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# Global Inventories of Secondary Uranium Supplies

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# GLOBAL INVENTORIES OF SECONDARY URANIUM SUPPLIES

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The Agency's Statute was approved on 23 October 1956 by the Conference on the Statute of the IAEA held at United Nations Headquarters, New York; it entered into force on 29 July 1957. The Headquarters of the Agency are situated in Vienna. Its principal objective is "to accelerate and enlarge the contribution of atomic energy to peace, health and prosperity throughout the world".

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# GLOBAL INVENTORIES OF SECONDARY URANIUM SUPPLIES

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## FOREWORD

This publication is intended for IAEA Member States with existing nuclear power programmes and Member States considering adding nuclear power to their energy mix. The security of nuclear fuel supply is essential when considering the sustainability of nuclear energy. This publication focuses on assessing the global inventories of secondary uranium supplies, which are an important part of the total uranium supply for nuclear power plants.

The publication qualifies and quantifies the secondary supplies available across the world at the front end of the nuclear fuel cycle. It explains some of the key drivers for inventory policy related to nuclear fuel supply management and addresses the current ability of surplus or strategic uranium supplies to supplement the primary uranium supply chain for front end components of the nuclear fuel cycle. It also informs Member States of the important question as to the appropriate level of inventories sufficient to ensure the ongoing supply of nuclear fuel for end users.

This publication includes a supplementary file, available on-line, and contains tables of uranic inventories by country and region.

The IAEA acknowledges the contributions of the experts who participated in the consultancy meetings for the drafting and review of this publication. In particular, the IAEA would like to acknowledge the contribution of S. Harding (United Kingdom) for extensive reviews and contributions. The IAEA officer responsible for this publication was A. Hanly of the Division of Nuclear Fuel Cycle and Waste Technology.

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# 1. INTRODUCTION

## 1.1. BACKGROUND

Ensuring the reliable, safe, secure and sustainable supply of uranium for use as nuclear fuel is crucial to demonstrating the long-term viability and sustainability of nuclear power. Primary (freshly mined and processed[1]) uranium supplies represent the mainstay of resources for this purpose, but secondary uranium supplies have also periodically been an important component of nuclear fuel supply. It is therefore essential to have an understanding and assessment of these secondary supplies of uranium in support of current and future nuclear plant operations.

Market participants in the front end of the nuclear fuel cycle have traditionally held uranics[2] inventories as a dependable secondary resource that can be used to flexibly fill potential shortfalls in primary uranium production. This approach is facilitated by cyclical oversupply against nominal demand. These uranium supply overhangs (i.e. excess supply) have been held off-market for periods of time due to regulatory, commercial or political factors, but have eventually been made available to end users through individual disposition programmes. Often a release has been coincident with market downturns and so also represents a conservation of primary production that could not otherwise be economically deployed. Those periods of primary uranium production conservation have eventually restored a market equilibrium and gradually drawn down the inventories of secondary uranium supply, particularly in component markets or regional sectors.

Historically, primary uranium supply has often exceeded civil uranium needs. In the period 1945–1990, military procurement of uranium was a significant and even a dominant part of world demand. Since 1990, the partial reduction of nuclear arsenals has been an important element of ongoing uranium supply for commercial and non-weapons purposes. Defined programmes by the United States of America (USA) and the Russian Federation reduced significant portions of their surplus highly enriched uranium (HEU) and stockpiles of other forms of uranics during this period. Thereby, the oversupply created by ex-weapons uranium stocks was gradually reduced between the 1990s and the early 2010s, in civil nuclear power programmes, research reactors and by naval propulsion demand. As implied by Fig. 1[1], between 1990 and 2013 a gap between primary uranium supply and civil reactor-related uranium requirements was capable of being filled by secondary uranium supply stockpiles, a supply gap that sometimes represented close to 50% of total annual civil uranium requirements. The demand for nuclear propulsion (not shown[3]) also served to shorten the periods of oversupply by a meaningful amount. Since 2015, secondary uranium supplies have again become an increasingly important factor in achieving a balance between uranium supply and demand.

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1 Natural uranium oxide, uranium hexafluoride as feed material and enriched uranium product or powdered uranium dioxide for fabrication into fuel pellets.

2 Products relating to or containing uranium.

3 http://www.mining.com/web/uranium-collapse-signals-2020-positive-supply-shock-goviex-ceo/world-uranium-production-and-demand-chart/

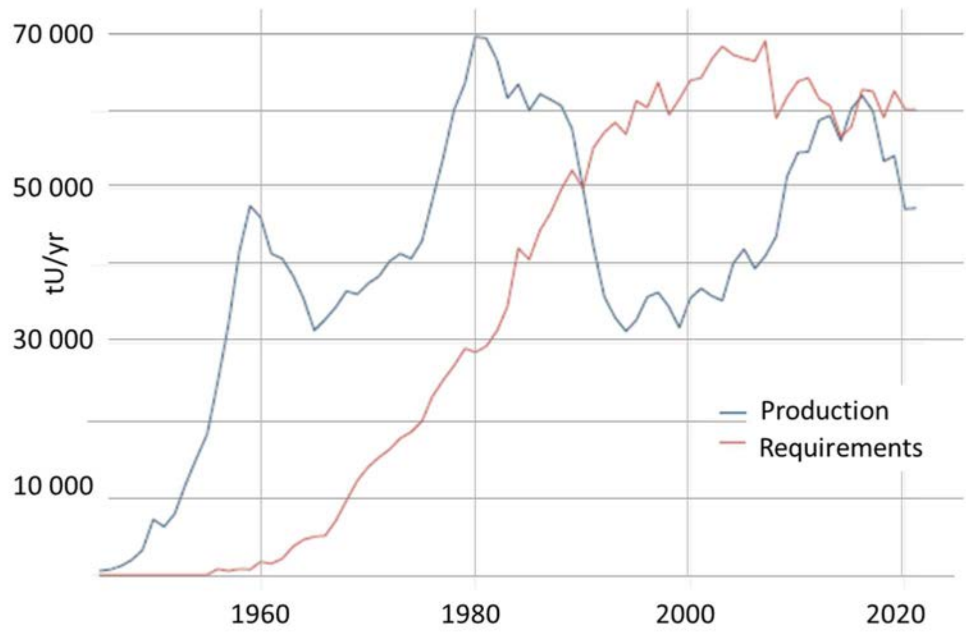


*FIG 1: World Annual Uranium Production and Civil Nuclear Requirements (1949-2021) reproduced from Ref. [1] with permission courtesy of OECD.*

During the last 25 years there have been notable trends in inventory management, influenced by prominent events. For instance, by 2010 new fuel cycle capacity programmes were at a peak. Governments were discussing the creation of strategic stockpiles of uranics (such as in China, Japan, the Russian Federation and the USA), as was the IAEA. Action was taken in the USA to set up the American Assured Fuel Supply and MOX backup inventories, as well as additional down-blending and tails upgrading to create a low enriched uranium (LEU) tritium production stockpile for the Tennessee Valley Authority (TVA). In the Russian Federation, the 'LEU Reserve' at the International Uranium Enrichment Centre in Angarsk was created in 2011. Meanwhile, China began a programme in 2007 of acquiring the natural resources needed for the fulfilment of its nuclear power ambitions. The IAEA proposed an 'LEU Fuel Bank', which subsequently became operational at Ulba in 2019 as a global assurance mechanism. During this period, fuel cycle market price indicators were suggesting a supply shortfall in some sectors (especially for uranium and enrichment services), with price levels driven by the investment costs necessary for new primary capacity to be deployed.

Following the accident at the Fukushima Daiichi nuclear power plant, plans for the development of nuclear power were changed: The cessation of operations at more than 20% of the world civil nuclear fleet by mid-2012 had an immediate and lasting impact on the uranium supply and demand balance. Furthermore, in China, France, Finland, Japan, the United Kingdom and the USA advanced new-build plans were either halted or delayed. Phase-outs were imposed (or re-imposed) in China, Belgium, Germany, Republic of Korea (ROK), Spain and Taiwan, and other countries stepped back from project initiations (e.g., Vietnam). The accelerated closure of nuclear power plants under more stringent regulatory environments were also seen in France, Japan, ROK, Spain and Sweden Switzerland, and the USA.

At the same time, many fuel cycle expansion commitments were already underway, both creating unwanted secondary uranic inventories and primary uranic supply overcapacity. Through the middle of the last decade, much of this was delivered under existing contracts to utilities in material that was surplus to uranium demand. From the second half of the decade as contractual commitments ended, the surplus capacity was reoptimized or moved into care and maintenance by suppliers. This move had an impact on adjacent segments of the fuel cycle, such as the substitution of primary uranium conversion supplies by uranium enrichment capacity.

For those utilities who were decommissioning plants, their unused nuclear fuel has remained stranded for long periods. This is particularly true for German, Japanese, Swedish, and Taiwanese utilities who have had to construct a re-use supply chain for fresh nuclear fuel defabrication. In 2020, material finally began to flow under these new arrangements. Furthermore, the reuse of partly burned fuel in Germany and Japan has depressed uranium demand in those specific markets.

The above events serve to provide a contextual backdrop to the snapshot of uranic inventories being analysed in this publication. However, there are recent changes in the secondary market. Until 2021, inventory policy was driven by nuclear power programmes – declining markets became more reliant on Just-In-Time (JIT) supply and enacted drawdown policies (e.g., in the EU, Japan, Republic of Korea and Taiwan, China and the USA), while growth markets took a more strategic view (e.g. in China, India and the Russian-aligned markets). The armed conflict in Ukraine that began in February 2022 has meant that security of supply has become foremost in any nuclear fuel procurement policy. The nuclear industry's credentials for energy security and zero emissions are once again being promoted and recognized internationally. This security of supply edict and a reversal of globalization are both impacting decisions in the nuclear fuel cycle. The response has been to again consider the strategic value of uranic inventories, irrespective of the growth status of nuclear energy within individual countries.

To identify the part being played by uranic inventories in the market, the methodology of this study has focused on expert analysis of the available public information to identify the extent of secondary uranic supply inventories. The study was conducted by an Expert Group comprised of industry consultants, nuclear fuel cycle primary suppliers, utility fuel buyers and supra-national monitoring bodies. Information was gathered from resources that include regulatory and financial filings, industry body reports, press statements, trade statistics and (where publicly available) safeguards data. This information has been assessed alongside modelled front end component uranium demand [2] and aggregated market price information, in order to estimate volumes. By specifically tracking the ownership of material, rather than attempting to simply determine its location, this approach also provides an ability to assign a confidence level to the results for each country under review.

Preliminary findings based on key regional statistics from 2020 were presented at the World Nuclear Fuel Cycle conference in April 2021 [3]. The Expert Group has now widened the scope to all nuclear power countries and updated the analysis with the most recently available information and insights, to present a snapshot of total global inventories.

## 1.2. OBJECTIVE

The role played by the various stakeholders in building or depleting secondary uranium supply inventories needs to be more rigorously understood. Moreover, the trends of responsible consumption and circular economy are increasing the importance of maintaining secondary supplies in the nuclear fuel cycle. The outputs of this publication are intended to widen the discussion from a largely generic and face-value analysis of reported secondary uranic stockpiles, to a more quantitative analysis based largely on financial statistics within which material forms and quantities are aggregated. It also provides regional insights into the purpose, liquidity and mobility of the identified nuclear fuel inventories, which are critical factors in judging the availability of secondary uranium supply.

This publication can inform private industry, government entities and policy makers in all countries, in support of assuring a dependable supply of nuclear fuel to civil nuclear power programmes — both existing and under development. An overview of uranium supply fundamentals and the types of secondary uranium inventories guides the reader in understanding the role of the secondary uranium supply in fulfilling the demand for uranium. Security of supply is evaluated through an analysis of publicly reported or statistically implied holdings of front end uranic material (referred to as 'uranic inventories'), before discounting the volumes therein that are needed for continued reactor operation (often described as supply chain work in progress (WIP) and in-core partly burned fuel). It may also inform the debate for a more detailed look at back end inventories (including depleted uranium, reprocessed uranium and plutonium) that will be important for the potential closed cycle and circular economy credentials of nuclear power and the opportunities for next generation reactor technologies.

### 1.3. SCOPE

This publication provides a comprehensive evaluation of front end nuclear fuel inventories in the public domain, while considering the approach of end users towards the reliability of their once-through supply chain. It presents and analyses data from a variety of complementary sources and qualifies, where appropriate, the reported information in order to align definitions and metrics to avoid misinterpretation.

This publication considers global nuclear power markets, with research covering 31 countries including a review of national or commercial policies in relation to front end uranic inventory management. The research covers secondary uranic materials owned by most utility operators, primary suppliers, brokers and traders, financial investors and national or international agencies.

This publication provides a snapshot of uranic material as of 31 December 2021, which represents the end of the most recent reporting cycle for most entities at the time of drafting of this publication.

### 1.4.STRUCTURE

This publication comprises a high-level overview of uranium supply fundamentals with a focus on concepts and definitions of secondary uranium supplies. This is followed by an introduction to the background and methodology of the main part of the technical document, which is a study of uranic inventories grouped by six regionalized blocks of countries (i.e. Africa and Middle East, Eurasia, Europe, North America, South America, and South and East Asia). Supporting material is tabulated and referenced in the Annex.

## 2. GENERAL OVERVIEW OF THE NUCLEAR FUEL CYCLE

The nuclear fuel cycle starts with the exploration and mining of uranium and ends with the disposal of nuclear waste (Fig. 2 [4]). Mined uranium has to undergo several steps before it is suitable for use in a nuclear reactor. Depending upon the type of reactor (shown in circles in Fig. 2 [4]), additional steps can include processing, refining, conversion, enrichment, deconversion and fuel fabrication. These steps prior to the fuel being loaded into the reactor make up the front end of the nuclear fuel cycle and typically can take two to three years to accomplish. As such, it is typical in a normal fuel supply chain for an end user to have a years' worth of demand in each form appropriate to its needs (e.g., for light water reactors this would result in one year's demand as $U_3O_8$, one year's demand as $UF_6$ and one year's demand as $UO_2$).

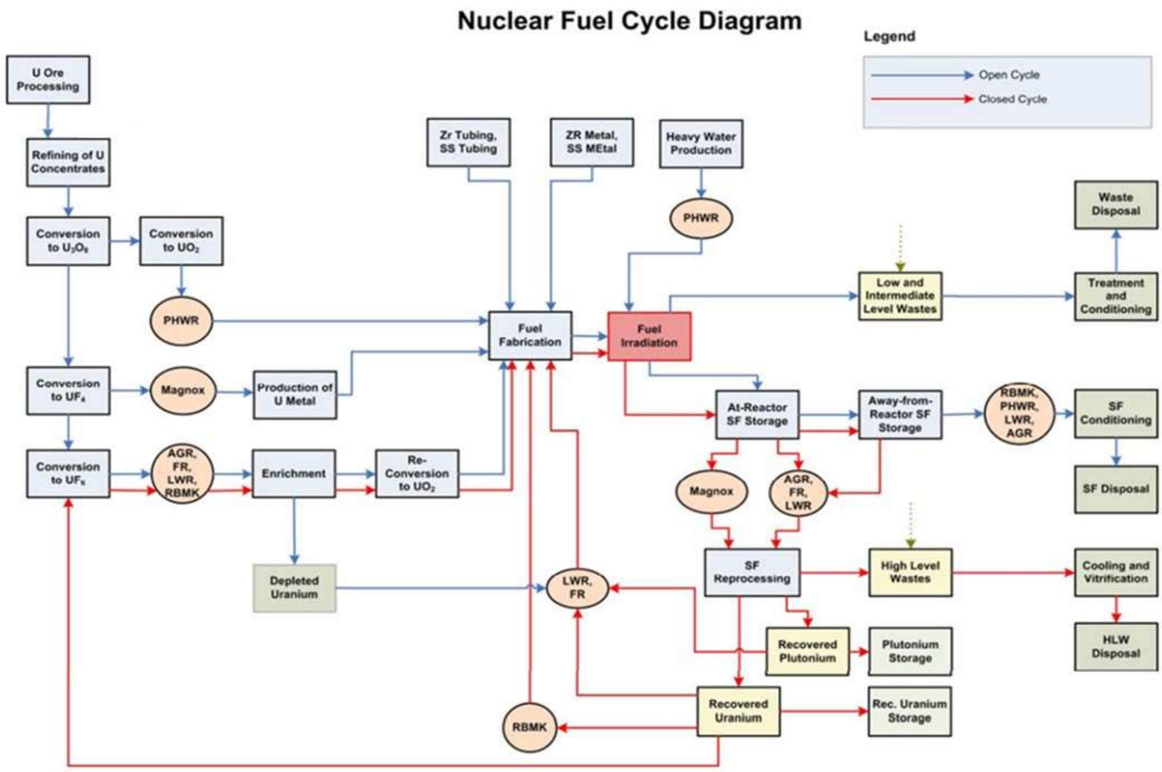


*FIG 2: Flowsheet of processes in the typical nuclear fuel cycle (reproduced with modification from Ref. [4]).*

After uranium has spent up to five years in a reactor core to produce electricity, the irradiated fuel may undergo a further series of steps including temporary storage, reprocessing and recycling. Residual nuclear waste products are targeted for temporary, short-term or long-term disposal depending on the form. These steps performed after the spent fuel has been removed from the reactor are known as the 'back end' of the fuel cycle. A closed cycle is achieved when reprocessing of spent fuel is utilized as an alternative to a 'once-through' cycle. The scale of secondary uranium supply from reprocessed uranium is determined by a few existing spent nuclear fuel reprocessing plants. As of 31 December 2021, such plants were available in France, the Russian Federation and the United Kingdom. China, India and the USA have small-sized research or test reprocessing facilities. One major difference between the front and back end of the nuclear fuel cycle is that global commercial markets exist for most front end components, whilst the back end is largely a localized/internal market based on national policies.

## 3. URANIUM SUPPLY FUNDAMENTALS

This publication is focused on the availability and reliability of secondary sources of uranium supply to satisfy any imbalance between demand and primary supply. The greatest demand for uranium is to supply the components of nuclear fuel for civil nuclear power, which is almost entirely dedicated to the generation of electricity[4]. Military uranium demand, which during the period 1945–1990 was a significant and even dominant part of demand, is beyond the scope of this publication, as is nuclear propulsion and research reactor demand.

Uranium demand can be characterized as a predictable function of the number of operating nuclear power plants, their capacity factors and fuel burn-up levels. Fuel cycle component demand is an essentially economic relationship governed mainly by the price of uranium and the cost of each beneficiating service step in the process of turning uranium into nuclear fuel.

## 3.1. PRIMARY URANIUM SUPPLY

Uranium supply is divided into primary and secondary supply, with primary supply defined as fresh fuel in the form of newly mined $U_3O_8$, upon which conversion, enrichment and fabrication are applied. It is either sold directly by primary producers, or traded through a series of intermediaries. The production of freshly mined uranium is relatively highly concentrated, both geographically and commercially. In 2021, 93% of mined uranium came from seven countries (Australia, Canada, Kazakhstan, Namibia, Niger, the Russian Federation, and Uzbekistan) and 89% was controlled by the ten largest mining companies with 53% of production originating from the ten largest operating mines (Table 1).

TABLE 1: THE TEN LARGEST URANIUM PRODUCING MINES IN 2021[5]

| Mine | Country | Owner(s) | tonnes U |
|---|---|---|---|
| Cigar Lake | Canada | Cameco/Orano/TEPCO | 4 693 |
| JV Inkai LLP | Kazakhstan | KAP/Cameco | 3 449 |
| Husab | Namibia | CGN/Epangelo | 3 309 |
| Karatau LLP | Kazakhstan | KAP/Uranium One | 2 561 |
| Rössing | Namibia | CNU | 2 444 |
| Four Mile | Australia | Quasar Resources | 2 241 |
| SOMAIR | Niger | Orano/Sopamin | 1 966 |
| Olympic Dam | Australia | BHP | 1 922 |
| ME Ortalyk LLP | Kazakhstan | KAP/CGN | 1 579 |
| JV Khorassan-U LLP | Kazakhstan | KAP/Uranium One | 1 579 |
| Others | | | 22 589 |
| **Total** | | | **48 332** |

The performance of these production resources has a direct impact upon the accumulation of and need for secondary uranic stockpiles. Operational, economic and political factors will influence the availability of supply from each resource. These supply risks are compounded by the relative distribution of the downstream processing steps, with China, Canada, France, the Russian Federation, the United Kingdom, European Union and the USA providing the majority

[4] Plus limited urban and industrial heating applications
[5] http://world-nuclear.org/information-library/nuclear-fuel-cycle/mining-of-uranium/world-uranium-mining-production.aspx

of global capacity for the conversion, enrichment and deconversion stages of the front end industry.

