fukushima catastrophe, and it should, among other factors, lower the impact of accidents by modifying certain fuel compositions. The goal is to produce nuclear fuel without zirconium content because this leads to hydrogen development under accident conditions. It was this that led to explosions at the Fukushima unit 1 when the hydrogen that was being created rose to the ceiling of Unit 1, leading to a spark that led to the reactor exploding. In 2019, TVEL was reported as testing fuel with up to 7% U-235. TVEL also tried to enter the US market with TVS-Kvadrat for Western PWRs.[39]

This ATF is required in order to allow include nuclear generated power under the currently prepared EU taxonomy (draft CDA).[40]

High-assay low-enriched uranium (HALEU) for SMR

Currently some politicians and lobbyists claim that the answer to the energy crisis will be to deploy so-called next-generation or advanced nuclear reactors, many of them Small modular reactors. Many of these reactors need HALEU – which is higher enriched than the approx. 5% enriched fuel for Light Water Reactors (LWR) currently used, as the following overview shows:

- Small modular reactors, LWR-based → mostly use UO2 with enrichment < 5%
- Small modular reactors, HTR-based → mostly use HALEU
- Small modular reactors, MSR-based → mostly use HALEU
- Small modular reactors, sodium- or lead-cooled → mostly use HALEU or mixed oxides (MOX)
- Advanced reactors > 300 Mwe.[41]

These are mostly fast reactors, sodium or lead-cooled, and use MOX fuel or, in some cases, HALEU.

[39] NIW July 5, 2019.
[40] https://www.euractiv.com/wp-content/uploads/sites/2/2022/01/draft-CDA-31-12-2021.pdf.
[41] ESA 2019, Securing the European Supply of 19.75% enriched Uranium Fuel.

So-called next-generation nuclear reactors generally require fuel enriched with up to 20 percent U-235, called HALEU. Higher enrichment allows nuclear power plants to operate longer before refuelling. The more energy-dense fuel also allows for smaller reactor designs. But the only major supplier of HALEU is in Russia. With the Russian invasion of Ukraine, this type of fuel will also be out of reach. The US Administration which is supporting SMR development has acknowledged this problem. Two Department of Energy-funded demonstration projects for advanced reactors will need HALEU by the end of 2024. Until then, a production facility must be established in the US; this will take at least 4-5 years. President Biden's budget proposal for 2023 includes a funding boost for the DOE that includes money to help "secure the availability" of HALEU.[42]

After having banned the import of oil, gas and coal from Russia, US uranium imports from Russia remain an open issue. The obvious alternative to uranium imports from Russia would be to re-open US mines. The obvious problem would also be re-opened: environmental pollution on a vast scale, and often close to sacred Native American sites.[43]

3. From Uranium Mines to Nuclear Fuel Assemblies

Several steps outlined in the following chapter are needed to produce nuclear fuel assemblies which are then used in NPP. They are very specialised and only available in some countries for several reasons. To understand why Russia's nuclear fuel deliveries to European countries cannot be simply replaced by importing Australian uranium, for example, it is necessary to understand that fuel is specific for reactor types and the different production phases are available only on a limited scale in certain countries, and there can be bottlenecks. In addition, some data are not available, e.g., for decades Germany managed to keep the origin of the uranium it used a secret, and until today the uranium deployed in French reactors is mostly labelled "French", in spite of being imported from Niger, because the initial processing is undertaken in France.