## 3.2. SECONDARY URANIUM SUPPLY

The categorization and definition of secondary supply stockpiles or ‘inventories’ is not straightforward. Differences in how they are described by practitioners and analysts in the industry can be confusing to non-experts and experts alike. Therefore, a brief introduction to the types of secondary uranium supply will be provided in this section. A useful starting point for describing and understanding secondary uranium supplies is a scheme developed by the World Nuclear Association (WNA) [2]. Secondary supplies can be categorized on the basis of the following characteristics (as shown in Table 2):

- Originating stage in the nuclear fuel cycle;
- Type of initial source;
- Owner;
- Marketable forms of secondary material and its mobility.

TABLE 2: DESCRIPTIONS OF SECONDARY URANIUM SUPPLIES (*modified and adapted from WNA* [2])

| **Originating Stage in the Nuclear Fuel Cycle** | **Type of Initial Secondary Source** | **Owners** | **Marketable Forms of Secondary Material** |
|---|---|---|---|
| Front End<br><br>(Pre-loading/ irradiation in nuclear reactors) | Commercial Inventories | Commercial Entities (producers, traders, funds, utilities, converters, enrichers, fuel fabricators) | Natural Uranium Ore Concentrate [a], Natural $UF_6$<br><br>EUP [b] as $UF_6$, EUP as Uranium Oxides, fabricated fuel and its feed/SWU components |
| | Military-related materials and depleted uranium | Governments and their contractors | EUP from surplus weapons-grade HEU<br><br>Natural uranium equivalent as $UF_6$ |
| | Other government owned uranic material | Governments and their contractors | Natural $UF_6$<br><br>Off-spec. EUP as UF6 and other forms (potential future source) |
| | Comparable to commercial inventories in terms of specifications | International Fuel Banks | EUP as $UF_6$ stocks |
| | Unused fuel assemblies | Commercial Entities (utilities) | Unused fuel assemblies |
| | Legacy tails | Commercial Entities (enrichers) or governments and their contractors | Natural uranium equivalent or EUP as $UF_6$ from tails |

TABLE 2 (cont.): DESCRIPTIONS OF SECONDARY URANIUM SUPPLIES

| Originating Stage in the Nuclear Fuel Cycle | Type of Initial Secondary Source | Owners | Marketable Forms of Secondary Material |
|---|---|---|---|
| Back End<br><br>(Post-irradiation in nuclear reactors) | Recycled Material | Commercial Entities or governments and their contractors | Reprocessed uranium (RepU)<br><br>Enriched reprocessed uranium (ERU) mostly as $UO_2$<br><br>MOX fuel containing plutonium from spent fuel or defence<br><br>Unprocessed spent fuel (potential source) |
| | | Commercial entities (Enrichers) | EUP from depleted slightly irradiated uranium<br><br>Depleted RepU as $UF_6$ or $UO_2$ |

[a] Natural Uranium Ore Concentrate, $U_3O_8$ or other forms of uranium produced by mines and mills
[b] EUP = Enriched Uranium Product, includes all enriched uranium with $^{235}U$ <20 % enrichment levels, i.e., includes HALEU

This publication is designed to refine and improve upon the approach used by the WNA Nuclear Fuel Report [2]. As such, this publication is only concerned with uranic inventories that are physically held by national operators, suppliers, governments or institutions in countries with existing commercial nuclear power industries. To that extent, this publication excludes underfeeding as a source of secondary uranium supply (being an economic optimization of separative work production capacity, rather than a physical stockpile). The resulting focus is on the following forms of uranic material, listed in the order of the relevant nuclear fuel cycle processing stages:

— Natural uranium concentrates (usually held as $U_3O_8$);
— Natural or reprocessed uranium as $UF_6$ or $UO_2$;
— LEU or enriched uranium product (EUP) as $UF_6$ or $UO_2$;
— High assay LEU or HEU, often in metal forms;
— LEU and EUP as $UO_2$ in fabricated fuel (including viable part-burned fuel);
— Reprocessed uranium as $U_3O_8$ or $UO_3$ and separated plutonium as oxides.

The more beneficiated products tend to have increased regulatory controls placed upon them. Furthermore, the physical location of the inventory and ownership of the material are additional factors that can result in jurisdictional controls. These elements can restrict both the material's mobility and liquidity, so this publication will also seek to clarify the physical mobility status of various inventories at a country level by also considering its liquidity (i.e. the ability to commercially trade or monetize material). In many circumstances, these factors are often significantly influenced by the need to further process any recycled materials, thereby permitting this publication to narrow the focus of its analysis on the materials that are most accessible for global secondary supply.

### 3.2.1. Secondary uranium supplies existing within the front end

There are several categories of inventories or secondary supplies:

- Commercial inventories that are owned by producers, traders, funds, utilities, converters, enrichers, and fuel fabricators. Several marketable forms of these inventories exist, including: natural uranium ore concentrate (mainly as $U_3O_8$); natural $UF_6$, enriched uranium product as $UF_6$ and uranium oxides, fabricated fresh fuel[6] and its feed and separative work unit (SWU) components.
- Government-owned uranic materials potentially including surplus High assay LEU (HALEU) and (HEU stockpiles - often managed by designated contractors and having uses beyond power generation (e.g. military propulsion or research reactor fuel).
- International fuel banks represent a third class of holding, governed by supra-national bodies, such as the IAEA.

### 3.2.2. Secondary uranium supplies derived from recycling

Many industry observers class the recycling of uranic material within the definition of inventories or secondary supplies. Within this category resides:

- Depleted uranium (tails) for upgrading (held as $U_3O_8$ or $UF_6$);
- Fuel cycle scrap recovery (oxides);
- Partly burned fuel;
- Spent fuel reprocessing (generating separated Plutonium for MOX fabrication and reprocessed uranium as $U_3O_8$ or $UO_3$).

Recycled material can displace primary front end uranium supply through a number of channels, the most prominent examples of which are tails upgrading and reprocessed fuel.

Tails upgrading is often cited as a major secondary uranium supply resource for countries with enrichment capacity, in particular within France, the Russian Federation, and the USA. Significant stockpiles of depleted uranium as $U_3O_8$ or $UF_6$ exist, and large proportions contain viable $^{235}U$ assays (>0.1wt% $^{235}U$). Those in $UF_6$ form are readily accessible and (subject to surplus enrichment capacity being available) can be upgraded to levels equivalent to natural uranium. Tails in $U_3O_8$ form are far less accessible, as this often represents a form intended for long-term storage and would require surplus conversion and enrichment capacity to enable re-use.

Another potential source of secondary supply is reprocessed fuel. After it has been burned in a reactor, uranium oxide fuel still contains most of the fissile matter that was present in the original 'fresh' uranium fuel and therefore in principle could be used again to create more nuclear fuel. The plutonium created during fission can be separated, as well as unused uranium oxide to form the components of mixed oxide (MOX), RepU or depleted slightly irradiated uranium fuels. The commercial processes currently used enable 25–30% more energy to be

[6] Unused fuel assemblies. For example, in Japan there have been delayed reactor restarts and premature closures and this has resulted in stranded, unused (i.e. non-irradiated) fuel assemblies that are no longer suited for direct use in reactors. However, practical utilization of this material has several challenges including potential (defabrication) capacity constraints and commercial considerations.

utilized from the original fuel and also reduce by about a fifth the amount of spent fuel that needs to be stored. China, France, India, Japan and the Russian Federation, currently follow an active recycling policy and thus have laid the foundations for sustainable use of fuel, in contrast to a once-through fuel cycle. However, the supply of these fuels is limited by the reprocessing capacity and output is exclusively directed to the small number of recycling countries who have licensed their reactors to accommodate the alternative fuel characteristics.

These activities cover elements in both the front and back end of the supply chain as they are subject to the application of additional processing steps that consume primary production resources (i.e., reconversion, upgrading, enriching, blending or chemical separation). This reliance on primary capacity and more complicated processes to deal with radiological hazards means that the lead time for re-use of recycled material is beyond what could be readily considered as tradeable (i.e. liquid) and/or physically mobile. Therefore, channels to re-introduce legacy material into a market (be it locally or internationally) have significant constraints.

As with down-blended HEU (to HALEU or LEU), the above recycled material is more likely to play a part in guaranteeing the future fuel cycle availability for Generation IV or small modular reactors, research, reactors and advanced reactors than existing nuclear power fleets. Therefore, this technical document will focus on secondary uranium supplies originating in the front end of the fuel cycle which can be directly substituted for freshly mined resources (i.e., without additional processing to reach American Society of Testing and Materials' standards for their chemical form). Irrespective, reference has been made in specific circumstances to the availability of recycled material at a country level, in order to recognize where supply gaps are currently being filled or to inform the reader to this additional (less liquid) resource.

## 4. COMMERCIAL INVENTORY DEFINITIONS AND DRIVERS

The term nuclear fuel 'inventory' or 'stocks' has a number of subdivisions, specifically:

**Work-in-progress (WIP)** also known as pipeline or in-process inventories: These are uranic materials in all forms, based on normal commercial lead times for processing/beneficiation and shipment and are effectively servicing the ongoing periodic refueling needs of a nuclear power plant. As such, their absence would result in an immediate or imminent shutdown of a reactor or otherwise significantly limit its availability to produce electricity at the rated capacity. The study assumes a three-year supply chain that puts WIP at one year's demand for natural uranium, enriched uranium and fabrication.

**Surplus inventories related to short-term needs**: These may include temporary excesses of uranic material beyond WIP that are due to: advanced purchasing (buy-and-hold policies); a temporary mismatch between supply and demand; or a buyer otherwise implementing longer than usual lead times for material supplies. However, the material will have been purchased in the expectation of internal consumption in a relatively short time frame (i.e., less than 12 months, being similar to material designated as 'current assets' for financial purposes). One example is a utility that purchases a fixed amount of uranium (uranic material) each year, regardless of its nuclear fuel requirements varying from year-to-year. This results in surpluses in some contract years followed by a drawdown in subsequent periods.

**Surplus inventories related to long-term needs:** There are circumstances when quantities of nuclear fuel components are purchased, but result in a surplus that will likely become permanent (or at least semi-permanent). The reasons for such an accumulation are often unforeseen, for instance due to the early or temporary shutdowns of a reactor or delays in startups or cancellation of new units. When an entity is unable to consume these quantities itself, the expectation is that the material will eventually be liquidated to recover its purchase costs. The timing of the liquidation is usually dependent upon a number of financial determinants, as well as more practical regulatory constraints.

**Strategic inventories:** These occur where an entity determines the need for security of supply beyond diversified sourcing of nuclear fuel components, or alternatively if uranic material is considered as a financial asset to hedge against future developments in price or availability. As a result, risk-based policies may be enacted to secure and maintain a certain volume of material as a fixed stockpile. Such strategic stockpiles may physically revolve material through them in a first-in-first-out (FIFO) manner, but the basic level of inventories is maintained. This type of inventory can take a number of forms:

— Extended lead time purchasing of components, so that an entity always has a significant quantity of material readily available at one or more stages in the fuel cycle to mitigate against short- or medium-term supply interruptions;
— An immobile but accessible physical stockpile held at one or more locations across the fuel cycle, to compensate for a deficiency in deliveries under supply contracts;
— An inventory of finished fuel in dry or wet storage at a reactor to cope with fuel failures or a disconnect in the upstream fuel supply chain.

The scope of this publication will attempt to consolidate and identify three main types of inventories: WIP, surplus and strategic, with the latter two categories considered to represent a buffer against supply shortfalls from primary production of uranic material.

## 4.1. REASONS FOR HOLDING INVENTORIES OF URANIC MATERIAL

Normal nuclear fuel operational practices and the length of supply chains determine a minimum requirement for inventory hold-up as WIP. As already noted, from mine to core an indicative processing time for LWR fuel can be up to three years, subject to the location of each of the processing steps. For Pressurized Heavy Water Reactors (PHWRs) where fuel chain steps are often localized and $UF_6$ and enrichment services are not necessary, the lead times are somewhat reduced. Diversified markets where uranium mining, milling, conversion, enrichment, deconversion and fabrication can all happen in different countries tend to accommodate for longer lead times under component contracts. In contrast, centralized/localized production industries — such as in Canada, China, India and the Russian Federation — can operate with shorter lead times and thus tolerate somewhat lower total working inventories. Irrespective, both examples will require a working stock to be held by suppliers in order to smooth production peaks or troughs and to buffer against supply chain risks.

Reserves held by commercial entities are a hedge against price fluctuations and supply shortfalls from factors such as contractual performance or operational issues. The level of such inventories is largely dictated by the risk profile of each individual entity, be it end user, primary supplier of trader or broker. For utilities and primary suppliers, there is often a national perspective in terms of security of energy supply that is dictated by government policy.

Additionally, at a national level, strategic reserves and stockpiles are often established to cover supply interruptions and the potential for geopolitical disturbances. Some of these stockpiles are specifically dedicated and managed, but otherwise such uranium inventories are simply a nominal allocation from surpluses that are held across a number of material forms that are not readily substitutable for fresh nuclear fuel components (e.g. HEU, tails material, reprocessed/separated spent fuel or scraps and residues).

Finally, financial institutions see investment opportunities from holding homogeneous commodities, but less so more bespoke products in the nuclear fuel cycle. As such they contribute to the level of liquidity in the upstream front end markets ($U_3O_8$ and to a limited extent $UF_6$ and EUP). However, they can equally represent a repository that holds material off-market, thereby changing an otherwise fairly predictable market equilibrium state. Their fundamental driver is therefore reward-related, rather than a response to operational risk.

## 4.2. WHERE URANIC INVENTORIES RESIDE

Utility inventories are located across the fuel cycle. Depending on the reason for their creation, they are either held strategically to ensure uninterrupted supply or are stockpiled after processing. The latter state is often the result of a temporary or persistent oversupply, where additional spend on further downstream processing does not represent added value to the owner. Meanwhile, strategic stocks are best held after whichever stage of the fuel cycle that represents the most risk, or at the stage where a delay in availability could impact rapidly escalating consequential damages. The ultimate (but most costly) form of inventory is fabricated fuel. If held on a rolling stock basis, fabricated fuel can assure an operator of future power generation capability. However, it carries with it the risk of redundancy due to being a highly bespoke product, tied to a specific design of core and reactor.

For primary suppliers, inventories will be held at their respective production facilities. Licenses for individual installations may prescribe the need for on-site processing, so husbanding of third-party stockpiles may be deprioritized if space is limited.

Government holdings are often intermingled with primary supplier holdings, particularly where a supplier is a state owned enterprise. Otherwise, nuclear material reserves are held at national facilities under state ministry control or supra-national body supervision. Legacy nuclear sites in the process of being decommissioned or remediated have also been designated as appropriate locations, albeit largely due to the pre-existence of stocks on site.

Financial institutions or brokers and traders arrange for holding accounts at primary supply locations or dedicated storage facilities. The ability of the site owner to conduct location swaps is often of prime interest as it enhances the liquidity and mobility of their asset.

## 4.3. HOW DIFFERENT ACTORS VALUE THEIR URANIC HOLDINGS

Utilities generally value inventories on a FIFO or average cost basis. This is particularly the case for a once-through fuel cycle, where the spent fuel has zero value once it is discharged from a reactor core. However, for utilities in countries using a closed fuel cycle (such as France, Japan and the Russian Federation), a residual value can be extracted from back end recycling and is therefore included in the value of spent nuclear fuel undergoing reprocessing.

Traders, intermediaries and financials dealing with (almost exclusively) front end components will assign net realizable values to their stocks. This imbues their holdings with more liquidity and mobility. Governments consider all aspects, but are generally too slow to act on market index valuations for anything but long-term policy decisions.

As such they are mindful of impacts on the market from disposition programmes and tie the release of supra-national stockpiles to achieving market neutrality (e.g., requiring secretarial determinations for US Department of Energy (DOE) inventory disposals, or IAEA-sanctioned call-off from fuel banks).

Often the desire to build inventories is a reaction to market dynamics, for example when high prices are taken to indicate material shortages for a particular component. Often these price signals encourage utilities and suppliers to re-optimize their contractual commitments, which has the effect of widening the impact of price movements or perpetuating a trend. Also, utilities who had once deemed material to be economically surplus are considering either how best to monetize their holdings in a (currently) rising market, or whether there is now a need to consume or stockpile material internally. One further aspect is the increasing interest in the market from financial entities, for whom market volatility generally pays dividends.

## 5. RESEARCH METHODOLOGY FOR THE STUDY OF FRONT END URANIC INVENTORIES

### 5.1. TRIANGULATION METHOD

To accurately identify front end uranic inventories, three distinct but complementary methodologies have been employed:

1) A 'top-down' analysis using periodic regional or country reporting by national or international bodies. There are a number organizations that report on inventories for particular regions or countries: these include the Euratom Supply Agency for the European Union, the Energy Information Administration (EIA) for the USA, the Nuclear Regulatory Authority for Japan, the National Agency for Radioactive Waste Management (ANDRA) for France, the Finnish Radiation and Nuclear Safety Authority (STUK) for Finland, the Federal Energy Office for Switzerland and the Nuclear Decommissioning Authority for the United Kingdom[7].

2) An evaluation of fuel cycle supplier and nuclear utility financial reports since 2010 (where available) and interpretation of policy statements by governments. Almost all holders of nuclear materials make audited financial reports of their nuclear fuel inventory status. However, many combine the categories referenced above (e.g. including WIP stocks and even partly burned fuel) such that a clear indication of quantities and forms is not possible. Also, many governments mandate an inventory policy as part of a strategic approach to national energy security. As such, both financial and policy statements can provide guidance for further analysis and extrapolation, which has been conducted with the assistance of industry expert reviews. Where necessary, reporting in local currency values has been converted to US dollars using an average foreign exchange rate for 2021.

3) A 'bottom up' research approach using trade statistics and demand modelling to estimate supply and consumption, particularly for markets with no domestic fuel processing or where material is dedicated directly to the in-country end user. Where neither of the above-mentioned sources (points 1 and 2) of intelligence were available or the resources are considered unreliable or lack transparency, then this third approach can provide meaningful insights. It involves collating publicly available trade statistics

[7] The UK data is for April 2022.

(e.g., UN Comtrade or locally reported statistics) to track net imports over a reasonable period of time. For this study, data since 2010 was considered (which, in the expert group's opinion) was the last time the nuclear fuel market was in a reasonable equilibrium state. The resulting information was used to establish whether a surplus of material has been accumulated after modelled consumption was deducted. The material forms were identified and reported under the harmonized system of tariff codes[8] as follows: 261210/284410 – natural uranium ore/oxide/$UF_6$; 284420 – enriched uranium as $UF_6$; and $UO_2$ and 840130 – unirradiated fabricated nuclear fuel. An evaluation of the reported material forms was then made in order to translate gross weights into metric tonnes of uranium (tU). Demand actuals, or more usually estimates modelled by the WNA [2] and/or OECD-NEA [5], are deducted from net imports (i.e. after any exports of processed or returned material) to estimate the physical inventories remaining in-country. These quantities are used as a proxy for material ownership, whilst noting that non-domicile third party inventories may also be held internationally. As such, the results require a degree of reconciliation with the available intelligence on supply chain characteristics and flows for each market.

## 5.2. PRICING ASSUMPTIONS

To align the volumes and values of the results from all three approaches, prices are needed for uranium in different chemical forms. Where possible, trade data has been analyzed to inform these price levels for individual countries. In some cases, it is valid to replace those indicators with locally reported prices. However, for most markets this information was not available (or was not considered robust), so alternative best estimates were taken, based upon the period average market indices between 2010 and 2021[9] or (in the case of downstream sectors) extrapolations from published accounts. These values are approximately:

- US \$90/kgU as $U_3O_8$;
- US \$100/kgU as $UF_6$;
- US \$1 500/kgU as EUP;
- US \$1 650/kgU as $UO_2$;
- US \$1 800/kgU as fabricated fuel[10].