Mining of uranium

Uranium mining is a very hazardous and environmentally damaging activity. The next step is milling and processing the uranium ore, where the goal is to isolate uranium oxide (U3O8), the so-called yellowcake which, after conversion, is then sold to companies for further enrichment. Enrichment of uranium is seen as a safeguarding risk and therefore the IAEA non-proliferation policy bans this technology from being exported to countries which do not yet have enrichment capacities. Increasing the share of uranium's most fissile isotope, U-235 is called enrichment. Low-enriched uranium, which typically has a 3-6% concentration of U-235, is used for fuelling NPP. The fuel loaded into EU reactors has an average enrichment assay of 3.94%, with 85% falling between 3.43% and 4.52%.[44] Highly enriched uranium, or HALEU, is 20% enriched or more, while weapons-grade uranium for nuclear bombs is 90% enriched or more. The

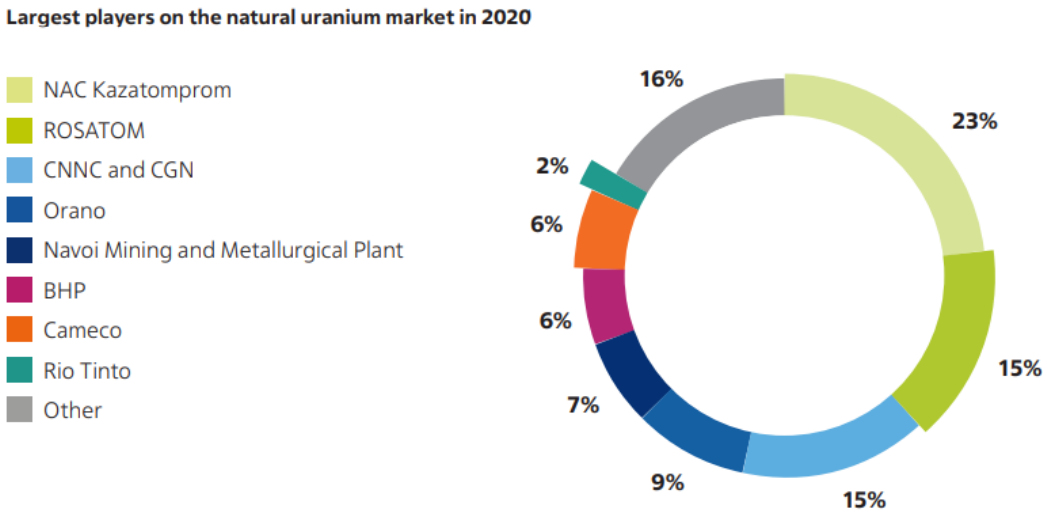
[42] https://www.theverge.com/2022/3/31/23003494/war-ukraine-nuclear-energy-uranium-russia-supply-chain (Accessed April 2, 2022).
[43] https://www.theguardian.com/us-news/2022/mar/28/native-americans-ban-russian-uranium (Accessed April 5, 2022).
[44] ESA European Supply Agency— ANNUAL REPORT 2020, p. 21.

very same plant can be used to enrich all the way through to bomb-grade material, making it a safeguarding risk.

Uranium mining capacities

About 40% of uranium imported in the EU stem from Rosatom's mine or from Kazakhstan, which is politically considered an ally of Russia. Some of the mines in Kazakhstan are owned or co-owned by Russian companies.

Figure 2: Largest players on the natural uranium market in 2020[45]



Europe has no uranium production

Europe's last uranium mine in Rožná in the Czech Republic closed in 2017. However, the government reserved the option of reopening other mines, such as Brzkov open. Brzkov is said to contain 3000-4000 tU around 300 m deep; state company Diamo said it would take six to seven years to commission the mine; local resistance it high. In Spain, the Salamanca project was under preparation and could produce 4.4 million pounds (Mlbs) of uranium concentrate annually for 14 years. But this was also recently cancelled. Similarly, the Kvanefjeld mining project didn't start after the Greenland Parliament approved a bill prohibiting uranium exploration and mining in 2021.