These estimates are intended to reflect market levels over the past decade, accepting that individual commercial agreements will vary within an acceptable range around these representative benchmarks.

## 5.3. CONFIDENCE LEVELS

In most cases this publication has sought to combine the available intelligence from at least two different methodologies to triangulate and benchmark its results. This multi-faceted approach provides a more robust outcome and a higher degree of confidence on the resulting predictions of material forms and volumes. However, despite such methodological rigour the above approaches cannot provide 100% clarity on national inventories, due to a lack of fully transparent data. As such, in Table 3 a level of confidence is indicated on a country-by-country or regional basis to act as a rider for the report.

[8] https://www.trade.gov/harmonized-system-hs-codes
[9] As published by UxC, TradeTech and Energy Intelligence
[10] Part-burned fuel is evaluated at 50% of the fresh fuel cost

TABLE 3: SUMMARY OF METHODOLOGIES USED TO ASSESS URANIC INVENTORIES BY REGION AND COUNTRIES

| **Region/Country** | **Method 1: Public Reports** | **Method 2: Financials (Utility/ Supplier)** | **Method 3: Trade analysis** | **Confidence level (%)** | **Comments and caveats** |
|---|---|---|---|---|---|
| North America: | | | | | |
| Canada | No | Yes/Partial | Yes | 75% | Utility and supplier data is incomplete |
| Mexico | No | Yes | Yes | 85% | Utility data ambiguous in terms of material in use |
| USA | Yes | Yes/Partial | Yes | 90% | EIA data exhaustive; some supplier data withheld |
| South America: | | | | | |
| Argentina | No | Yes | Yes | 80% | Potential for overlap between utility and supplier data |
| Brazil | No | Yes | Yes | 80% | Potential for overlap between utility and supplier data |
| Europe: | | | | | |
| European Union [a] | Yes | Yes/Partial | Yes | 75% | ESA does not report supplier data |
| Switzerland | Yes | Yes | Yes | 95% | Assumptions made on utility financial data (i.e., locations) |
| Ukraine | Yes | Yes/No | Yes | 60% | Inconsistencies between trade and financial data |
| United Kingdom | Yes | Yes/Partial | No | 60% | 2022 data only records aggregated material forms |
| Eurasia: | | | | | |
| Armenia | Yes | Yes | Yes | 90% | Trade statistics align with policy statements |
| Belarus | Yes | No | Yes | 90% | Trade statistics align with commercial agreements |
| Kazakhstan | Yes | Yes | No | 90% | Supplier financial information and IAEA |
| Russia | Partial | Yes/Yes | No | 70% | Ambiguity on supply chain forms from single sources |
| Uzbekistan | No | Yes | No | 50% | Limited supplier financial information |
| Africa/Middle East: | | | | | |
| Islamic Republic of Iran | Yes | No | Yes | 80% | Trade stats align with commercial agreements |
| Pakistan | No | No | Yes | 80% | Trade stats align with commercial agreements |
| South Africa | No | Yes | Yes | 80% | Mismatches between trade and financial data |
| United Arab Emirates | No | No | Yes | 50% | Supply chain inventories not clearly identified |
| East Asia: | | | | | |
| China | No | Yes/No | Yes | 60% | Over-reliance of trade statistics |
| India | Yes | No | Yes | 66% | Over-reliance of trade data and limited public statements |
| Japan | Yes | Yes/No | Yes | 75% | Foreign located inventories not clearly identified |
| Republic of Korea | No | Yes | Yes | 65% | Over-reliance of trade data and limited financial reporting |
| China [b] | Yes | Yes | Yes | 95% | Good alignment between trade stats and public statements |

[a] Nuclear countries in the EU comprise Belgium, Bulgaria, Czechia, Finland, France, Germany, Hungary, Netherlands, Romania, Slovakia, Slovenia, Spain and Sweden.

[b] Taiwan

# 6. REGIONAL REPORT: AFRICA AND THE MIDDLE EAST

## 6.1. OVERVIEW OF AFRICA AND THE MIDDLE EAST

- Africa and the Middle East is a geographically diverse region that has a relatively low installed nuclear power capacity base.
- Domestic capabilities to produce nuclear fuel are either limited or non-existent.
- A heavy reliance on the international nuclear fuel cycle for JIT supply of finished fuel is further complicated by non-proliferation treaty or Nuclear Suppliers Group controls or restrictions regarding bilateral arrangements.
- In most cases, the result is an underdeveloped strategic stock policy, exacerbated by long commercial lead times due to the geographical dispersal of fuel suppliers (i.e. in Europe, Republic of Korea, the Russia Federation and China).

As of 31 December 2021, the total value of inventories in the region is estimated to be only US $274 million, little of which is truly strategic in nature or commercially liquid. Table 4 summarizes the analysis of inventories in the region, by country and form.

TABLE 4: SUMMARY OF AFRICA AND MIDDLE EASTERN INVENTORY STATISTICS

| **Country** | **Nuclear entities reviewed** | **Value of inventories (US $ millions)** | **Value of inventories Reported (R) or estimated (E)** | **Estimated volumes (tU)** | **Assessed material form** [a] |
|---|---|---|---|---|---|
| Iran, Islamic Republic of | 1 utility/supplier [b] | 4 | E | 3 | EUP |
| | | 97 | E | 54 | Fabricated fuel |
| Pakistan | 1 utility [b] | 160 | E | 89 | Fabricated fuel |
| South Africa | 1 utility | 3 | R | 2 | EUP |
| | | 66 | | 38 | Fabricated fuel |
| United Arab Emirates | 1 utility [b] | 284 | E | 158 | Fabricated fuel |
| Totals | All | 612 | | 0 | tU Natural Uranium |
| | | | | 5 | tU as EUP/enriched $UO_2$ |
| | | | | 338 | tU as $UO_2$ (Fabricated fuel) |

[a] Tonnes U (tU), not tonnes U equivalent (tUe) unless otherwise stated

[b] Utility had no publicly available statistics on inventories

## 6.2. BACKGROUND FOR AFRICA AND THE MIDDLE EAST

The Africa and Middle Eastern region includes four commercial nuclear power countries: Islamic Republic of Iran, Pakistan, South Africa, United Arab Emirates. As of 31 December

2021 the region operators had approx. 8GWe (net) of nuclear power in service with an average demand for nuclear fuel products as shown in Table 5.

TABLE 5: NUCLEAR POWER CAPACITY AND NUCLEAR FUEL CYCLE DEMAND IN AFRICA AND THE MIDDLE EAST

| Country | **NPPs** (operating or in temporary shutdown + under construction) **and generating capacity** [a] | **Estimated annual demand in 2021** [b] **(tU)** | **Fuel cycle component (tU as)** |
|---|---|---|---|
| Islamic Republic of Iran | 1+1 VVER-1000; | 146 | $U_3O_8$/$UF_6$ |
| | 915MWe (net) | 18 | EUP/fabricated fuel |
| Pakistan | 5+1 PWRs; | 454 | $U_3O_8$/$UF_6$ |
| | 2 242MWe (net) | 55 | EUP/fabricated fuel |
| South Africa | 2 PWRs; | 290 | $U_3O_8$/$UF_6$ |
| | 1 854MWe (net) | 37 | EUP/fabricated fuel |
| United Arab Emirates | 2+2 PWRs; | 604 | $U_3O_8$/$UF_6$ |
| | 2 762MWe (net) | 107 | EUP/fabricated fuel |

[a] IAEA PRIS database.

[b] WNA 2021 Nuclear Fuel Report

## 6.3. LOCAL INVENTORY POLICIES AND STATUS

The nuclear power industries in the Africa and Middle East region are specific to the operations of the respective State-owned nuclear utility. Their inventory polices are therefore considered as being an extension of government policies on nuclear power.

### 6.3.1. Islamic Republic of Iran

Nuclear fuel for Atomic Energy Organisation of Iran’s (AEOI) Bushehr 1 VVER-1000 reactor is supplied by Russia’s TVEL. The reactor core consists of 76tU in 163 fuel assemblies, for which the long term fuel contract was signed in 2006. Also, AEOI/TVEL signed a new contract in June 2017 for the delivery of reserve fuel. Since 2007, TVEL has supplied a total of approx. 620 assemblies to the Bushehr 1 reactor site, including reserve fuel in 2017. Historical deliveries are shown in Fig. 3.

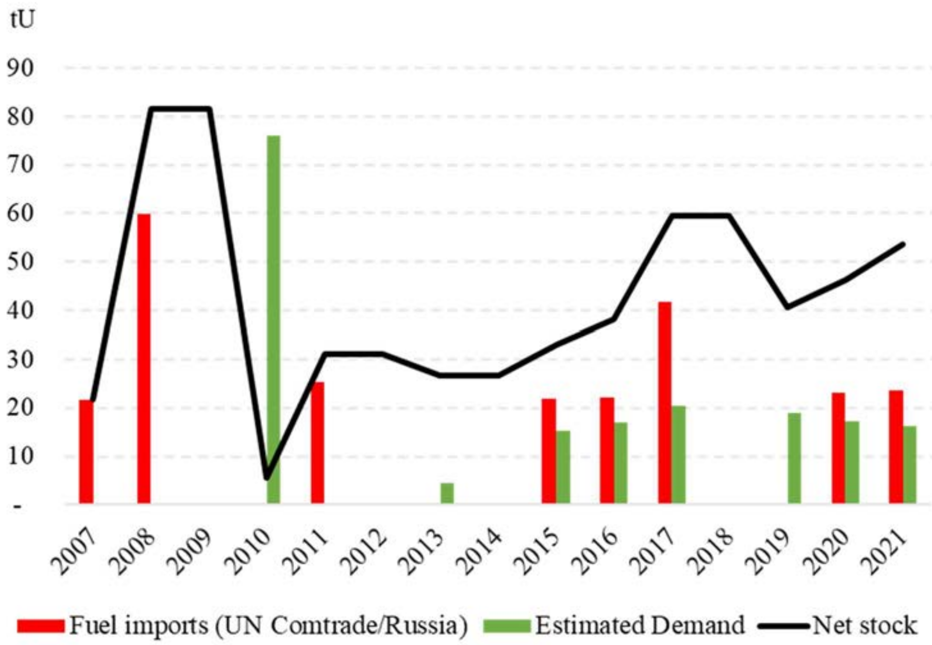


*FIG 3: AEOI imports and fuel demand*

As of 31 December 2021, AEOI was estimated to have the following stocks [6]:

- Approx. 55tU or 120 assemblies of fabricated fuel for Bushehr 1, including the next reload of approx. 50 assemblies;
- HALEU <20wt%$U^{235}$, 182.1kg;
- LEU $UF_6$ (LEU as EUP), <5wt%): 2.7t.

The HALEU and EUP quantities relate to production from AEOI's domestic enrichment plants. These are monitored by the IAEA and held for Iran's internal needs. AEOI, has recently stated that it wishes to integrate domestic EUP production into the TVEL fabrication contract.

### 6.3.2. Pakistan

Pakistan's Atomic Energy Commission (PAEC) relies on Chinese imports to fuel the Chasma and Karachi (KANUPP) nuclear power plants that were built by China National Nuclear Corporation (CNNC). The nuclear fuel is supplied under a bilateral civil nuclear agreement signed in 2010 (albeit that Pakistan is not a signatory to the Non-Proliferation of Nuclear Weapons treaty, nor a member of the Nuclear Suppliers Group). Despite having domestic fuel cycle technology, PAEC does not independently produce or procure the front end components for its fuel, so is entirely reliant on imports from China Nuclear Energy Industry Corporation (CNEIC) for the bundled package of enriched uranium and fabrication services. Figure 4 shows PAEC imports and fuel demand from 2009 to 2021.

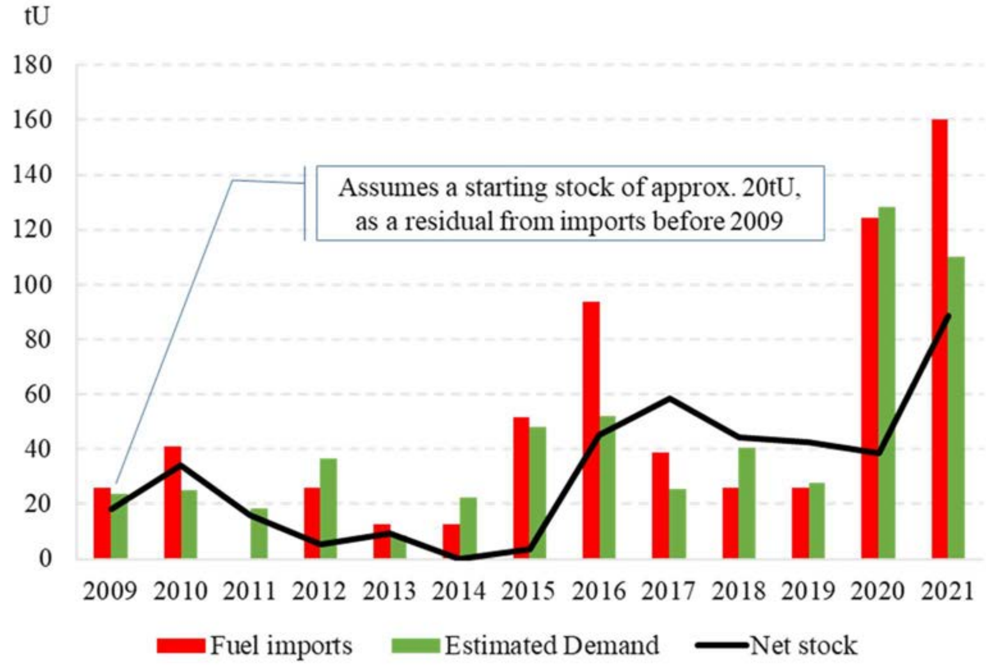


*FIG 4: PAEC imports and fuel demand*

Based on trade statistics[11], as of 31 December 2021, PAEC's net fabricated stocks (Chinese imports less demand) had climbed to approx. 85tU. This may largely be due to the imminent start of fuelling for KANUPP Unit 3 (permission was received to load the initial core of approx. 81tUe on 31 December 2021). That being the case, PAEC is assessed to have no appreciable stocks of fresh fuel in Pakistan, other than a limited number of spare assemblies (<10), so is entirely reliant on a requirements-based supply from CNEIC.

### 6.3.3. South Africa

The national utility Eskom operates two pressurized water reactors (PWRs) at the Koeberg site near Cape Town. These units each have a core with 72tU and 157 assemblies. A normal reload on a 16–18-month cycle is 56 assemblies (approx. 26tU, or 52tU for both units). Fuel procurement is enacted through periodic public tenders; Westinghouse and Framatome are the incumbent fuel manufacturers from European production facilities[12]. As of 31 December 2021, Eskom declared the following commercial stocks in its financial accounts:

- Rand 2.6 billion (approx. US $174 million) as 'Nuclear Fuel Inventories';
- Rand 41 million (approx. US $3 million) in 'Future Fuel', which is effectively pipeline/WIP material (i.e. Uranium and EUP).

Eskom reports 'Nuclear Fuel Inventories' that include in-core material and finished fuel. Therefore, to avoid counting partly burned fuel, an estimate of fresh fuel inventories is established from reported 'Finished Fuel Transfer' values (relating to fabricated fuel imports

[11] UN Comtrade export statistics and reactor demand modelling has been used for this analysis, as PAEC doesn't produce any financial or operating statements

[12] In addition, NECSA operates the Safari-1 test reactor at Pelindaba. It has used stockpiles of domestic HEU to fuel this research reactor, before switching to importing HALEU from the US, fabricated by Compagnie pour l'Etude et la Realisation de Combustibles Atomiques, France.

for reloads), net of spent nuclear fuel depreciation (based on FIFO accounting) plus 'Future Fuel' derived from Eskom accounts as shown in Fig. 5.

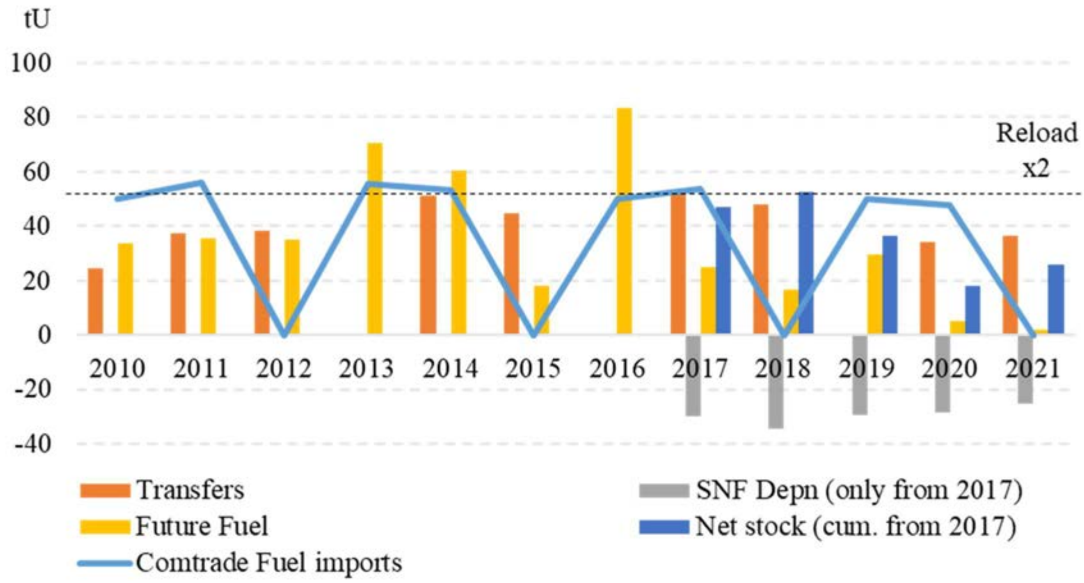


*FIG 5: Eskom nuclear fuel volumes (financially derived values shown in bars; cum=cumulative)*

Future fuel values peaked in 2016, but have since declined to negligible quantities (possibly due to the prospect of extended outages at Koeberg for steam generator replacements). Some finished fuel stocks appear to have accumulated in 2017/18, resulting from large amounts of pipeline material and subsequent reactor availability and performance issues. The net increase in finished fuel stocks since 2017 is approx. 26tU, which is equivalent to one reload. However, this may not be a true like-for-like comparison, as it is dependent on spent nuclear fuel costs being equivalent to fresh fuel values. Irrespective, the current holding may well be in anticipation of the next reload for the Koeberg units as show in 'Finished Fuel Transfers' of Rand 970 million (approx. US $66 million) in 2021. As such, the analysis points to Eskom's buffer stocks of approx. 38tU being largely restricted to upcoming reloads.

### 6.3.4. United Arab Emirates

As a new nuclear power country, the United Arab Emirates (UAE) has developed its fuel cycle policy from scratch since 2010. The implementation has been left to Emirates Nuclear Energy Corporation (ENEC) with the aim to ensure material availability for the predicted online dates for the four Barakah APR1400 reactors. American style fuel management was implemented, including diversified contracts for front end materials. First core and initial reload fabrication was left to the reactor vendor (Korea Electric Power Corporation (KEPCO)/KEPCO Nuclear Fuel (KNF)) and strategic inventory management was largely handled between ENEC and KNF), including advanced fabrication campaigns and modest buffer stocks.

According to the Republic of Korea export data, as of 31 December 2021, ENEC had received a total of approx. 370tU in fabricated fuel in approx. 820 fuel assemblies. This equated to:

— Three first cores (241 assemblies each for units 1–3);

— A rolling buffer inventory of ¼ of a first core (i.e., 62 assemblies);
— A first reload for Unit 1 (typically 69 assemblies).

Excluding the first cores, ENEC is believed to hold approx. 51tU in fabricated fuel. Due to delays in reactor commissioning, there was also a potential for ENEC to accumulate an oversupply of upstream front end components. This may have led to temporary surpluses throughout the upstream supply chain. However, this cannot be independently verified as ENEC and the operator Nawah Energy Company do not produce public financial statements.

## 6.4. REGIONAL SUMMARY

Figure 6 shows estimates for the four Africa and Middle Eastern nations' uranic inventories. While it is believed that Eskom and AEOI have some modest $U_3O_8$/$UF_6$ holdings due to legacy/domestic production, the lack of publicly available evidence means that these categories are left blank. Similarly, ENEC is known to contract directly with uranium and conversion suppliers, so will likely own material within the supply chain at these stages. However, no financial statements are available to identify the respective quantities (and regardless they may simply be work-in-progress). Meanwhile PAEC is known not to buy front end components, so is deemed to have zero holdings.

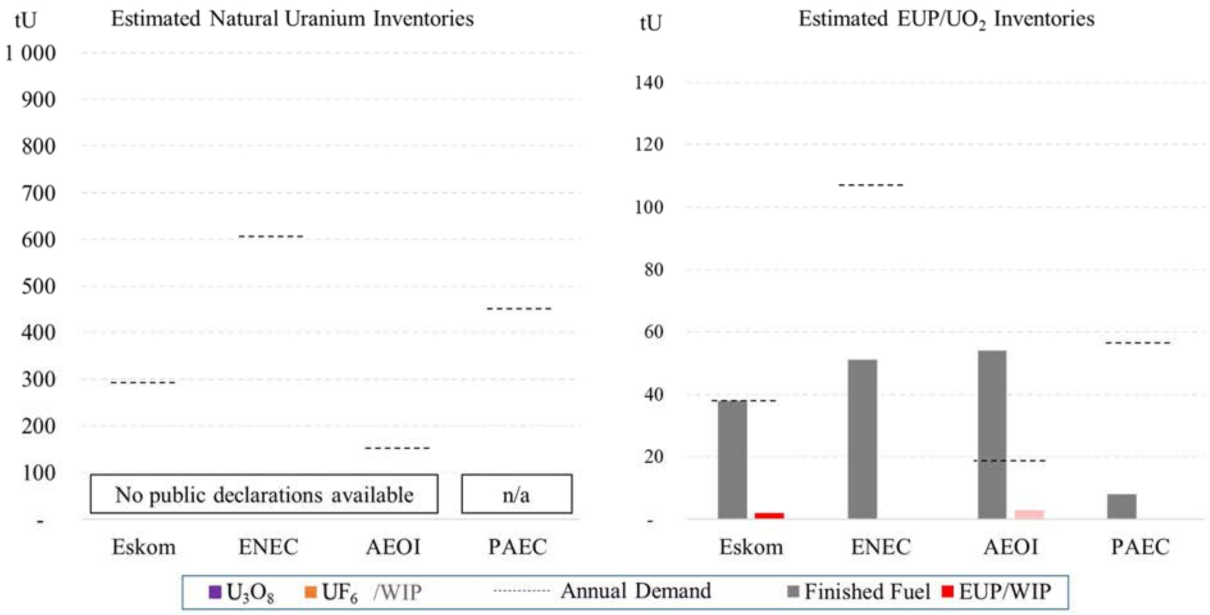


*FIG 6: African and Middle Eastern uranics inventories by form (n/a=not available).*

With regard to enrichment and fabrication, two utilities are believed to have established strategic stockpiles: ENEC has quantities of buffer stock to facilitate the core loadings at Barakah, and AEOI has worked with TVEL to establish a strategic stock of approximately two years' worth of fabricated fuel. It also holds domestically produced quantities of EUP (LEU and HALEU), which it has requested to be integrated into its supply chain for Bushehr. In contrast, Eskom and PAEC have almost no appreciable buffer stocks available, despite their respective international supply chains having long transport and processing lead times.

### 6.5. INVENTORY LIQUIDITY AND MOBILITY

In summary, from available evidence the Africa and Middle Eastern region has very limited quantities of inventory material. Those that do exist are specifically intended to ensure domestic security of supply and on the whole do not displace ongoing requirements from primary suppliers.

#### 6.5.1. Islamic Republic of Iran

The reserve of fabricated fuel for Bushehr is intended to provide for ongoing operation in the event of a supply interruption. As such, it is not considered to be either liquid or mobile, particularly given the current geopolitical constraints on both the supplier and end user. AEOI stocks of enriched uranium (including HEU) are also exclusively for domestic use. While Iranian EUP may be drawn down to supplement Russian supplies, it is unlikely to cover more than a fraction of the needs of Bushehr, particularly if unit 2 comes online later this decade.

#### 6.5.2. Pakistan

Chinese-produced fuel for PAEC is specific to the China–Pakistan bilateral nuclear cooperation and the Chinese-designed reactors for which it is intended. Fuel imported by PAEC will be used in-country and therefore any small emergency/buffer stocks that remain after the commissioning of KANUPP 3 are considered both immobile and illiquid.

#### 6.5.3. South Africa

Any finished fuel inventories in South Africa are immobile, as they are held as bundles dedicated to the Koeberg PWRs. As such, they are not considered liquid and aside from the next reload in hand, may only amount to a small supply of backup assemblies to mitigate fuel failures. Low reported ‘Future Fuel’ (effectively front end WIP) values means that surplus pipeline material is also very limited.

#### 6.5.4. United Arab Emirates

It is assumed that ENEC’s in-country inventories of fabricated fuel will be consumed during progressive unit commissioning (including the ¼ first core buffer, specifically due to the low assays tailored for start-up operations). Thereafter, supply chain surpluses will decrease as operations continue, so none of the suspected work-in-progress inventories are likely to become commercially liquid.

## 7. REGIONAL REPORT: EURASIA

### 7.1. OVERVIEW OF EURASIA

- Russia and Kazakhstan represent significant shares in all supply chain sectors for the Eurasia region. As such localized primary production adds significantly to supply guarantees.
- Rosatom has a fully integrated domestic fuel cycle, plus HALEU, $DUF_6$, Reprocessed Uranium (RepU) and Slightly Irradiated Uranium (SIU) inventories to backstop supply interruptions to Rosenergoatom, but stockpiles of natural material may be running low.
- Russia’s capabilities in spent fuel management have allowed it to follow a strategy to use a closed nuclear fuel cycle, which supports security of supply.

- All countries within this region (with the exception of Russia) have built medium- to long-term inventories to ensure reactor operations.
- Regional membership of the International Uranium Enrichment Centre (IUEC) provides certain additional supply guarantees.
- As of 31 December 2021, total regional inventories (including pipeline material) were valued at approx. US $2 billion.

Table 6 summarizes the analysis of inventories in the region, by country and form.

TABLE 6: SUMMARY OF EURASIAN INVENTORY STATISTICS

| Country | Nuclear entities reviewed | Value of inventories (US $ millions) | Value of inventories: Reported (R) or estimated (E) | Estimated volumes (tU) | Assessed material form [a] |
|---|---|---|---|---|---|
| Armenia | 1 utility | 42 | R | 20 | Fabricated fuel |
| Belarus | 1 utility | 409 | E | 281 | Fabricated fuel |
| Kazakhstan | 1 supplier | 615 | R | 8 824 | $U_3O_8$ |
| | | 135 | R | 90 | EUP |
| | 1 utility | 122 | R | 177 | Fabricated fuel |
| Russian Federation | 1 supplier | 390 | R | 6 119 | $U_3O_8/UO_3$ |
| | | 286 | | 191 | EUP |
| | | 44 | | 25 | Fabricated fuel |
| Totals | All | 2 043 | | 14 943 | tU Natural Uranium |
| | | | | 281 | tU as EUP/enriched $UO_2$ |
| | | | | 502 | tU as $UO_2$ (Fabricated fuel) |

[a] Tonnes U (tU), not tonnes U equivalent (tUe) unless otherwise stated

- Fabricated fuel is estimated to make up around US $0.6 billion of this figure, specifically for Russian-designed reactors.
- Intermediate upstream front end materials are held by Atomenergoprom in the Russian Federation, along with primary uranium reserves reported by Kazatomprom.
- There are also strategic reserves readily available to the commercial sector (e.g., the IUEC Fuel Reserve and IAEA Fuel Bank), as well as the Russian national reserves of $DUF_6$, RepU and SIU that support Rosatom's domestic and international orders. However, these latter categories are not included in the above table, as they require further primary processing capacity to restore their material form to a natural-equivalent level.

## 7.2. BACKGROUND FOR EURASIA

The Eurasian region consists of only three commercial nuclear power countries: Armenia, Belarus and the Russian Federation. As of 31 December 2021, the region operators had approx. 29GWe (net) of nuclear power in service with an average demand for nuclear fuel products as shown in Table 7.

TABLE 7: EURASIAN REACTOR FLEETS AND NUCLEAR FUEL CYCLE DEMAND

| **Country** | **NPPs** (operating or in temporary shutdown + under construction) **and generating capacity** [a] | **Estimated annual demand in 2021** [b] **(tU)** | **Fuel cycle component (tU as)** |
|---|---|---|---|
| Armenia | 1 VVER-440; | 50 | $U_3O_8/UF_6$ |
| | 448MWe (net) | 7 | EUP/fabricated fuel |
| Belarus | 1 VVER-1200; | 358 | $U_3O_8/UF_6$ |
| | 1 110MWe (net) | 40 | EUP/fabricated fuel |
| Russian Federation | 2 KLT-40S/2+1 FBR/3 EGP/6 VVER-440/12 VVER-1000/4+3 VVER-1200/8 LWGR1000; | 5 925 | $U_3O_8/UF_6$ |
| | 27 727MWe (net) | 725 | EUP/fabricated fuel |

[a] IAEA PRIS database.

[b] WNA 2021 Nuclear Fuel Report

As key nuclear fuel cycle producer countries, Kazakhstan and Uzbekistan are added for completeness, where they have some impact on nuclear fuel inventories and stockpiling.

## 7.3. LOCAL INVENTORY POLICY AND STATUS

The nuclear power industries in the countries of the Eurasian region all fall under a single State-owned national entity. Their respective inventory polices are therefore considered as being an extension of government policies on nuclear power.

### 7.3.1. Armenia

Haykakan Atomayin Electrakayan CJSC (Armenia NPP, HAE) operates a single VVER-440 at Metzamor (unit 2). Life extension work will see the unit operate until 2026 and further renovations will extend this to 2036. Nuclear fuel is supplied under lifetime arrangements with TVEL, with periodic renegotiation for terms. Armenia's 10% shareholding in the IUEC at Angarsk also provides certain assurances with regard to accessing supplies of front end components[13].

Financial reports indicate that inventory values increased significantly in 2021, from AMD 11.8 billion to AMD 21.2 billion (US $42 million)[14]. This reflects a delivery of 139 fuel assemblies

[13] http://eng.iuec.ru/activities/supplies_to_shareholders/

[14] http://armeniannpp.am/page_files/documents/hashvetvutyun/fin_vijak%2C%20fin_ardyunq_2021.pdf

from TVEL (78 above the typical reload volumes for Unit 2[15]). Statements made in 2019 stated that “Based on the documents that were signed in 2017, a nuclear reserve stock has been formed at the power plant ... to replenish its reserve on the platform of the station”[16]. It is therefore likely that HAE has restored a 1–2 reload strategic inventory at the site in 2021 (equivalent to 9–14tU as EUP).

### 7.3.2. Belarus

Commissioning of the second of two Ostrovets VVER-1200 units has now begun, the first having achieved commercial operation in June 2021. The fuel supply contract between TVEL and Belarus covers the next 14–15 years [7]. In addition to supplying a full core of 163 fuel assemblies, two more spare core loads will be delivered to each Ostrovets unit. The operator stated that "[as] we are launching the station, and we already have a supply of fuel for 10–12 years without any economic and economic perturbations" [8].

The target acquisition is 878 assemblies, giving two first cores and eight spare reloads each (assuming 25% of the core is ejected after an annual cycle)[17].

So far (according to Russian and UN Comtrade export/import statistics) TVEL has delivered approx. 760 assemblies (i.e., 2 full cores in 2019 with 17 spare assemblies, plus approx. 400 spare fuel assemblies in 2020 and 2021), or 370tU. The target inventory amounts to approx. 480tU as $UO_2$, containing approx. 3 100tSWe and approx. 3 800tUe as $UF_6$, excluding first cores. This is expected to be accumulated on site by the end of 2022, given the existing volumes of annual deliveries from TVEL.

### 7.3.3. Russian Federation

Rosenergoatom buys all its nuclear fuel needs directly from TVEL, also a subsidiary of Atomenergoprom under Rosatom. Most of the fuel for Rosenergoatom is fabricated from irradiated uranium (either reprocessed or slightly irradiated feed) from domestic resources. From annual reports, it appears that an inventory including nuclear fuel amounts to approx. US $770 million. However, this is assumed to relate to the volume of part-burned in-core fuel plus finished fresh fuel required for the next reload. Rosenergoatom also specifically states that the inventory increase on 2020 levels was due to the first core needs for Beloyarsk, Novovoronezh and Rostov in 2021. Therefore, such values are not limited to a strategic holding and may only contain approx. 177tU as $UO_2$ in fresh fuel that is designate to the respective Generation III reactor cores.

In the absence of significant fresh fuel inventories, it is presumed that the proximity and capacity flexibility within the Russian fuel cycle provides a suitably robust front end supply chain for Rosenergoatom. The security of supply assurances that TVEL, as a sister company under Rosatom, can provide are considered in Section 7.4.2.

Figure 7 shows the estimates of total uranic inventories across the Eurasian region.

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[15] http://stat.customs.ru/analysis

[16] http://armeniannpp.am/en/info/news/rosatomi-tvel-vareliqayin-ynkeroutyouny-khamalri-haykakan-aek-i-mijoukayin-vareliqi-pashary-houshagir-e-storagrvel.html

[17] https://belaes.by/ru/novosti/item/2841-toplivo-dlya-atomnoj-stantsii-gde-ono-prokhodit-kontrol-i-kak-khranilishcha-gotovyatsya-k-ego-priemke.html

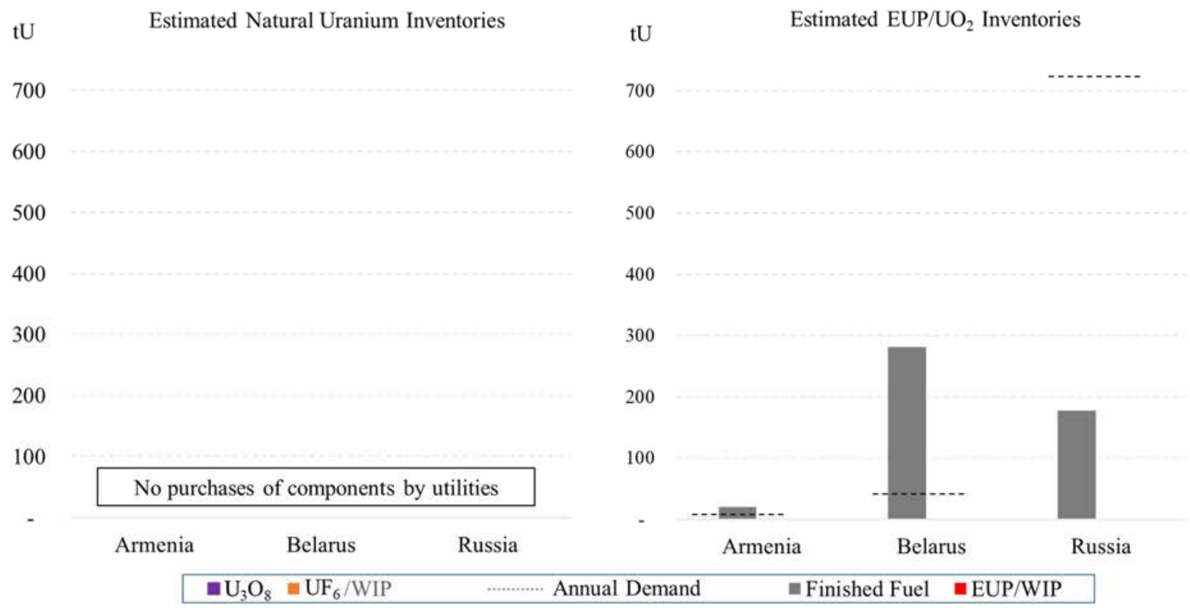


*FIG 7: Eurasian utility uranic inventories by form*

## 7.4. MAJOR SUPPLIER INVENTORY POLICIES AND STATUS

### 7.4.1. **Kazakhstan**

Kazatomprom (KAP) Group's 2021 year-end inventories were equal to 8 824tUe [9]. KAP continues to target an ongoing inventory level of approximately 6–7 months of annual attributable production. A number of JVs also have their own stock that are not published together with KAP Group figures. Kazatomprom also holds certain quantities of EUP necessary for the commissioning of the CGN fabrication Joint Venture. In total, uranium inventories are valued at ₸222.2 billion and another ₸45.3 billion (approx. US $510 million and US $105 million) in raw materials and WIP.

Kazatomprom also hosts the IAEA fuel bank at Ulba, containing 90tU as EUP with assays up to 4.95wt%.

### 7.4.2. **The Russian Federation**

The Russian Federation has historically held a national uranium reserve [10]. This formed a strategic stockpile to ensure a stable supply of uranium for national needs. There is no reliable information on the current size of these reserves, but according to historical information Russia's uranium stockpiles stood at 200 000tUe in 1991. However, during the 1990s much of this stockpile was sold off, such that by 2010 uranium reserves had dwindled to 47 000tUe and were expected to run out completely by the mid-2020s. Consequently, Russia stopped selling uranium from its commercial reserves to foreign customers, but continued to use approx. 3 000tU/a for domestically consumed nuclear fuel derived from RepU and SIU, respectively [11]. As recently as the WNA Symposium in 2018, TVEL asserted that it had no surplus inventories of EUP.

Any depletion of Russia's uranium reserves may have been stemmed or at least slowed by TVEL and TENEX independently accessing significant quantities of Kazakh uranium and foreign depleted uranium respectively. A recent deal to buy 1 150t of RepU from Orano to bolster national reserves[18] may also be an indicator as to its current status. The regular drawdown of approx. 3 000tU/a noted above would imply SIU and RepU inventories of >27,000tUe to help cover the domestic fleet requirements until 2030. Articles point to a similar amount of material in reserve, with a 1 500tU/a deficit covered by stocks that are assumed to last until 2040–2045 (i.e., 27 000–34 500tU) [12].

In most countries, $DUF_6$ tails are not regarded as true secondary supplies due to the need for primary enrichment production capacity to generate equivalent natural uranium. However, due to the low costs of domestic upgrading, Russia's current requirements for $UF_6$ and continuing excess uranium enrichment capacities make their stockpile of over 1 million $tUF_6$ [13] a viable resource. The Angarsk Electrolysis Chemical Complex (AECC) has been dedicated to tails upgrading since at least 2014, producing approx. 2 500tU annually for immediate consumption.

In total, Atomenergoprom (AEP) declared ₽232 billion of inventories (US $3.1 billion) as of 31 December 2021, but the subset related to fresh nuclear fuel and uranic components only amounted to ₽113 billion (US $1.5 billion). This is divided into finished nuclear fuel, work-in-process, uranium bearing products and shipped materials, which generally demonstrates pipeline volumes of 3–12 months domestic requirements for each stage of the fuel cycle. Evidently, AEP furnishes an international as well as a domestic orderbook, so such quantities appear to be close to an operational minimal.

In addition to the above, in 2010 Rosatom created its own international low enriched uranium Fuel Reserve at the IUEC[19], located at AECC. It contains >120tU as EUP with assays between 2–4.95wt%[20] and at least one-third being at 4.95wt%[21]. This material is accessible upon request from the IAEA and bolsters reserves for that part of the supply chain.

### 7.4.3. Uzbekistan

Domestic uranium miner Navoiyuran declares a mix of inventories across its range of products (including gold). However, the non-current assets are limited to US $30 million, so indicate little in the way of strategic reserves beyond WIP to meet planned orders.

Figure 8 shows Eurasian supplier uranic inventories by form.

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[18] https://www.orano.group/en/unpacking-nuclear/recycled-uranium-an-energy-source-for-low-carbon-electricity

[19] International Uranium Enrichment Centre is a JV, with 70% of shares held by Russia plus 10% each for Kazakhstan, Ukraine and Armenia.