Uranium prices and increasing production

Uranium does not trade on an open market like other commodities. Buyers and sellers negotiate contracts privately. Uranium spot prices have surged more than 30% since Russia's invasion of Ukraine to trade at about $58/lb, the highest level since before the 2011 Fukushima-Daiichi disaster. The Wall Street Journal reported fears of disruption to uranium supplies due to sanctions on Russia. (…).[46] In the current situation, uranium

[45] UxC, Company reports.
[46] NucNet's Weekly News Review, April 1, 2022.

producers remain cautious before increasing production, which takes several months, in some cases years, and are waiting for long-term contracts before making risky investments.[47]

An IAEA/NEA report summarised this in saying that "significant investment and technical expertise will be required to bring these resources to the market. Producers will have to overcome a number of significant and, at times, unpredictable issues in bringing new production facilities on stream, including geopolitical and local factors, technical challenges and legal and regulatory frameworks. To do so, strong market conditions will be critical for achieving the required industry investment".[48]

When evaluating the issue of replacing dependency on Russian and/or Kazakh uranium, costs are important. Uranium price plays a minor role for the operator of a nuclear power plant, but it is decisive when opening or enlarging a uranium mine. An example here is the US, where the dramatic decline in uranium production from 2016 to 2018 was due to low market prices. At the same time, US utilities started importing cheaper uranium from Rosatom; by March 2022 the dependency was so high that they lobbied hard to prevent the White House from banning the import; this may well be overturned.

The IAEA/NEA reported on global supplies: "Globally, Australia continues to lead with 28% of the world's identified resources in the category <USD 130/kgU (equivalent to USD 50/lb U3O8), with over 64% of Australia's national total endowment related to a single site, the world class Olympic Dam deposit. In terms of lower cost resources <USD 80/kgU and <USD 40/kgU, equivalent to USD 30/lb U3O8 and USD 15/lb U3O8), Kazakhstan leads with 49% and 36% of the world total, respectively."[49] Uranium mine development takes long preparatory times, so no sudden new players can emerge. Also here Kazakhstan is leading. Only six countries announced development drilling in 2020: Canada, Iran, Kazakhstan, Namibia, Russia and Ukraine, with Kazakhstan accounting for half of the total global development drilling.[50]

On top of industrial considerations, ecological limitations will play a role and might in the end block efforts to increase uranium mining.

An embargo of Russian uranium cannot be excluded and has already started worrying the Kazakh state-owned uranium miner Kazatomprom. However, Kazakhstan is considered an ally of Russia and most likely would be become a target, even though Kazatomprom was responsible for a quarter of the world's primary uranium production in 2021, according to company data.

Conversion and enrichment

Western uranium converters and enrichers are facing an explosion in demand from nuclear fuel buyers preparing for a possible cutoff from Russian nuclear fuel. However, new additional capacities are needed and those are a long-term project. Some observers pointed out at the beginning of April 2022 that for many companies uncertainties remain, because if the war ends suddenly and Russian nuclear fuel never stopped

[47] NIW, March 25, 2022.
[48] IAEA, NEA: Uranium 2020, Resources, Production and Demand. https://oecd-nea.org/upload/docs/application/pdf/2020-12/7555_uranium_ _resources_production_and_demand_2020__web.pdf.
[49] Ibid., p. 9.
[50] Ibid., p. 45.

entering the EU or the US, the newly build-up capacities for mining, converting and enriching would have been in vain.

Today there are five major global suppliers of uranium conversion services, Orano/Comurhex (France), Cameco (Canada), Converdyn (USA), Rosatom/TVEL (Russia) and CNNC (China).

Table 3: Estimated world primary conversion capacity 2020[51]

Conversion plants are operating commercially in Canada, France, Russia and China. China's capacity is expected to grow considerably through to 2025 and beyond to keep pace with domestic requirements.

Estimated world primary conversion capacity 2020

Company	Country	Location	Nameplate capacity (tU)	Capacity utilization (%)	Capacity utilization (tU)
Orano*	France	Pierrelatte & Malvési	15,000	17%	2600
CNNC†	China	Lanzhou & Hengyang	15,000	53%	8000
Cameco	Canada	Port Hope	12,500	72%	9000
Rosatom	Russia	Seversk	12,500	96%	12,000
ConverDyn‡	USA	Metropolis	7000	0%	0
Total			**62,000**	**51%**	**31,600**

World Nuclear Association *Nuclear Fuel Report* (2021 edition)

* Orano's new conversion facility is still in the process of production ramp-up, which is expected to be finalized by 2023.