[20] http://www.nti.org/analysis/articles/uranium-fuel-reserve-angarsk

[21] http://eng.iuec.ru/activities/fuel_bank/

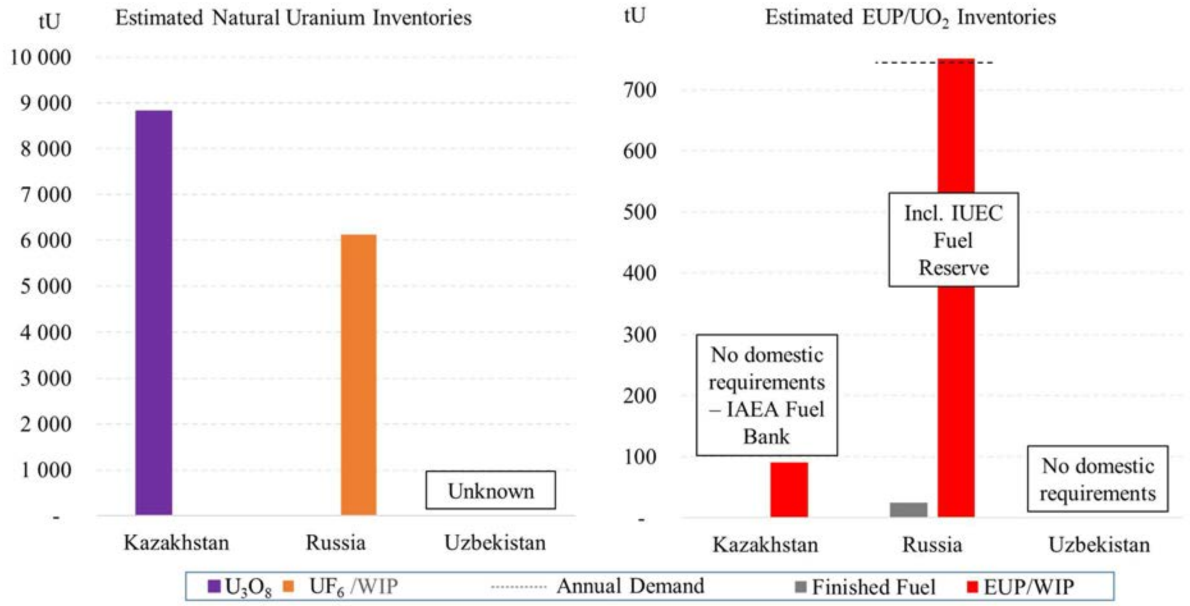


*FIG 8: Eurasian supplier uranic inventories by form*

## 7.5. EURASIAN INVENTORY LIQUIDITY AND MOBILITY

### 7.5.1. Armenia

The fabricated fuel at Metzamor is intended to provide a guarantee against supply interruption, so is considered illiquid. The fuel bank at the IUEC also provides similar guarantees against interruption in fuel supplies, but these are not exclusive to Armenia. The latter is therefore considered more flexible and mobile, subject to the procedures for accessing the material.

### 7.5.2. Belarus

Fabricated fuel stocks are held in dry storage at the Ostrovets site. The imperative of security of supply appears to have committed the station operator to significant expense (>US $400 million by the end of 2021) to ensure fuel supply with large strategic inventories. The material is therefore considered illiquid and solely for domestic use only. However, it is unclear whether Belarus will seek to maintain a stock going forward, or allow the reserve to be drawn down during the next ten years to a more conventional level.

### 7.5.3. Kazakhstan

KAP holds stock in $U_3O_8$ form, some of which is for strategic/WIP purposes (6–7 months of production). Since the remainder of the stock material is planned for sales, it is highly liquid and relatively mobile. However, KAP also continues to target an inventory level of approximately 6–7 months of annual attributable production. The IAEA LEU fuel bank is also considered liquid and mobile, subject to a request for supply meeting the criteria set by the IAEA Board of Governors.

### 7.5.4. Russian Federation

Within Rosatom, access to the various volumes and forms of reserves is determined by the current production needs of TVEL, both for its own customers and for those of TENEX. As such, any inventories are highly liquid and mobile, dependent upon the processing capacities of the Russian enrichment and fabrication industries.

Global access to the fuel bank of low-enriched uranium under IAEA control at the IUEC at Angarsk may determine the liquidity/mobility of that material. Theoretically, this material is available to any IAEA member state in good standing which is unable to procure fuel for political reasons.

### 7.5.5. Uzbekistan

All Navoiyuran inventories held as current assets are deemed necessary to implement near-term deliveries to customers, including in China, Republic of Korea and the US. As such, they are mobile but illiquid.

# 8. REGIONAL REPORT: EUROPE

## 8.1. OVERVIEW OF EUROPE

- The European nuclear power markets are diverse, covering 16 countries. Most (i.e. 13 countries) are represented by the European Union (EU) and governed by EURATOM Treaty requirements.
- EURATOM Supply Agency's (ESA) prescribed stock policy advises two years of inventories as well as supply diversification. However, individual inventory policies vary by country.
- Over-purchasing of nuclear fuel since 2010 is gradually being drawn down. Also, the impacts of early reactor closures on inventories are finally working through in Belgium, Germany, and Sweden.
- Quantities held tend to be overweight towards France. This nominally boosts EU averages and may hide a just-in-time approach for some operators.
- Appreciable amounts are held by front end suppliers, which are not reported by ESA.
- As of 31 December 2021, total inventories within Europe (including WIP/pipeline material) are valued at some US $15 billion, as detailed in Table 8.
- More than two-thirds of total inventories are held by French entities. Many utility holdings include WIP/pipeline quantities, so truly strategic reserves and surpluses are limited.
- Suppliers' holdings total approx. US $2.6 billion (some of which are integrated into national utility stocks; i.e. in Belgium, France and Spain, but otherwise are often dedicated to underpinning their respective international orderbooks).
- With financial entities holding over US $665 million of the stated inventories, this limits reserves that are considered to be uncommitted/liquid or mobile.
- EU/UK suppliers fuel most of the EU15 LWR fleet. Aside from France, there is little evidence of significant buffer stocks at production locations.
- Meanwhile, reliance on domestic fabrication exists for the UK AGRs and Romanian CANDU operators, where some reserves are evident.
- There is a significant dependence on TVEL for European VVER operators. Most have built inventories to mitigate any impacts from the current geopolitical uncertainties.

TABLE 8: SUMMARY OF EUROPEAN INVENTORY STATISTICS

| Country (EU members) | Nuclear entities reviewed | Value of inventories | | Estimated volumes (tU) | Assessed material form [a] |
|---|---|---|---|---|---|
| | | (US $ millions) | Reported (R) or estimated (E) | | |
| Belgium | 1 utility/supplier | 483 | R | 2 341<br>161 | $UF_6$<br>EUP |
| Bulgaria | 1 utility | 218 | R | 113 | Fabricated fuel |
| Czech Republic | 1 utility | 266 | E | 131 | Fabricated fuel |
| Finland | 2 utilities | 482 | R | 1 114<br>215 | $U_3O_8/UF_6$<br>Fabricated fuel |
| France | 1 utility/supplier | 7 617 | E | 37 800<br>3 290 | $U_3O_8/UF_6$<br>EUP |
| | 2 suppliers | 1 967 | R | 733 | Fabricated fuel |
| Germany | 3 utilities [b] | -<br>19 | -<br>R | -<br>11 | $UF_6$<br>Fabricated fuel |
| | 2 suppliers | - | - | - | - |
| Hungary | 1 utility | 235 | R | 114 | Fabricated fuel |
| Netherlands | 1 utility | 98 | R | 22<br>32 | EUP<br>Fabricated fuel |
| | 1 supplier | - | - | - | - |
| Romania | 1 utility | 62 | R | 106<br>113 | $U_3O_8$<br>Fabricated fuel |
| | 1 supplier | 37 | R | 81 | Fabricated fuel |
| Slovakia | 1 utility | 233 | R | 98 | Fabricated fuel |
| | 1 State body | 12 | E | 5 | Fabricated fuel |
| Slovenia | 1 utility | 28 | R | 11 | Fabricated fuel |
| Spain | 3 utilities | 422 | R | 235 | Fabricated fuel |
| | 1 supplier | 195 | E | 276<br>115 | $U_3O_8/UF_6$<br>EUP |
| Sweden | 2 utilities | 147 | R | 52 | EUP |
| | 1 supplier | 121 | R | 552<br>42 | $UF_6$<br>EUP |

TABLE 8 (cont.): SUMMARY OF EUROPEAN INVENTORY STATISTICS

| **Country (non-EU)** | **Nuclear entities reviewed** | **Value of inventories** | | **Estimated volumes (tU)** | **Assessed material form** [a] |
|---|---|---|---|---|---|
| | | **(US $ millions)** | **Reported (R) or estimated (E)** | | |
| Switzerland | 2 utilities | 63 | E | 646 | $U_3O_8$/$UF_6$ |
| | | 191 | E | 179 | EUP |
| | | 191 | R | 94 | Fabricated fuel |
| Ukraine | 1 utility | 44 | R | 484 | $U_3O_8$ |
| | | 669 | R | 346 | Fabricated fuel |
| | 1 supplier | - | - | - | $U_3O_8$ |
| United Kingdom | 1 utility | 162 | R | 90 | Fabricated fuel |
| | 2 suppliers | 156 | R | 1 538 | $UF_6$ |
| | | 114 | R | 76 | EUP/enriched UO2 |
| | 1 financial entity | 665 | R | 6 060 | $U_3O_8$ |
| European Totals | All | 14 895 | | 50 917 | tU Natural Uranium |
| | | | | 3 936 | tU as EUP/enriched $UO_2$ |
| | | | | 2 424 | tU as $UO_2$ (Fabricated fuel) |

[a] Tonnes U (tU), <u>not</u> tonnes U equivalent (tUe) unless otherwise stated

[b] One utility had no publicly available statistics on inventories

## 8.2. BACKGROUND FOR EUROPE

The European region consists of 16 nuclear power countries: Belgium, Bulgaria, Czech Republic, Finland, France, Germany, Hungary, Netherlands, Romania, Slovakia, Slovenia, Spain, Sweden, Switzerland, Ukraine and the United Kingdom. As of 31 December 2021, the region's operators had approx. 123GWe (net) of nuclear power in service with an average demand for nuclear fuel products as shown in Table 9.

TABLE 9: EUROPEAN REACTOR FLEETS AND NUCLEAR FUEL CYCLE DEMAND

| **Country (EU members)** | **NPPs** (operating/temporary shutdown + under construction) **and generating capacity** [a] | **Estimated annual demand in 2021** [b] **(tU)** | **Fuel cycle component (tU as)** |
|---|---|---|---|
| Belgium | 6 PWRs; | 790 | $U_3O_8/UF_6$ |
| | 4 936MWe (net) | 96 | EUP/fabricated fuel |
| Bulgaria | 2 VVER-1000; | 322 | $U_3O_8/UF_6$ |
| | 2 006MWe (net) | 38 | EUP/fabricated fuel |
| Czechia | 6 VVER-440/1000; | 706 | $U_3O_8/UF_6$ |
| | 3 934MWe (net) | 88 | EUP/fabricated fuel |
| Finland | 2 VVER-440/2 BWRs/1 EPR; | 421 | $U_3O_8/UF_6$ |
| | 4 394MWe (net) | 59 | EUP/fabricated fuel |
| France | 56 PWRs (+1 EPR) | 8 233 | $U_3O_8/UF_6$ |
| | 61 370MWe (net) | 1 084 | EUP/fabricated fuel |
| Germany | 3 PWRs; | 521 | $U_3O_8/UF_6$ |
| | 4 055MWe (net) | 66 | EUP/fabricated fuel |
| Hungary | 4 VVER-440s; | 320 | $U_3O_8/UF_6$ |
| | 1 916MWe (net) | 37 | EUP/fabricated fuel |
| Netherlands | 1 PWR; | 69 | $U_3O_8/UF_6$ |
| | 482MWe (net) | 8 | EUP/fabricated fuel |
| Romania | 2 PHWRs; | 185 | $U_3O_8$ |
| | 1 300MWe (net) | 185 | Fabricated fuel |
| Slovakia | 4 (+2) VVER-440s; | 359 | $U_3O_8/UF_6$ |
| | 1 868MWe (net) | 40 | EUP/fabricated fuel |
| Slovenia | 1 PWR; | 127 | $U_3O_8/UF_6$ |
| | 688MWe (net) | 15 | EUP/fabricated fuel |
| Spain | 6 PWRs/1 BWR; | 1 287 | $U_3O_8/UF_6$ |
| | 7 123MWe (net) | 191 | EUP/fabricated fuel |
| Sweden | 2 PWRs/4 BWRs; | 914 | U3O8/UF6 |
| | 6 885MWe (net) | 116 | EUP/fabricated fuel |

TABLE 9 (cont.): EUROPEAN REACTOR FLEETS AND NUCLEAR FUEL CYCLE DEMAND

| Country (non-EU) | **NPPs** (operating/temporary shutdown + under construction) **and generating capacity** [a] | **Estimated annual demand in 2021** [b] **(tU)** | **Fuel cycle component (tU as)** |
|---|---|---|---|
| Switzerland | 3 PWRs/1 BWR; | 412 | $U_3O_8/UF_6$ |
| | 2 973MWe (net) | 50 | EUP/fabricated fuel |
| Ukraine | 2 VVER-440s/13 (+2) VVER-1000s; | 1 876 | $U_3O_8/UF_6$ |
| | 13 107MWe (net) | 231 | EUP/fabricated fuel |
| United Kingdom | 8 AGRs/1 PWR (+2 EPR); | 1 259 | $U_3O_8/UF_6$ |
| | 5 883MWe (net) | 185 | EUP/fabricated fuel |

[a] IAEA PRIS database.

[b] WNA 2021 Nuclear Fuel Report

## 8.3. LOCAL UTILITY INVENTORY POLICIES AND STATUS

For the purposes of the analysis, the European region is divided into EU and non-EU countries. The former reports in a consolidated manner through the ESA, while three non-EU countries (Switzerland, the United Kingdom and Ukraine) are assessed separately.

European Union (EU) countries with ESA oversight include: Belgium, Bulgaria, Czech Republic, Finland, France, Germany, Hungary, Netherlands, Romania, Slovakia, Slovenia, Spain and Sweden.

ESA publishes data on utility nuclear fuel inventories held within the EU [14]. The latest data for 2021 indicates that stocks (expressed in tonnes of natural uranium equivalent (tUe)) have dropped 13% to approx. 36 800tUe. These quantities include WIP destined for the next scheduled reloads. ESA estimates demand for 2022 annual reloads at approx. 13 000tUe, so the net level of inventories going into 2022 is closer to approx. 23 800tUe or just less than two years' requirements (approx. 24 500tUe).

While the year-on-year drop is significant, reductions can often be associated with utilities deploying their next reload from within the quantities that ESA had designated as inventories. In 2021, a number of one-time examples were evident:

— The last reloads for the German reactors, primarily supplied from legacy inventories;
— Similarly, inventory drawdown in Belgium continues, in advance of phase-out plans for up to five of the operating units by 2025;
— Teollisuuden Voima Oyj (TVO) loaded the initial core for the Olkiluoto 3 EPR, ahead of commissioning.

Within the ESA survey population of 17 reporting bodies:

— 10 utilities held quantities of material lower than 1 000tUe (with eight of them holding less than 500tUe);
— Three utilities held quantities of material between 1 000 and 2 000tUe;
— Two utilities held quantities of material between 2 000 and 3 000tUe;
— The remaining two held quantities above 3 000tUe, with a combined total of at least 18 800tUe. However, within this category the largest EU operator (Électricité de France (EDF)) is assumed to holds the majority. One further caveat of note is that EDF Energy's inventories are now excluded from the ESA figures due to BREXIT.

Therefore, while on average EU utilities hold approximately two years' worth of annual demand in inventories, the fact that two out of the 17 operators hold more than 55% of the reported quantities may imply insufficient coverage amongst the remaining 15 operators. Furthermore, it is typical for uranic inventories to be spread evenly across the fuel cycle due to processing lead times. This is demonstrated by Figure 9, where ESA reports that the material is held in the following forms:

| | | |
|---|---|---|
| Fabricated fuel | 31% | (approx. 11 400tUe in 1 440tEUP[22]) |
| $UO_2$ powder | 4% | (approx. 1 500tUe in 190tEUP) |
| Enriched Uranium Product (EUP) | 23% | (approx. 8 500tUe in 1 070tEUP) |
| Natural Uranium Hexafluoride ($UF_6$) | 31% | (approx. 11 400tUe) |
| $U_3O_8$ concentrates | 11% | (approx. 4 050tUe) |

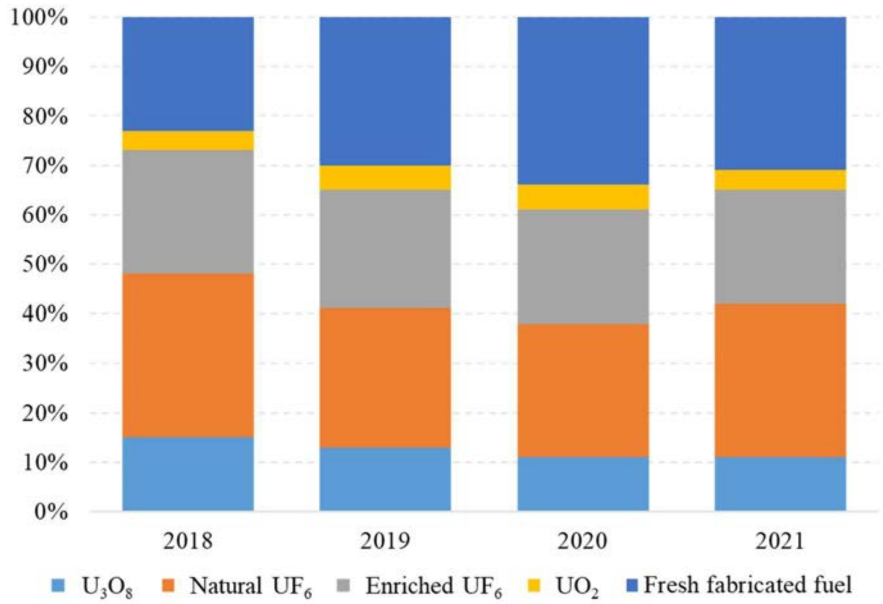


*FIG 9: EU utility inventories by form (tUe)*

22 tU as EUP or $UO_2$ calculated using 2021 average annual product and tails assays stated by ESA (4.11wt% and 0.22wt% respectively)

Evidently there was enough $UO_2$ and fabricated fuel at the respective reactor sites or fabricators to service 2022 requirements (12 293tUe, net) [14]. EUP within the supply chain is about 80% of what is required in 2023 and uranium amounts to 130% of the respective 2024 demand. However, these would largely match expectations for the levels of processing hold-up rather than strategic stocks and do not take into account that a number of utilities report excesses due to reasons of policy or prudence.

In order to qualify the status of WIP, strategic or surplus stocks it is therefore necessary to review individual utility statements in the countries across the EU.

### 8.3.1. Belgium

Synatom supplies nuclear fuel to Engie, with its procurement policy based on diversification. It also manages a strategic stock in line with ESA recommendations. In total these resources are expected to cover two years of demand[23]. Synatom has seen stocks grow over the early part of the last decade (in nominal values) following extended outages and unscheduled shutdowns at its Doel and Tihange plants. Notably, strategic stocks were available and utilised in 2015 to respond to the decision to extend the operating lifetimes of Doel units 1 and 2. Conversely, low reactor availability in 2018 (50%) meant an unplanned increase in stocks.

Synatom is constantly adjusting its coverage strategy in order to achieve a final stock level of close to zero for all products when the last Belgian reactor is closed. As of end 2021, Synatom's stock (including WIP) was valued at €408 million (down €179 million since a high in 2018). Material is reportedly held at enrichment facilities, split between $UF_6$ feed and EUP stocks. This level is equal to Synatom's annual turnover and reflects a progressive drawdown towards last deliveries for most reactors in 2023. However, the life extension for another 10 years of Tihange 3 and Doel 4 will likely alter the strategic inventory requirement. Engie (which effectively overlaps/mirrors Synatom's stockpiles) also states values for uranium inventories of €408 million at the end of 2021 (down from €530 million in 2020) [15].

### 8.3.2. Bulgaria

One of the four pillars for nuclear material under the Bulgarian government's Strategy for Sustainable Energy Development is to maintain a sufficient reserve of fuel at the Kozloduy NPP site [16]. All inventories are held as finished fuel, currently sourced from TVEL. In 2019, Bulgaria Energy Holdings (BEH) received 162 assemblies costing US $117 million and in 2020, 186 assemblies costing $134 million, whereas their average demand (between 2011–2018) was typically 88 assemblies. Import data suggests that stock accumulation was not repeated in 2021, with only 90 fuel assemblies imported. Consequently, it appears that Kozloduy NPP accumulated additional buffer stocks of finished fuel that now represents at least two years' worth of fuel inventories. In their 2021 annual report [17], BEH Kozloduy NPP made the following statements:

- Fresh fuel stocks = BGN 360 million (US $218m[24]);
- The 2021 fuel cost approx. US $70 million, which at average fabricated fuel import prices of US $1 920/kgU equals two approx. 20tU reloads.

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[23] https://www.forumnucleaire.be/actus/nouvelle/mix-electrique-belge-fevrier-2022

[24] Using a forex rate of BGN Lev 1 = €0.51

It would therefore appear that stocks equate to six reloads, two of which are presumably to satisfy the next annual requirement. This data corroborates statements by BEH that indicate Unit 1 is covered to April 2024 and Unit 2 to 2027 [18].

### 8.3.3. Czech Republic

CEZ Group aims to have a strategic inventory of nuclear fuel in line with the Czech Republic's Government policy. The National Energy Concept in 2015 called for long term stocks amounting to four years' worth of demand to be in place by 2040 [19]. CEZ acted between 2015–2021 to bolster fabricated fuel inventories and mitigate the impacts of a potential supply interruption, essentially following ESA recommendations relating to security of supply. Consequently, as of March 2022 [20]:

— Dukovany's four VVER-440 units had eight reloads (12-month cycles) in strategic stocks of TVEL fuel, delivered between 2017–21;
— Temelin's two VVER-1000 units had two reloads (12-month cycles) of strategic stock, delivered in 2015 and 2016.

At a minimum, this equates to approx. 130tU and is in addition to purchases related to the next reloads. Furthermore, CEZ also confirmed that it maintains strategic inventories across the front end of the fuel cycle to support Temelin fuel supplies. Under proposals outlined on 4 November 2022 by the Ministry of Industry and Trade, CEZ will now be required to hold reserves of nuclear fuel, fuel assemblies or other necessary/related equipment that allow its nuclear power plants to operate for at least three years. Any new law would allow the mandatory three years' nuclear fuel reserve to be reduced to 18 months "in the case where the operator can demonstrate that it has contractual agreements in place allowing replacement supplies". CEZ has confirmed that for Dukovany it is seeking to have a four-year inventory, to be achieved by smaller reloads, longer cycles and re-use of partly burned fuel [21].

### 8.3.4. Finland

Finnish law apparently requires up to one year's nuclear fuel requirements to be held in stock per reactor. There is no central stockpile of nuclear fuel, so each utility provisions for its own requirements at the respective plants. According to 2021 financial reports for Olkiluoto (OL1-3) operations, TVO is holding the following at year end:

— €99 million of uranium (raw and natural) (approx. 1 100tUe), which represents 4.5 years' worth of uranium demand;
— €167 million of nuclear fuel;
— The OL3 first core, recorded separately as CAPEX worth €250 million = 129tU fabricated.

Annual safeguard declarations (which are public) by the Finnish Radiation and Nuclear Safety Authority (STUK) [22] confirm that the above values of nuclear/fabricated fuel inventories include in-core material. In terms of strategic fabricated fuel holdings, the quantities total 14.7tU and 10.1tU for units 1 and 2 respectively. OL3 fabricated inventories include 128.6tU as first core and a further 44.8tU as strategic reserve, the latter having been delivered in 2021. Both sets of data fit with the expected 7–12 months of buffer inventories prescribed.

Meanwhile, Fortum states that for Loviisa

> "[t]he power plant's current nuclear fuel storage is sufficient for a maximum of two years" [23].

Reporting by STUK indicates a strategic inventory of 16.9tU as fabricated fuel at the plant, which equates to 80–90% of annual demand and so is in line with national policy.

### 8.3.5. France

As a major nuclear power user and fuel cycle supplier, the inventory status of France is somewhat complicated. Quantities of national stockpiles are reported by ANDRA [24]. Their statistics cover the inventories of Électricité de France (EDF), Orano Cycle, Framatome and also the French Alternative Energies and Atomic Energy Commission, although their respective holdings are not identified and international holdings are not included in the statistics. The latest report of French-owned front end quantities states that at the end of 2021:

- Natural uranium stocks totalled 37 800tU, down 2 000tU on 2021 and up 21 800tU since 2010;
- Enriched uranium stocks totalled 3 290tU, down 100tU on 2019, but up 290tU since 2010;
- Fresh fuel stocks totalled 733tU, up 121tU on 2021 (not reported separately in 2010).

In its accounts, the EDF Group (including EDF Energy in the UK[25]) reported a stable net value for nuclear fuel on its books of €10.479 billion in 2021 [25]. €8.576 billion of these stocks will not be consumed within one year, so are considered to primarily relate to upstream fuel cycle components (i.e., RepU, Natural $U_3O_8$ and $UF_6$ or EUP). Current assets, mostly assumed to be fresh nuclear fuel, represent €1.9 billion. For the purposes of analysis, all segments of component material have been discounted by the value of partly burned nuclear fuel in the cores of the French fleet (estimated to be €3.8 billion).

At EDF's current average rates of consumption (€1.4–1.6 billion/year), their unirradiated inventory quantities represent about four years of stocks in various forms. OECD/NEA demand data [8] estimates that EDF's French fleet requires approx. 1,000tEUP in fresh fuel annually (plus approx. 100tHM/a as MOX) and approx. 6 000tU as $UF_6$. That being the case, it is likely that the ANDRA fresh fuel stocks belong predominantly to EDF and represent annual variations in work-in-progress related to upcoming reloads, whilst impacted by reactor performance.

The ANDRA EUP and uranium inventories are well beyond annual requirements (being more than three- and five-times French demand, respectively) and so could either be identified as generous strategic holdings or significant work-in-progress holdings on behalf of EDF and French suppliers (see section 8.4.1). These results are in line with ESA data, although ESA's data excludes reprocessed material. There is also reasonable alignment between ANDRA data and the interpretation of financial reporting by EDF, Orano and Framatome, as demonstrated in the Annex. However, ANDRA data does not capture internationally held stocks.

[25] The extent to which EDF inventories overlap with UK-dedicated stocks is unclear. For the purposes of analysis they are assumed to be fully consolidated, so UK stocks have therefore been deducted from French declarations.

### 8.3.6. Germany

Under the German Atomic Law, the last three operating reactors were shut down in April 2023. During calls for their continued operation beyond December 2022, it was claimed that the three plants ‘have no fresh uranium fuel rods that would allow them to continue operating beyond year-end’ [26]. PreussenElektra (PEL) stated that its reactors all had sufficient fuel to operate until their [planned] closure dates. Consequently, PEL had stopped procuring uranium in 2020 and the last fuel deliveries were made to Grohnde and Isar 2 in 2021. PEL also confirmed to the German government that it could keep the NPP Isar 2 running into 2023 ‘if the government so wishes’ [27], but no additional fuel purchases were permissible. RWE had confirmed that the Emsland plant would use up all of its available fuel by December 2022. The last outage (Reload 34) did not consume any new fuel assemblies, but the core was reshuffled. However, RWE’s financial report statement regarding upstream inventories is ambiguous and implies that they will be selling surplus uranium after the closure of the Emsland unit [28]. EnBW reported €16 million of residual nuclear fuel in its accounts, with which Neckarwestheim 2 started its last cycle (Reload 38) in 2021. Additionally, Vattenfall Europe Nuclear Energy (VENE) is believed to have now defabricated most of the surplus Krümmel and Brunsbüttel fuel at Framatome Lingen for resale[26]. As of 31 December 2021, the following status is assumed:

- Natural uranium – RWE is believed to hold an undetermined quantity of uranium, in excess of its needs.
- Fabricated fuel – VGB [29] reports that onsite fuel inventories are depleted at the German reactors. Legacy fresh fuel from Grafenrheinfeld and Unterweser went to Brokdorf. VENE fuel is thought to have already been resold or consumed.

### 8.3.7. Hungary

The Hungarian Government’s policy is to have two years’ worth of fuel supply as inventory to run the Paks station. This material is held in dry storage, the capacity of which is understood to be greater than the current inventory levels at the site. Recent fuel airlifts from the Russian Federation may have increased the amount of material held at the plant [30]. MVM Paks reports upon nuclear fuel inventories as a separate line item in their accounts [31], such that at the end of 2021, inventory amounts equated to US $285 million:

- About 70% was held as finished fuel (approx. US $200 million), where annual reloads of US $90 million indicate that fabricated stocks represented two years’ worth of demand [32];
- Work-in-progress amounting to US $85–90 million equates to one years’ worth of demand and presumably reflects the supply chain lead times in Russia.

### 8.3.8. Netherlands

Elektriciteits Produktiemaatschappij Zuid-Nederland (EPZ) takes fuel made from Enriched Natural Uranium (ENU), Enriched Reprocessed Uranium (ERU) and Mixed Oxide (MOX) [27]

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[26] https://www.framatome.com/EN/businessnews-2188/betriebsbericht-fr-den-zeitraum-01-bis-30--november-2021.html

[27] http://zoek.officielebekendmakingen.nl/stcrt-2011-11565.html

in the ratio of 30:30:40 respectively. It also receives fabricated fuel from three fabricators; Framatome Lingen, TVEL MSZ and Orano Melox in larger quantities than can be used in any single refuelling[28]. The total amount of fresh and spent nuclear fuel permitted at Borssele is limited to a maximum of 200 tons, a level which is maintained through storing new fuel in the pond and recycling assemblies at Le Hague on an annual basis [33]. EPZ's financial accounts show the amount of fresh fuel inventory it holds as of 31 December 2021 [34]:

- Fabricated inventories plus in-service core totalled €90 million (of which €15.3 million relates to irrecoverable core material, i.e., fuel that will have a residual value upon shutdown). Assuming that the partly burned fuel in the core is worth approx. €34 million, then €56 million or approx. 32tHM is assumed to be fresh fuel;
- Advanced purchases of €28 million (approx. 22tU as EUP if valued at US $1 500/kgU), which have been accumulated by EPZ soliciting for EUP on a buy-and-hold basis.

These nuclear fuel inventory values imply a stock of fuel in-country of at least 32tU. However, at least 20–25% of the core is reloaded, so up to 8–10tU more may be fresh $UO_2$ or MOX fuel awaiting insertion. This indicates that EPZ is holding buffer stocks at Borssele equivalent to at least two reloads.

### 8.3.9. Romania

Nuclearelectrica reports that according to its strategic policy, the requirements for the implementation of the annual fuel production plan also provides for a 'reserve inventory' [35]. Nuclearelectrica records the impact of consumption at Cernavoda units 5 and 6 to on-site fuel stocks on a monthly basis. Fresh fuel stocks at the station were 5 615 assemblies as of 31 December 2021, supplemented by depleted fuel stocks of 182 assemblies (in total equating to approx. 110tU, worth RON212 million (approx. €42.5 million). In addition to nuclear fuel, Nuclearelectrica declares a uranium stock valued at RON44 million (approx. €9 million). The two CANDU reactors consume approx. 10 080 bundles each year (approx. 200tU), so the units have approximately 6 months of onsite stock (before considering inventories at the Pitesti nuclear fuel plant). The uranium quantities are presumed to be WIP requirements.

### 8.3.10. Slovakia

The State Material Reserves Administration of the Slovak Republic (SŠHR) is obliged to maintain a minimum reserve of nuclear fuel, in addition to material balances held by Slovenské elektrárne (SE). A plan was developed in 2014 to increase stocks of fresh nuclear fuel in Slovakia. However, as of early 2016 it was stated that:

> "The reserve management considers the current situation to be unsatisfactory and will address the issue of the number of stored fuel [assemblies] in the nuclear reactor as a matter of priority ... [so that] … together with stocks and reserves owned by the nuclear operator, [SE would be able] to operate the reactors for a certain period without its nuclear fuel supplies [from TVEL]" [36].

As of 31 December 2021, SE reported the following:

[28] The core of Borssele is comprised of 121 assemblies with a total of 38.8MTU; each reload comprises of 22-28 assemblies (7-9MTHM).

— €201.2 million of nuclear fuel stocks [37];
— Annual transfers of approx. €10 million between 2005-2021 from SE into the State Materials Reserve.

Based on average annual fuel consumption (€64 million), SE appears to hold an amount equivalent to approx. three years' worth of fuel. Fuel revolving through the State Reserves amounts to less than one VVER-440 reload (noting that the average consumption of Bohunice units 3 and 4 and Mochovce units 1 and 2 is 240–280 assemblies per annum or approx. 40tU as EUP). Meanwhile, the first core supplies to Mochovce units 3 and 4 are 349 assemblies each [38] or 42tU as EUP per core. SE took larger than normal deliveries from the Russian Federation in 2012, 2014, 2016 and 2018, presumably for these reactor start-ups. Therefore the €200 million figure above is likely to include approx. 84tU as EUP in fabricated first core fuel. Consequently, with Mochovce unit 3 core loading in 2022, the volumes of inventories reported by SE may well drop significantly.

Therefore, while recent fuel airlifts reportedly assured that the Slovak economy now has reserves of another strategic commodity, stocks were only estimated to be enough for 2022 and some of 2023. Consequently, in August 2022 the Slovak Cabinet approved the spend of around €8 million on purchase of 36 nuclear fuel assemblies to bolster the country's State Material Reserve [39].

#### 8.3.11. Slovenia

From the Nuklearna elektrarna Krško (NEK) annual report [40] it would appear that the utility does not declare any stocks of nuclear fuel as work-in-progress. NEK states that [40]:

> "Due to the nature of production, we do not hold unfinished production or half-finished or finished stock among inventories. Inventories consists only of material, including only nuclear fuel, spare parts and material."

The implication from their reported stock dropping from €52.6 million in 2020 to €24.6 million in 2021 during a year with limited purchases and a reload outage is that NEK retains little in the way of finished fuel inventories at Krško.

#### 8.3.12. Spain

ENUSA S.A., S.M.E. and the three of the four Spanish nuclear utilities (Endesa, Iberdrola and Naturgy) represent the main holders of uranium inventories in Spain[29]. The Spanish Government decrees the need for a basic reserve of 721t$U_3O_8$ and 363tSWe [41] (60tU as $UO_2$ at 0.3wt% tails). This implies that there will be enough uranium stock to manufacture fuel for two reloads of a 1 000 MW reactor in the Spanish nuclear fleet. The electricity companies also keep what is known as a 'voluntary strategic uranium stock'. If there were an interruption of international uranium supply, this would allow for the continued operation of the entire nuclear Spanish fleet.

[29] Energias de Portugal, S.A. (EDP) also claims to hold inventories of €14.8m, specific to the Trillo NPP.

As of 31 December 2021, each utility recorded the following stock levels in their accounts:

- Iberdrola had €58 million [42];
- Endesa had €255 million [43];
- Naturgy has €52 million [44].

The utility stocks (assumed to be fabricated fuel) translate into 17 months of average demand (160tU/a)[30].

### 8.3.13. Sweden

Sweden liquidated a national EUP inventory held by the Swedish Nuclear Fuel and Waste Management Company, SKB in the late 1990s (then determined as fuel equivalent to the production of 35TWh and equivalent to approx. 100 metric tonnes $UO_2$ or 8–12 months' supply [45]). Since 2000, the Swedish utilities have managed their own inventories. Vattenfall purchases nuclear fuel components on behalf of Forsmark AB and Ringhals AB as independent companies and Uniper/OKG buys for Oskarshamn 3 (OKG3).

Vattenfall's nuclear fuel inventory was SEK 5.975 billion as of 31 December 2021 (approx. US $630m), which includes partly burned fuel. This level has been relatively static for four years, having peaked in 2012. Extracting 503tU in-core material and based on average fleet consumption of approx. 120tU as EUP/year (and assuming values of US $1 800/kgU), the current inventory mostly represents normal pipeline/WIP volumes.

OKG reports inventories totalled SEK1.452 billion (US $170m) as of 31 December 2021. It is believed to keep a minor proportion of annual demand (approx. 24tU as EUP) as strategic inventory for OKG3. However, through a combination of contractual commitments and the premature closure of Oskarshamn units 1 and 2, OKG was left holding large stocks in late 2015, including 4–5 reloads of ERU fuel from TVEL. Drawdown is assumed to have been ongoing and may now be accelerated with the cessation of Russian EUP contracts in mid-2022. It is also likely that partly burned fuel from the 120MTU core of OKG3 is declared in the above values. Adjusting for this, cuts down fabricated fuel inventory values by approx. US $100m, such that the majority of inventory is held as EUP (40tU out of 45tU as EUP).

Non-EU Countries: Switzerland, Ukraine and the United Kingdom are considered below.

### 8.3.14. Switzerland

Swiss utilities maintain strategic stocks, in lieu of a national policy. Axpo confirms holding a stockpile of natural uranium and slightly enriched uranium in Western Europe for emergencies, while Kernkraftwerk Gösgen-Däniken AG (KKG) has existing uranium reserves which it intends to draw down. Reporting by the Federal Energy Office[31] confirms significant holdings of natural uranium and EUP outside of Switzerland, with nuclear material owned by the operators of Swiss nuclear installations being located in Germany, France, Sweden and the

[30] Each utility is expected to have the next reload ready two months in advance of the recharge.
[31] https://opendata.swiss/de/dataset/schweizer-kernmaterialbestande-im-ausland/resource/3bb60665-f390-44a1-9f63-42b6b3b5b93a

United Kingdom. Changes in stocks result from the procurement and processing of uranium into fuel elements. These depend on economic and operational requirements, so are deemed to include pipeline/WIP.

As of 31 December 2021, Swiss utilities held the following amounts of uranium in the international supply chain:

- Natural uranium: 956t (= 646tU if reported in the form of $UF_6$)
- EUP: 179t (= 121tU if reported in the form of $UF_6$)

In comparison, the two utilities carried the following amounts of fuel inventories on their books:

- Axpo (Beznau and Leibstadt) – CHF99.2 million (US $109 million)
- KKG (Gösgen) – CHF69.5 million (US $82 million)

Some of the monetary values above may include volumes additional to those reported for safeguards purposes, as it is assumed that the EUP contained in imported fuel assemblies is not counted by the FEO. Irrespectively, Axpo data indicates more than one year's stock of fuel (approx. 53tU) and KKG has at least two year's supply for Gösgen in its inventories (approx. 41tU).

### 8.3.15. Ukraine

Energoatom made the decision to create a two-year fuel reserve in 2014, when a security mission from the USA was working in Ukraine assessing the risks of a war with the Russian Federation. In 2020 Energoatom reported that it had 1.5 years' worth of fresh fuel reserves [46]. More recently, the head of Energoatom has made statements assuring that Ukraine had enough nuclear fuel for its power plants to last two years. It was confirmed that the country would not suffer any shortage of fuel over that period, even in the absence of replenishment of reserves.

Before the start of the current conflict, Ukraine bought small amounts of [reserve] fuel from TVEL, but most of the fabricated fuel stocks have been supplied by Westinghouse Sweden. Since the beginning of the conflict, Energoatom has completely abandoned Russian nuclear fuel, but still claims to have a large stock in its warehouses, which can be used over the next five to six years [47][32]. As of 31 December 2021, imports net estimated demand indicated the following:

- Fabricated Fuel – Energoatom has a net inventory of up to 680tU, including the next annual reloads;
- Approx. 440tU was added to inventories since 2016 (i.e., twice annual demand).

[32] Presumably reflecting the full operating cycle for the fuel of 4–5 years in core

Energoatom's annual reports [48] indicate that they hold a nuclear fuel inventory (excluding material in-core) valued at US $669 million (UAH18.3 billion). At US $1 490/kgU fabricated (based on average FIFO import prices declared since 2016), this would equate to 410–420tU of stocks. In comparison to an average annual demand of 200–220MTU, the current reserves equal about two years' requirements. This figure is also corroborated by an annual consumption value of UAH9.8 billion = US $332 million (approx. 220MTU). An additional US $44 million recorded by Energoatom as nuclear materials could represent ownership of VostGOK uranium or non-Russian EUP supplies (approx. 480tU). The cycling of such values in recent years would tend to indicate that this pipeline/WIP material.