† Estimated capacity according to the assumption that China will develop its conversion capacity to supply the needs of the domestic reactor fleet.

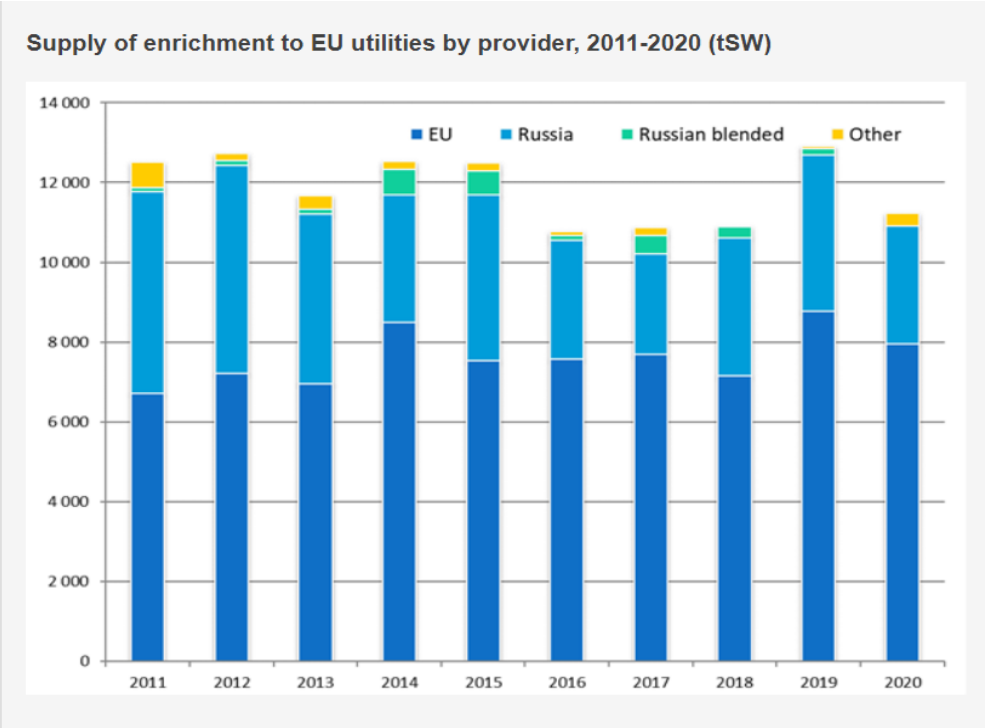
‡ ConverDyn reduced capacity of its Metropolis plant in 2016 then closed it down pending market improvement in 2017. In January 2021 it announced that it plans to restart the plant after refurbishment in 2023.

Enrichment capacities

According to European Supply Agency's data[52], Europe covers its enrichment demand by 60-70 % itself, the remaining amount needs to be imported from Rosatom's enrichment facilities:

[51] https://world-nuclear.org/information-library/nuclear-fuel-cycle/conversion-enrichment-and-fabrication/conversion-and-deconversion.aspx (Accessed April 4, 2022).
[52] ESA 2020. https://euratom-supply.ec.europa.eu/activities/market-observatory_en.

Table 4: Supply of enrichment to EU utilities by provider, 2011 - 2020 (tSW)



4. Outlook on Alternatives for New Reactors

A few days after the Russian invasion of Ukraine, discussions started on the fate of ongoing Rosatom projects in EU countries. This chapter explores the current new-build projects and gives an overview of the reactor types and reactor vendors available to replace the Russian supplier Rosatom Holding and its companies.

Russia's Rosatom with its many subsidiaries was the market leader in the nuclear industry. Russia was not only constructing nuclear power plants at home, but also successfully completed its NPP projects (Astravets-1/Belarussia) abroad, certainly with fewer delays and cost overruns compared to its competitors. Russia has dominated the nuclear export market since 2009 and was preparing new contracts in many countries. Following its attack on Ukraine and resultant sanctions, many of Russia's contracts, including those in Finland and in Hungary, are likely to be cancelled. Russia's ability to even complete the remaining contracts is also in question.[53]

EPR/France

The French nuclear industry, usually understood as a powerful branch, is vastly overrated. The issue here is the potential of French nuclear industry to replace the new reactors which were previously, or might have been, delivered by Rosatom in Russia.

The only European reactor on the market is the EPR-1600 MW, which 20 years ago was called the flagship of nuclear renaissance. This Generation III+ reactor, however, is infamously troubled, notorious for its cost overruns and delays: even the domestic

[53] M.V. Ramana, University of Colorado: https://www.colorado.edu/cas/2022/04/12/even-china-cannot-rescue-nuclear-power-its-woes (Accessed April 17, 2022).

project Framatome 3, and Olkiluoto-3 in Finland, are not scheduled to reach full capacity until September 2022 – is a delay of 13 years, following a total construction time of 18 years.

Table 5: EPR reactors – 1600 MWe net

Country and NPP unit	Construction start	Commercial operation
China, Taishan 1	Dec 2009	Dec 2018
China, Taishan 2	April 2010	September 2019
Finland, Olkiluoto 3	Aug 2005	Planned July 2022
France, Flamanville 3	2007	Planned end of 2022
UK Hinkley Point C 1	2018	Planned 2026
UK Hinkley Point C 2	2019	Planned 2027

Two key problems stand in the way of an export offensive: manufacturing capacity and the EPR's design deficiencies which became evident once the first EPR started operating in China. The Taishan NPP unit 1 was taken offline for inspection on July 30, 2021, and it was still shut in April 2022. The immediate cause was fuel rod leakage, however, later it turned out that the problem might be a design failure in the reactor pressure vessel for which EDF is required to present a design solution to the French nuclear regulator ASN. EDF needs to submit a plan for reinforcement of metal grids at the EPR in France. The plan has not yet been submitted and is delayed.[54] This might be a major design failure which affects all EPR reactors.

Czech Republic

The Czech Republic is of particular interest for the discussion for two reasons. It is the only country which has opened a tender procedure, and, after a severe political struggle, decided even before the war in Ukraine to exclude Russia and China from the construction of the fifth unit at the NPP Dukovany site in 2021 after GRU (Russian military intelligence service) involvement in the 2014 explosion of an ammunition depot in Vrbětice was confirmed.

The path chosen by the government and parliament in Prague when it comes to ordering a nuclear reactor can be understood as a path others also need to take. What remains unclear at the this point in time – May 2022 – is the issue of other suppliers such as Škoda JS. One key point applicable to all future NPP financing schemes is the 100% state funding, loan and guarantees provided. The government announced that they will not only keep an eye on the main supplier, but also their sub-suppliers. The following steps must be clear before any contracts are signed.

4.1 Status of Dukovany financing and tendering process

The notification of the project at the European Commission is ongoing. The past cases of state aid notifications for financing packages for new NPP (Hinkley Point C and Paks II) were granted, but the Czech Republic seems to fear problems on some points, namely the relationship between investor (ČEZ) and the state (70% shareholder is the state) and the minority shareholders, and exceptions from public tendering: in a letter to the

[54] https://www.montelnews.com/news/1313051/crucial-french-epr-report-4-months-late--regulator (Accessed April 18, 2022).

government[55] Transparency International Czech Republic criticising the unclear financing structure and unrealistic costs estimates[56] or rather the lack of a limit to the public funding assumed for the NPP and the possible loss of billions of taxpayers' money. The authors of the letter also reminded the Minister of Finance that the Czech Office for the Protection of Competition has informed the government that the NPP tender would not be exempted from public procurement law; moreover, this exemption might also stand in violation of EU law.