Clearly the impacts of the conflict in Ukraine and the status of the Zaporozhye station will have changed the evaluation of stocks and security of supply, particularly if reserves are held at the occupied facilities. However, the usefulness and deployment of a two-year strategic reserve appears to be evident at the current time.

### 8.3.16. United Kingdom

There does not appear to be any national policy directive in terms of UK commercial uranium inventories. Nevertheless, NDA reports UK commercial inventories at the end of FY2022 [49] as part of its publicly available safeguards remit. As such the UK has approx. 90tU in unirradiated fuel, split between the AGRs (50tU) and Sizewell B (40tU) [50].

Meanwhile, statements by EDF Energy also confirm that they hold fuel inventories for the UK AGR and PWR fleet [51], which overlaps with the NDA data. In May 2022, EDF Energy confirmed Sizewell B held stocks of two years of fuel from Russian sources [52] (supplied as ERU and EUP via Lingen).

In its 2021 Annual Report EDF Energy records the following:

- £1 614 million in unburned fuel. This likely relates to the in-core inventory of approx. 1 510tU[33] for the entire fleet [49], plus material that remains unconsumed at the time of unit closures[34].
- Other nuclear fuel and uranium (including reprocessed materials) is valued at £352 million; down one-sixth since 2020. This is assumed to be split between the 90tU in unirradiated fuel in the NDA report and approx. 3 500tU of uranium.

To summarise the overall European market position:

- The 17 EU utilities inevitably make up the majority of European inventories. Most have at least one reload in hand as well as having the next reload in EUP or $UO_2$/fabricated fuel form.
- A similar situation exists for the Swiss, Ukrainian and UK operators, albeit that reporting highlights the downstream sectors of the fuel cycle (i.e., EUP/$UO_2$ and fabricated fuel).

[33] As of 1 April 2022, the AGRs had approx. 1 520tU and Sizewell B had approx. 90tU

[34] EDF Energy has to provision for unburned fuel upon station closure, representing 38.1% of a reactor core. This quantity is valued at £255 million in current and £1 698 million in non-current liabilities.

Figure 10 is a summary of European utility uranic inventories by form.

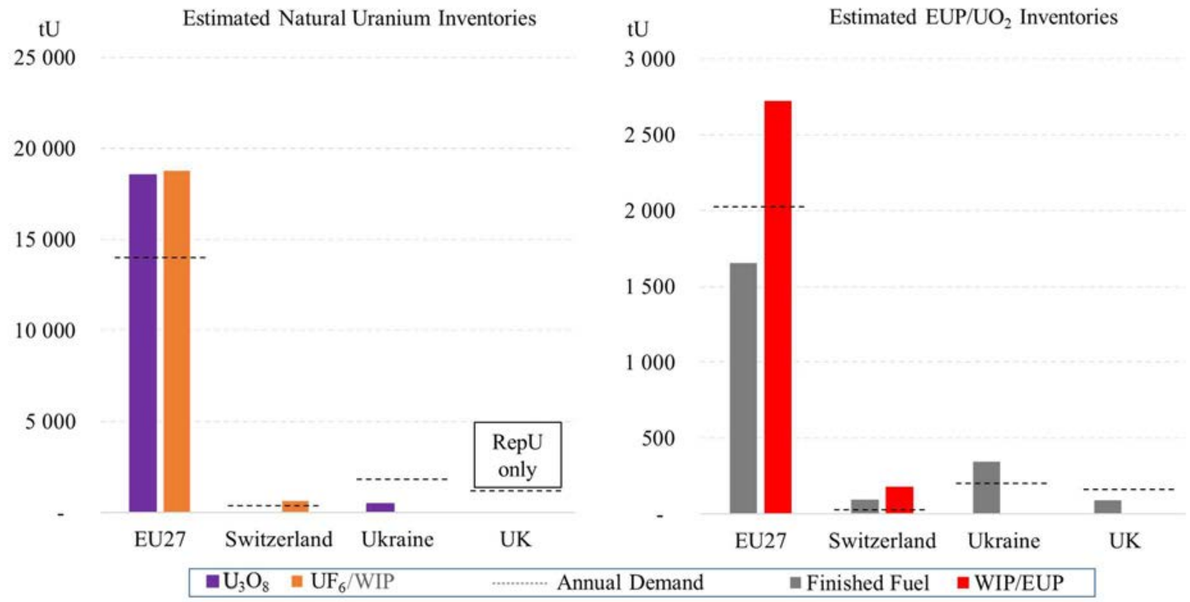


*FIG 10: European utility uranic inventories by form*

## 8.4. MAJOR LOCAL SUPPLIER AND TRADER INVENTORIES

### 8.4.1. France

Orano Chimie-Enrichissement's predecessor AREVA NC built stockpiles in the late 2000s as the closure of two production facilities approached (i.e., Comurhex 1 and George Besse 1). These were intended to guarantee contractual performance before the startup of the Philippe Coste and Georges Besse II plants. From observing movements in national inventories, the position since 2010 indicates that it has been difficult to work down these stockpiles, due to the impacts of Fukushima and the subsequent market downturn.

The latest accounts issued by Orano Chimie-Enrichissement state the following values and forms for their front end inventories [53]:

- €239 million in raw materials ($U_3O_8$ for conversion), estimated at 2,700tU;
- €510 million in WIP (mostly attributed to third party separative work units (SWU), estimated at approx. 400tU as EUP.

Meanwhile, Orano Mining declares stocks of €295 million[35], estimated at 3 350tU.

Framatome Group provides limited data on its inventories, simply stating a value of €656 million (up from €518 million in 2020) [54]. This is assumed to be mainly composed of work-

[35] https://www.societe.com/bilan/orano-mining-501493605202112311.html

in-progress and for the purposes of analysis is valued predominantly as EUP. This would equate to approx. 500tU as EUP, albeit covering operations in both Europe and North America.

### 8.4.2. Germany

Framatome GmbH (Lingen) does not independently state its inventories (which are consolidated into the Framatome Group accounts – see above). Urenco Deutschland GmbH's inventories are likewise included in consolidated statistics (see separate Urenco Group analysis in Section 8.4.6).

### 8.4.3. Romania

Since start-up, Nuclear Fuel Plant Pitesti (NFP Pitesti) has manufactured 218 240 bundles of natural $UO_2$ fuel, but only delivered 213 995 to the reactors. Most of the 4 285 assembly surplus has been generated since 2015 (3 763 assemblies), such that NFP Pitesti could now be holding approx. 80tU as a buffer to fabricated fuel production. This represents approx. 40% of annual national requirements. Combined with Nuclearelectrica's inventories, Romanian reserves could amount to 190–200tU of fabricated fuel and possibly up to 110tU as $U_3O_8$. Consequently, in total Romania has up to two years' worth of uranium stocks, including operational WIP and strategic reserve inventories at each stage of the fuel cycle.

### 8.4.4. Spain

Spain has legislated that ENUSA guarantees a Uranium Reserve Stock ("Stock Básico") for its nuclear fleet. Original quantities were high (5 000t$U_3O_8$ and 3 000tSWe), but since the mid-1980s these amounts have been steadily reduced. In 1985 the levels were prescribed by RD 1611/1985 at a maximum of 2 000t$U_3O_8$ and 1 300tSWe. Currently (under an order from 2005), Spanish legislation demands a minimum inventory of 721t$U_3O_8$ and 363tSWe (60tU as $UO_2$ at 0.3wt% tails, including approx. 600tUe). This implies that there will be enough uranium stock for ENUSA to manufacture fuel for two reloads of a 1 000MWe reactor in the Spanish nuclear fleet.

Enriched uranium is imported into Spain as $UO_2$ (as ENUSA is unable to locally deconvert enriched $UF_6$) and limited deliveries of fuel assemblies have come from Germany and Sweden. Fuel exports are predominantly made to Belgium, Finland, France and Sweden, resulting in a net trade outflow of fabricated fuel.

Based on ENUSA/Foro Nuclear annual statements, exports and imports (net of domestic demand) show a modest drawdown of domestic stocks over the last 12 years. ENUSA's current stocks are €165 million [55], including the Uranium Reserve Stock of 60tU as $UO_2$. Any additional material is assumed to be at various stages of the fuel cycle, but is likely to be held upstream at levels in excess of the 'basic' reserve in order to guarantee export contracts from Juzbado. It is assumed to be split between different fuel stages in similar volumes to the uranium reserve stock (i.e., 276tU as uranium and approx. 60tU as EUP).

### 8.4.5. Sweden

Westinghouse Sweden does not declare specific uranic inventories, but had WIP amounting to SEK548 million (approx. US $64 million) and raw materials of SEK489 million (approx. US $57 million) in 2021. The former quantities may well overlap with Uranium Asset Management

(UAM) materials (see below summary for the United Kingdom) and are not for near-term sale. They have been equated to approx. 550tU as $UF_6$ and approx. 40tU as EUP respectively.

### 8.4.6. United Kingdom

Urenco Group covers three jurisdictions: the USA, ESA/EU and the United Kingdom. The imports and exports of $UF_6$ feed, depleted uranium (DU) and enriched uranium appear in four country's statistics (Germany, the Netherlands, the USA, the United Kingdom), making separate identification difficult from a trade flow perspective. The sole reference used is therefore Urenco Group's financial reports.

Urenco declares its inventories as values of raw materials, WIP, SWU Assets and Finished Goods. Since SWU assets are dedicated to fulfilment of customer orders, this category in WIP can be ignored for the purposes of assessing inventories, as it will overlap with global utility data. Actual inventories include inaccessible WIP and finished goods, where timing of sale completion goes beyond the current period. As such truly liquid inventories have been reduced in recent years to relatively modest quantities.

In relation to these categories, Urenco's reported inventories peaked in 2016/17, but as of 31 December 2021 had reduced to the following values:

- Raw materials (mainly $UF_6$): €88.4 million (60%)
- WIP (plant operational inventory of SWU): €39.8 million (27%)
- Finished goods (incl. uranium trades): €18.7 million (13%)

As such, the $UF_6$ raw materials could equate to approx. 1 000tU[36]. This material is owned by Urenco and considered available for resale or for use internally. WIP as plant hold-up and rolling buffer stocks is an operational inventory and in effect is inaccessible in the medium to long term. Finished goods may represent approx. 30tU as EUP and may already be committed under contract, so are potentially inaccessible.

Springfields Fuels Limited/Westinghouse UK rely on Uranium Asset Management (UAM) for their uranic supply. Under this role, UAM both buys/sells and leases natural uranium and enriched uranium on their behalf. UAM reported [56] end of year 2021 holdings of US $96 million. It planned to sell surpluses amounting to US $22 million but hold a further US $67 million (approx. 40–45tU as EUP) for at least 12 months[37]. Meanwhile, Springfields Fuels Limited has a modest range of consumable stocks [57], but it is assumed that any uranic material is owned by customers.

One additional entity of significance in the United Kingdom is the Yellow Cake investment fund. This is a London-quoted company listed on the Alternative Investment Market (AIM), headquartered and incorporated in Jersey. As of 31 December 2021 it reportedly held 6 060tU as $U_3O_8$ in accounts at Cameco's Port Hope/Blind River facility in Ontario, Canada and in Orano Cycle's Malvési/Tricastin in France. The most significant portion of its inventory is

[36] This does not include customer uranium, which is an off-balance sheet item
[37] Possibly relating to a WIP loan to Westinghouse Sweden

purchased under a 10-year framework agreement with Kazatomprom. As a commodity fund, the material is not destined for resale.

#### 8.4.7. Ukraine

Most uranium domestically mined at VostGOK between 2010 and2021 was sent to Russia for conversion and enrichment at the International Uranium Enrichment Centre (IUEC) in Angarsk. According to the WNA[38], 8 300tU was produced between 2012 and 2021. The resulting uranium concentrate is largely used for the needs of the domestic Ukrainian nuclear reactor fleet. However, it is not currently known what level of ore stocks exist at VostGOK.

To summarise the level of inventories in the European supply chain; most front end component stocks are held by French entities (ignoring hedge fund volumes). Across the nuclear fuel cycle industry there is little available material to backstop utility requirements, if it experiences a supply chain interruption of much more than six months duration.

Figure 11 summarises European supplier uranic inventories by form.

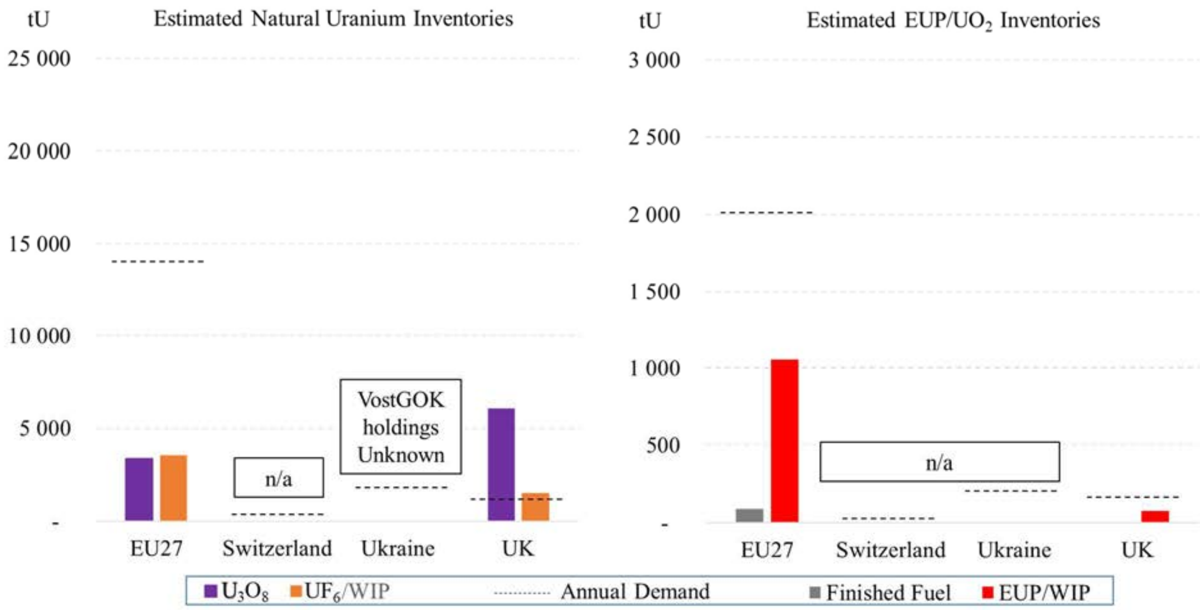


*FIG 11: European supplier inventories by form (n/a =not applicable)*

### 8.5. EUROPEAN INVENTORY LIQUIDITY AND MOBILITY

Given current geopolitical events and the efforts undertaken by certain operators during the last five years to secure an inventory position to avoid disruptions in supply, it would be reasonable to assume that few utilities have any truly surplus inventories. Some have gone beyond ESA recommendations to provide an additional level of assurance, in particular, EDF/Orano and CEZ. Others such as Vattenfall, ENUSA and Synatom have likely seen prescribed inventory plans frustrated by uncertainties over continued reactor operation, but are now able to plan ahead for domestic consumption of any surpluses accumulated during the 2010s. General

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[38] https://world-nuclear.org/information-library/nuclear-fuel-cycle/mining-of-uranium/world-uranium-mining-production.aspx

liquidity is therefore determined to be low within Europe, with stock mobility limited to reshuffling quantities between units as they retire, within the same regulatory jurisdiction.

In terms of suppliers, a similar process to utilities in terms of re-optimising their positions during the 2010s has apparently left few with significant inventories that can backstop utility demand for a protracted period. However, the inventories that do exist can be deployed globally, so these are considered more liquid and mobile than those of their local customers.

# 9. REGIONAL REPORT: NORTH AMERICA

## 9.1. OVERVIEW OF NORTH AMERICA

- The North American countries represent a single interdependent region in terms of fuel security and supply chain logistics.
- Most utilities largely rely on proximity of primary fuel cycle suppliers and open commercial markets to procure fuel on a diversified basis.
- In the USA, a progressive drawdown of stocks since 2010 means that simple commercial solutions may be insufficient to avoid any potential supply disruption. While only limited Federal Agency reserves exist, there has been a significant increase in policy interest in security of supply since the first quarter of 2022 and a focus on the accessibility of these reserves.
- Meanwhile, Mexico relies on the USA for fuel supply guarantees and Canadian brokering of Russian material, rather than independent strategic stockpiling.
- In contrast, Canada can domestically satisfy most utility needs, with security of supply based on local uranium reserves and domestic processing capacity.
- As of 31 December 2021, total regional inventories were estimated to be worth US $12 billion, as detailed in Table 10.
- Much of this value is held in utility inventories, which includes pipeline material or fuel destined for internal consumption. Few utilities hold an overly strategic stockpile of material to mitigate a supply interruption and available utility information also points to relatively illiquid inventory holdings.
- Supply chain inventories recorded by the EIA in the USA are estimated to be worth over US $1.5 billion and are almost matched by similar Federal holdings and reserves. The former is presumed to support the supplier's backlog of commercial commitments, so is relatively illiquid. Meanwhile the latter is designed to be accessible to the markets under certain call-off conditions and protocols.
- Canadian suppliers are also understood to have devoted commercial resources to backstop utility fuels supplies and plant operations.
- Potentially more significant is the world's largest uranium fund (SPUT), which has recently taken up a considerable amount of surplus material (as $U_3O_8$) into an illiquid state that is inaccessible from an end user standpoint.

TABLE 10: SUMMARY OF NORTH AMERICAN INVENTORY STATISTICS

| Country | Nuclear entities reviewed | Value of inventories (US $ millions) | Value of inventories: Reported (R) or estimated (E) | Estimated volumes (tU) | Assessed material form [a] |
|---|---|---|---|---|---|
| Canada | 3 utilities [b] | 291 | R/E | 1 164 | Fabricated Fuel |
| | 2 suppliers | 364 | R | 4 018 | $U_3O_8$, $UF_6$ or $UO_2$ |
| | 1 financial fund | 1 769 | R | 15 806 | $U_3O_8$ |
| Mexico | 1 utility | 38 | E | 30 | Fabricated fuel |
| USA | 21 utilities [b] | 6 700 | R | 7 550 | $U_3O_8$ |
| | | | | 13 931 | $UF_6$ |
| | | | | 1 934 | EUP |
| | | | | 411 | Fabricated fuel |
| | Suppliers/traders | 1 526 | E | 10 894 | $U_3O_8$ |
| | | | | 897 | $UF_6$ |
| | | | | 105 | EUP |
| | Federal agencies (DOE/NNSA) | 1 388 | E | 3 400 | $UF_6$ |
| | | | | 632 | EUP |
| Totals | All | 12 076 | | 56 497 | tU Natural Uranium |
| | | | | 2 670 | tU as EUP/enriched $UO_2$ |
| | | | | 1 605 | tU as $UO_2$ (Fabricated fuel) |

[a] Tonnes U (tU), not tonnes U equivalent (tUe) unless otherwise stated

[b] One utility had no publicly available statistics on inventories

## 9.2. BACKGROUND FOR NORTH AMERICA

The North American region consists of three countries with commercial nuclear power programmes, namely Canada, Mexico and the USA. As of 31 December 2021 the region's operators had approx. 110GWe (net) of nuclear power in service, with an estimated demand for nuclear fuel products as summarised below in Table 11.

TABLE 11: NORTH AMERICAN REACTOR FLEETS AND NUCLEAR FUEL CYCLE DEMAND

| Country | NPPs (operating/temporary shutdown + under construction) and generating capacity [a] | Estimated annual demand in 2021 [b] (tU) | Fuel cycle component (tU as) |
|---|---|---|---|
| Canada | 19 PHWRs; 13 624MWe net | 1 492 | $U_3O_8$ |
| | | 1 492 | Fabricated fuel |
| Mexico | 2 BWRs; 1 522MWe net | 226 | $U_3O_8/UF_6$ |
| | | 28 | EUP/Fabricated fuel |
| USA | 61+2 PWR/31 BWR; 94 718MWe net | 17 587 | $U_3O_8/UF_6$ |
| | | 2 197 | EUP/Fabricated fuel |

[a] IAEA PRIS database.