According to the timeline of NPP Dukovany, according to information provided by MPO, the Czech Ministry of Trade and Economy, the March 2022 start of tendering will end with a November 2022 deadline for the offers coming in from vendors, which will then be evaluated for approx. 2 years.[57] The tendering procedure should be completed by the end of 2023/beginning 2024, followed by 2029 construction start and 2036 start-up of the new reactor.

According to the French President, the new plants would be built and operated by state-controlled energy company EDF and tens of billions of euros in public financing would be mobilised to finance the projects and safeguard EDF's finances. The first new reactor, an evolution of the EPR known as the EPR2, would come online by 2035, Mr Macron said. Studies for a further eight reactors in addition to the initial half-dozen new plants would be launched.

EDF has submitted a preliminary, non-binding offer to the Polish government for the construction of four to six EPR nuclear power plants in Poland at two or three different locations. It is also hoping to build six EPRs at the Jaitapur site in Maharashtra state, Western India.

Poland has been planning the construction of four to six EPR for over a decade; India also intends to order six EPR. At the same time, half of the NPP fleet in France (as of May 2, 2022) is out of operation and in need of repairs, thus adding pressure on the existing lack of skilled workforce and other nuclear industry infrastructure. It is safe to doubt the ability of France to go from managing the construction of four EPR in the past 15 years to a significantly larger number. On top of the already envisaged orders of 12 for export and eight for France, and 2 ongoing reactors in UK (HPC), EDF might have a hard time demonstrating its capacities to manage over 22 reactors in the next years.

Rosatom has also been plagued by the inability to deliver new nuclear power plants. NPP Paks II in Hungary was scheduled for start-up in 2025, and Hanhikivi in Finland in 2024.

Concerning the ongoing tender in the Czech Republic for a max. 1200 MW reactor, the experts' opinion on the rumoured intent of EDF to offer a downscaled EPR remains split: some say no problem, other exclude this possibility on technical grounds; the deadline for offers is scheduled for November 2022.

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[55] https://www.transparency.cz/wp-content/uploads/2022/03/TI-MPO-JEDU-17.3.22.pdf.
[56] https://english.radio.cz/tender-new-nuclear-unit-dukovany-launched-after-years-delays-8745211 (Accessed April 4, 2022).
[57] https://www.mpo.cz/cz/rozcestnik/pro-media/tiskove-zpravy/stat-dal-souhlas-se-zahajenim-vyberoveho-rizeni-na-dodavatele-noveho-jaderneho-zdroje-v-dukovanech--266463/.

US / AP 1000

Another option is the US company's reactor, the AP 1000. Westinghouse is advertising its new reactor type with passive safety features: The AP1000 features a compact nuclear island per kWe produced (i.e., lower amount of concrete and steel per kWe) with fewer number of nuclear safety grade components relative to other GENIII/III+ reactors including the EPR and APR1400. This is due to AP1000 reliance on passive safety. AP1000's robust station black out scenario response without any need for offsite support already provides effective protection against Fukushima-type events.

This, however, could lead to a time-consuming licensing process, because many regulators lack experience and legal provision for this reactor type with more passive safety features replacing e. g. pumps. Switching from VVER-type reactors to the reactor from the US might need some time for the regulators, including finding staff with sufficient language skills to work with Westinghouse when it comes to constructing an AP1000 reactor to replace the planned VVER-1200 reactors in Kozloduj or Belene in Bulgaria.

In general, the costs of NPP are always hugely uncertain, consistently turning out to be extremely over budget and the most expensive method of generating power. Lazard projects the capital cost of a nuclear power plant at $6,900 – $12,200/kW, while OECD Nuclear Energy Agency projects the capital cost between $2,157-$6,920/kW.

The newly published MIT study on the AP1000[58] tries to argue several specific cost-driving factors which have led to the ongoing AP1000 Vogtle project's current cost overruns since its start of construction in 2012. Modular construction is currently promoted as the answer to the well-known delays and subsequent cost overruns. Westinghouse promised to beat this trend because of their expectation that "plant costs and construction schedules benefit directly from the great simplifications provided by the design" and because of the adoption of "modular construction techniques". Based on these, Westinghouse estimated a "cost per kWh of about 3.0 to 3.5¢/kWh for a twin unit plant". Westinghouse projected that the AP1000 reactor would have "an accelerated construction time period of approximately 36 months, from the pouring of first concrete to the loading of fuel". All of these projections have gone spectacularly wrong in both China, with the Sanmen and Haiyang projects, and especially with projects in the United States. The modular construction methods only had the effect of shifting some of the problems from the building site to the factory, found the World Nuclear Report in 2017. Among those technical problems was the unfinished design, pumps which had to be called back, shielding material which expanded in volume – a possibility the company had not considered as it had to admit in its report to the US nuclear regulator, the NRC. China publicly voiced criticism with Westinghouse handling construction of the reactor in China and it was the last order China placed with the US company. The AP1000 disasters in terms of cost overruns and delays with the reactor constructions at V.C. Summer and Vogtle are well-known and ongoing.

On top of technical issues, many observers doubt Westinghouse's abilities as a reactor supplier. Westinghouse filed for bankruptcy reorganisation in 2017, driven by liabilities related to the two US projects, and new owner Brookfield Business Partners has said the

[58] MIT-ANP-TR-193 March 2022, Koroush Shirvan: Overnight Capital Cost of the Next AP1000 Advanced Nuclear Power Program.

company wanted to remain a reactor supplier but not get involved in being the construction contractor on nuclear plant projects.

China as a vendor of nuclear power plants the Europe

Nuclear power features prominently in China's plans for exports of energy technologies under the Belt and Road Initiative. In February 2022, China National Nuclear Corporation signed an agreement to build a nuclear plant in Argentina. This marks China's first export of a nuclear reactor to a country other than Pakistan (with whom China shares a special relationship that also extends to sharing nuclear weapons and related military technology).[59] Already earlier, however, countries decided to avoid the risk of Chinese interference and possible threat to infrastructure. In summer 2020, in reaction to doubts which arose in the US, several UK politicians started taking a very critical view on the Chinese involvement in the Hinkley Point C project, as reported by the Telegraph 26th July 2020[60]:

"Another senior Tory MP has called for an inquiry over Chinese involvement in Britain's nuclear power stations amid rising concerns over the Hinkley Point C mega-project. Neil O'Brien said that urgent questions must be answered following conflicting reports about work by state-owned contractor China General Nuclear (CGN) on the £22.5bn scheme. The firm's role was originally thought to be limited to financial investment (…) Mr O'Brien said that US regulators were already taking aim at CGN and another business, China National Nuclear Corporation, after its department of defence accused them of having ties to Beijing's military forces. He said: "Both CGN and China National Nuclear Corporation have a kind of regulatory sword of Damocles hanging over their heads. Chinese reactors will be built even less, even if the design might be accepted, as the Economist reported in early 2022: "Hualong One…has a more straightforward design than other reactors being built in Europe… Publicly, the government says no decision has been taken. Privately, it is clear that Chinese involvement in British nuclear-power plants is at an end."[61]

The Czech Republic had already banned Chinese participation in this new reactor project in 2021 with its so-called Lex Dukovany which took effect on January 1, 2022.

Korea Hydro and Nuclear Power (KHNP)

South Korean energy company Korea Hydro and Nuclear Power (KHNP) has confirmed it intends to take part in the Czech Republic's tender process. Its flagship export technology is the 1,345 MW APR-1400 pressurised water reactor design, so far deployed overseas only at the United Arab Emirates' Barakah nuclear power station. Domestically, KHNP operates the APR-1400 at Shin-Kori-3 and 4 and is building more units at Shin-Hanul-1 and 2 and Shin-Kori-5 and 6.[62] However, since 2009, when South Korea won this contract thus beating France, South Korea has not won a single reactor export contract.

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[59] M.V. Ramana, University of Colorado: https://www.colorado.edu/cas/2022/04/12/even-china-cannot-rescue-nuclear-power-its-woes (Accessed April 17, 2022).
[60] Telegraph on 26th July 2020 at https://www.no2nuclearpower.org.uk/news/hinkley-chinese-involvement-28-7-20/ (Accessed April 17, 2022).
[61] https://www.economist.com/britain/2022/02/12/british-regulators-have-approved-a-chinese-reactor-design (Accessed 17 April 2022).
[62] NucNet Nuclear News Daily/1 April 2022.

4.2 Difficult future of Rosatom reactor exports

VVER reactor producer dependent on Western I&C

Rosatom Holding, the market leader in the past decades, also might run into difficulties because it relied on Framatome's Instrumentation & Control systems in its reactors, as well as receiving support for licensing in Western countries. In many cases it is a Framatome-Siemens consortium providing this service to Rosatom.

The possibly politically or economically forced end to this field of cooperation could pose a serious problem both for Rosatom's new-build and modernisation business, because Framatome has been delivering the I&C systems for VVER reactors. It is almost impossible to replace the supplier of Instrumentation & Control systems which are the brain of a nuclear power plant: only very few companies are able to produce them. It may be that only Framatome can deliver the I&C for Rosatom's VVER reactors, both old and new, as it has many times in the recent past: In 2009, Framatome completed the Dukovany plant (Czech Republic) I&C refurbishment, a nine-year project considered one of the most significant I&C modernisation projects, and was used in 2018 to modernise key parts of the two Loviisa (Finland) VVER plants.[63] Framatome also delivered the I&C for Russian and Chinese plants.

Back in 2020, the I&C Business Unit at Framatome announced: "We are delighted to provide our I&C expertise and partner with RASU JSC to support the construction of the Hanhikivi-1 Nuclear Power Plant," and continued by saying that this contract "demonstrates our unique capabilities to support Russian reactor designs in the field of I&C."[64] The Rusatom/Framatome/Siemens cooperation for another planned NPP in an EU country was already signed in 2019: Paks-2 in Hungary.[65]

WNN also reported that in 2018, Framatome and Rosatom subsidiary JSC Rusatom Automated Control Systems (RASU) signed an MoU to enhance their cooperation in the field of I&C, including cooperation in the fields of maintenance and modernisation, training, development of nuclear infrastructure, and support for the certification of Russian equipment to ensure compliance with European and international norms and standards.

In 2021 Framatome and RASU signed a contract to provide technical support in design and integration of the I&C system for Fennovoima's Hanhikivi-1 nuclear power plant project in Finland. Under the terms of the contract, Framatome was to provide consulting support for I&C system integration and design in the plant construction

[63] https://www.framatome.com/solutions-portfolio/docs/default-source/default-document-library/product-sheets/a3038-b-fr-g-en-0422-spinlinefinal.pdf?Status=Master&sfvrsn=c378d37e_2 (Accessed April 25, 2022).
[64] https://rosatom.ru/en/press-centre/news/rosatom-and-framatome-sign-instrumentation-and-control-design-support-contract-for-hanhikivi-1-npp-f/?sphrase_id=2953088 (Accessed April 26, 2022).
[65] https://emerging-europe.com/business/rusatom-and-framatome-siemens-to-deliver-control-systems-for-hungarys-paks-npp/ (Accessed April 26, 2022).

project based on a VVER-1200 reactor. The role of RASU is to review design documentation and to be I&C technical leader and integrator for the Hanhikivi-1 plant.[66]

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[66] www.world-nuclear-news.org/Articles/Framatome-and-Rosatom-expand-cooperation (Accessed April 26, 2022).

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