[b] WNA 2021 Nuclear Fuel Report

Together, these countries currently represent the largest combined regional nuclear market in the world, but with aging fleets that have seen numerous retirements during the last 10 years. As such, lifetime extension applications and refurbishment programmes represent a major focus for the local industry.

## 9.3. LOCAL UTILITY INVENTORY POLICIES AND STATUS

### 9.3.1. Canada

The country has a general policy of self-sufficiency for its front end nuclear cycle, which includes domestic uranium mining, conversion and fabrication to support the indigenous CANDU reactor market. However, the Canadian government does not provide a strategic stockpile of nuclear fuel. Nuclear power utilities therefore independently hold natural uranium, $UO_2$, WIP and finished fabricated fuel to ensure their security of supply. In order to buffer against supply shocks, natural uranium and other downstream services are purchased years in advance, allowing time for a number of processing steps before a finished fuel bundle arrives at the power plant [58]. There are no significant quantities of enriched uranium in Canada and there are no utility-owned uranic inventories held outside of Canada.

Considering the three operators in turn:

1. Bruce Power does not publicly state its inventory policy or holdings. The two Bruce generating stations are leased by Ontario Power Generation (OPG) to Bruce Power and were quoted by OPG as having invested CAD $84 million in nuclear fuel during 2021. Bruce Power may rely in part on their dedicated fuel supplier Cameco for buffer stocks, but are also believed to have a finished fuel inventory for security of supply that is conservatively estimated to be six months of fuel (approx. 360tU).

2. New Brunswick Power values its nuclear fuel inventory at CAD $57 million at the end of 2021. The utility purchased CAD $33 million worth of nuclear fuel during the year, implying only a modest stockpile when considering their inferred annual requirements. This may relate to New Brunswick having purchased the remaining inventory from Hydro-Québec when the Gentilly reactor shut down (as they share a common fuel design) and is estimated to be approx. 180tU.

3. OPG held CAD $196 million worth of nuclear fuel inventory at the end of 2021, compared to a fuel expenditure of CAD $251 million. In their 2011 Uranium Procurement Plan, OPG's Target Inventory Policy stated an intent to hold a minimum strategic and working inventory of 1 million lbs$U_3O_8$ (approx. 380tU). In addition, OPG sought to maintain individual inventories at each stage of the nuclear fuel supply chain:

   - An inventory of finished fuel bundles equivalent to 12 months expected forward usage to allow continued refuelling.
   - A working inventory of $UO_2$ to feed the manufacturing process, described generally as a 2–3 months $UO_2$ supply.
   - Their uranium conversion supplier is also contractually required to maintain an inventory of $UO_2$ for OPG's use in the event of any supply interruption.

Assuming OPG's inventories are currently held as fabricated fuel, the values equate to approx. 625tU (approximately one years' current demand). The six Pickering units were planned to close in 2024–2025, so OPG's longer term requirement for strategic inventories may well have declined significantly as a consequence. However, these units' lifetimes are now extended to 2026 and a review of potential refurbishment is underway. In the short to medium term, the phased restart of three Darlington units with fresh cores may well increase purchases and/or deplete inventories that would otherwise be held as a hedge against future years' supply disruptions [59]. Any further reprieve for the Pickering units could add to this requirement.

From aggregating the utility financial statements, the utility inventory position is considered to be in excess of 1 160tU in fabricated bundles, which represents approximately nine months of fuel. As stated by OPG, these quantities are required to ensure continuous refuelling.

### 9.3.2. Mexico

The nuclear operator, Comisión Federal de Electricidad (CFE) Mexico, buys finished fuel for the two Laguna Verde units from GNF-A [60] in the USA and procures EUP by public tender. Most recently Nukem/Cameco (brokering on behalf of Russia's TENEX) combined to win the contract for EUP supply to the two BWR units between April 2022 and June 2025. Notwithstanding independent procurement, GNF-A is contractually bound to guarantee EUP supply if there is a failure of CFE's own supplier or a tender collapse. Presumably this backup gives CFE a degree of comfort and security of supply, protecting against the length of the international supply chain for its nuclear fuel.

As of 31 December 2021, CFE held nuclear fuel in inventories valued at Ps2.88 billion (US $142 million) at Laguna Verde.

The financial value has been as high as Ps4.2 billion during the last 10 years. It is assumed to include in-core inventories of unburned fuel[39] representing approx. Ps2.1 billion. This leaves Ps779 million equating to approx. 30tU as fresh fabricated fuel. On that basis, the nuclear fuel inventories are assumed to be limited to the next planned reload, with CFE potentially relying on JIT deliveries by GNF-A.

### 9.3.3. United States of America

Utilities in the USA buy all of their fabricated fuel from one or more of the domestic fuel fabrication suppliers (i.e., Framatome in Richland, GNF-A in Wilmington or Westinghouse in Columbia). A significant proportion of their enriched uranium needs are also covered by supplies from Urenco's Louisiana Energy Services (LES) enrichment plant in Eunice, New Mexico. Consequently, the downstream segments of the nuclear fuel supply chain inventories are largely conducted within the USA. However, supplies of $UF_6$ and mined uranium are almost entirely sourced from outside the USA, due to much of the domestic production capacity being idle in 2021.

The collective ownership of front end inventories is tracked and reported on by the United States Energy Information Administration (EIA) in its Uranium Marketing Annual Report [61]. Data from the EIA includes utility fuel intended for the upcoming reloads of the US commercial nuclear fleet and WIP for the primary suppliers. Therefore, it potentially represents an inflated view of the US nuclear fuel inventories. For the end of 2021, the inventory quantities provisionally reported were as follows:

Owned by operators of nuclear power plants[40]:

- $U_3O_8$ 19.7mlbs $U_3O_8$ = 7 550tUe (US $0.8 billion)
- $UF_6$ 36.4mlbs $U_3O_8$e = 13 930tUe (US $1.7 billion)
- EUP 43.2mlbs $U_3O_8$e = 16 530tUe = 1 930tU as EUP[41] (US $3.7 billion)
- Fabricated Fuel 9.2mlbs $U_3O_8$e = 3 510tUe = 410tU as EUP[42] (US $0.9 billion)
- Total 108.5mlbs $U_3O_8$e= 41 520tUe (US $7.2 billion)

Owned by suppliers and traders:

- $U_3O_8$ 28.5mlbs $U_3O_8$ = 10 900tUe (US $1.2 billion)
- $UF_6$ and EUP 4.7mlbs $U_3O_8$e = 1 800tUe

Assuming that the latter category is split equally, this would equate to 900tU as $UF_6$ and 105tU as EUP[43] (valued at US $110 million and US $203 million respectively).

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39 Each core takes approx. 81tU and CFE typically refuels 25–30% of the core

40 EIA reports in millions lbs (mlbs) or uranium as $U_3O_8$. Values expressed are at average reported EIA prices for $U_3O_8$ and SWU over the last 10-years (US$123.87/SWU; US$42.60/lb$U_3O_8$)

41 Evaluated at average assays of 4.44wt% $^{235}$U for product and 0.2175wt%$^{235}$U for tails material (implied by EIA data)

42 Using the average assays quoted above

43 Using the average assays quoted above

When compared to annual demand for each component in the USA (approximately 17 200tU of natural uranium and 2 100tU as EUP), EIA data demonstrates that utilities have 15 months of uranium inventories and just over 13 months coverage for EUP in all forms. Meanwhile, suppliers may have 7–8 months of uranium and approximately one month's worth of EUP on hand. Given that the combined supply chain would normally hold 12 months requirements at each stage of the cycle (concentrates, conversion, enrichment and fabrication), then the above data indicates that little is held by way of excess. The fact that US suppliers also export to international clients may further highlight the limitations of available material.

This outcome is further emphasised by utility financial data. However, such data sources rarely reference distinct strategic inventories and instead often capitalises nuclear fuel investments as plant assets 'in core'. Where nuclear fuel inventories are separately reported, quantities tend to equate to annual demand in the same way as EIA data. For instance, the largest US nuclear operator Constellation (representing more than 20% of the US nuclear fleet) reports in its 2021 10-K filings report:

- At the end of 2021, Constellation had US $5.166 billion in nuclear fuel assets, of which US $2.765 billion were amortised (i.e., partly burned fuel).
- Additionally, US $0.859 billion was stated to be in the form of fresh fuel or at the processing stage.
- Therefore, US $4.307 billion of fuel was in reactor cores, of which 64% is amortised.

Assuming that volume is proportionate to value, about 20% of the total volume of fuel necessary is held as WIP or finished fresh fuel. Based on approx. 2 270tU in reactor cores at Constellation's plants, at an average cost of approx. US $1 900/kgU as fabricated fuel can be extrapolated. This implies that with US $0.859 billion in fresh fuel/components, then a minimum of approx. 450tU of nuclear fuel is available to Constellation in its front end supply chain, which equates closely to their average annual fuel requirements. Therefore, strategic stocks may be embedded in the supply chain, but are chiefly dedicated to near-term requirements. From evidence gathered from all but one of the US utility 10-K filings and further breakdowns provided in Federal Energy Regulatory Commission (FERC) submissions, this situation does not appear unusual with only 11% of the declared inventories designated as true stock rather than WIP.

A further example is Tennessee Valley Authority (TVA). The utility only states amortized fuel inventories and annual purchases of US $1.492 billion and US $421 million during 2021 respectively. However, with TVA fleet cores containing approx. 760tU as EUP and based on a generic residual value of US $900/kgU, partly burned fuel would only equate to US $685 million, leaving US $807 million for inventories as WIP and strategic stocks. Such inventories will include pipeline fuel costing on average approx. US $300 million/a plus inventories of US $507 million. The latter could in part equate to expenditures towards down-blending under the US DOE's Tritium programme. The creation of a 10-reload reserve of EUP for TPBAR[44] fuelling under the Down Blending Offering for Tritium (DBOT) programme was slated to cost US $770 million value and run between 2019 and 2025 [62].

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[44] Tritium Producing Burnable Absorber Rods

Based on the above and further investigation into FERC records, the US utilities hold material estimated to be worth US $6.6 billion, a figure comparable to the values extrapolated for the above EIA quantities. Companies known to hold meaningful inventories include:

- Ameren UE (as part of STAR strategic holdings);
- Energy Northwest (from US DOE tails upgrading for onward sale to TVA and strategic purchases on its own behalf);
- Southern Company (for the Vogtle 3 and 4 units first cores);
- Dominion/SCE&G (residual from surplus Summer units 2 and 3 first cores being directed to Summer unit 1 and a contingency reserve [63]);
- Southern California Edison (SCE), who holds residual material from the now-retired San Onofre units;
- TVA that manages material from the US DOE's down-blending and tails upgrading initiatives, largely to feed the US DOE/NNSA tritium production programme (as noted above).
- Vistra Corp., who subsequently sold surplus inventories worth US $57 million in 2022.

Evidently, the status of most of these stocks is well-defined in terms of end use, meaning that only the SCE inventories are genuinely surplus to ongoing requirements. As a consequence, much of the US fleet is apparently relying on the proximity of the fabrication supply chain to ensure deliveries, despite that supply chain itself having little in the way of commercial buffer stocks to mitigate upstream supply disruptions.

To summarise the overall market positions in the region: Canada's three operators appear to apply a mixed regime of long lead times/supply chain assurances together with prescribed inventory and buffer stock policies to fuel the fleet of CANDU units. Meanwhile, the 21 utilities in the USA typically have their next reload in EUP or $UO_2$/fabricated form plus the requisite amount of feed to support the next year's delivery. However, truly strategic physical stockpiles are almost non-existent. Where held, there are concentrated in a small number of utilities, only two of which appear to follow an espoused strategic holdings policy. The remaining utilities have diversified their contracting to limit any single disruption event, but otherwise would look to the US DOE-funded reserves (see section 9.4.2) to mitigate shortfalls. Similarly, Mexico's national operator largely relies on the proximity of the supply chain in the USA and its commercial guarantees, plus access to an open commodities market to ensure the regularity of fuel supplies.

Figure 12 summarizes North American utility uranic inventories by form.

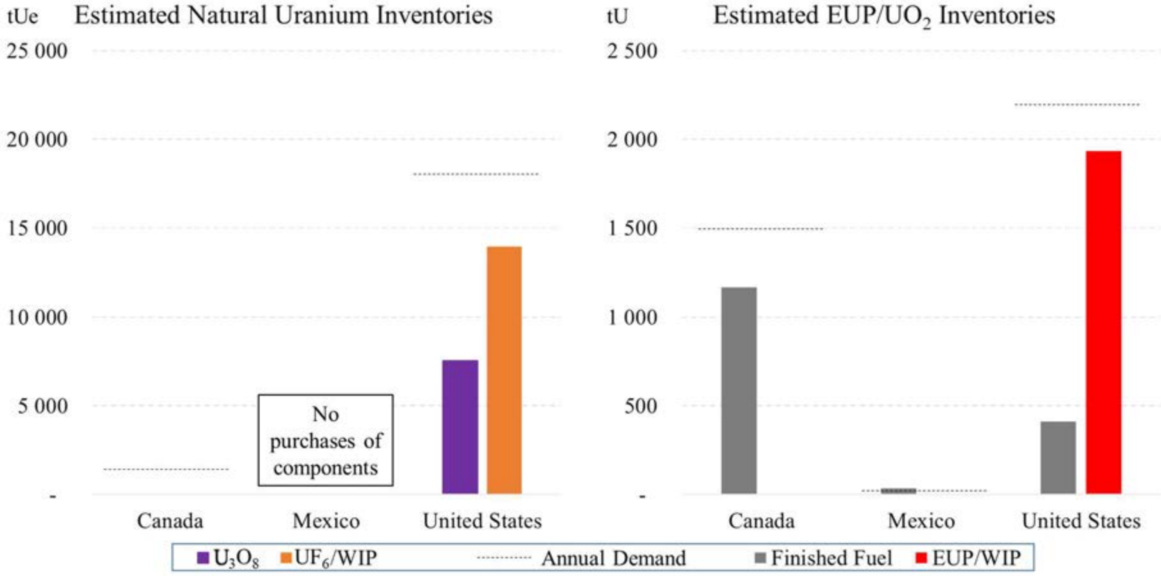


*FIG 12: North American utility inventories by form*

## 9.4. MAJOR LOCAL SUPPLIER AND TRADER INVENTORY POLICIES AND STATUS

### 9.4.1. Canada

BWXT Peterborough is dedicated to PHWR fuel supply for OPG. It does not make any public statements on its uranic inventories, but is presumed that they comply with OPG's requirement to hold WIP and buffer quantities to manufacture the fuel to reload the Darlington and Pickering reactors [64].

At Cameco's mines and conversion facilities, utility and other supplier inventory mainly constitutes WIP. These quantities are routinely destined for other conversion and/or enrichment facilities, with Cameco only holding a minor strategic inventory that is not available to the market. This quantity is presumably included in the 8mlbs $U_3O_8$e stated as inventory in its 2021 annual accounts. Most is held as $U_3O_8$ (CAD$319 million), with a minority as processing material for the fuel services segment (CAD$43.5 million).

Denison Mines reportedly holds 2.5mlbs $U_3O_8$ of physical uranium in North American storage facilities as a long-term investment expected to enhance access to future project financing for Wheeler River [65]. In addition, modest amounts of $U_3O_8$ and mill WIP are recorded in the annual accounts (approx. $3.9 million).

In 2021, Canadian-domiciled Sprott Physical Uranium Trust (SPUT) issued an At-The-Market (ATM) programme allowing it to sell discretionary shares and use the proceeds to purchase $U_3O_8$. Sprott held approx. 41.3mlbs $U_3O_8$[45] (including 18.3mlbs acquired from Uranium Participation Corp. and the concentrates component they had after selling off the conversion component of their 300tU as $UF_6$) and has been a significant purchaser of surplus $U_3O_8$ inventories on the spot market. However, their prospectus states that there is no redemption of trust units, which renders this a source of secondary supply illiquid [66].

[45] https://sprott.com/investment-strategies/physical-commodity-funds/uranium/

### 9.4.2. United States of America

It is believed that ConverDyn, Framatome, GNF-A, Urenco LES and Westinghouse all hold limited stocks beyond operational WIP. Westinghouse holds $141 million of uranium stocks in current and non-current inventories, but otherwise none of the above declare their stocks in publicly available financial filings (and some are consolidated into foreign-owned parent accounts).

The four domestic miners with public declarations have confirmed inventories as $U_3O_8$ totalling US $80 million. One broker, Centrus Energy, makes limited statements about its inventories, which totalled US $9 million as SWU (approx. 200tSWe) and US $74 million as feed/uranium (approx. 850tU) at the end of 2021. EIA data is presumed to include all available American inventories held by suppliers, brokers and traders.

Meanwhile, DOE-related stocks amount to significant holdings of EUP and $UF_6$. However, while primary suppliers have access to inventories linked to Federal stockpiles, they are not reported in the EIA data. These programmes include:

- USA Assured Fuel Supply (230tU as EUP);
- MOX Backup (173tU as EUP);
- Surplus and National Security HEU to the DBOT programme (229tU as EUP out of a possible 400tU was assumed to have been generated at the end of 2021) [67];
- DOE surplus uranium disposition barters (3 400tU as $UF_6$, with release dependent upon Secretarial Determinations).

In total, the Federal EUP stockpiles that are accessible on extended lead times could backstop approximately 20% of US demand for one year, albeit subject to call-off constraints and other commercial terms. Further moves by the US Government to create a Uranium or ‘LEU Reserve’ are ongoing.

Figure 13 summarises North American supplier uranic inventories by form.

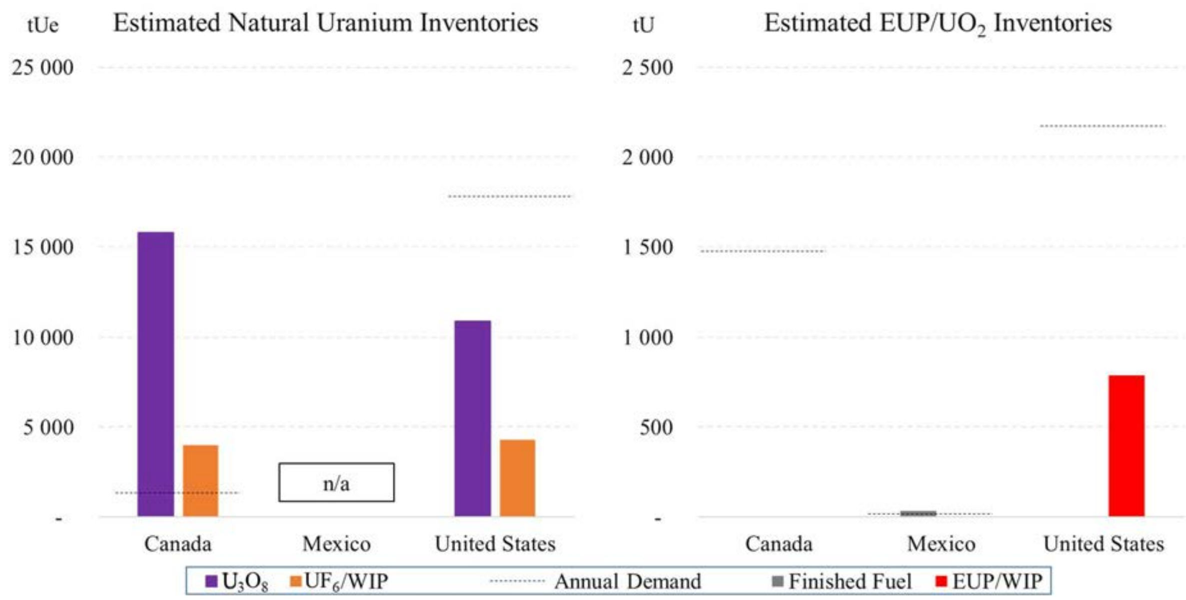


*FIG 13: North American supplier inventories by form (n/a=not applicable).*

Irrespective of US-owned inventories, there are significant amounts of Japanese inventory that have occupied storage pads across the US front end supply chain in recent years (e.g. approx. 1 000tU as $EUP/UO_2$). These may provide an additional form of security against market shocks, albeit requiring commercial arrangements for its use with the utility owners.

## 9.5. NORTH AMERICAN INVENTORY LIQUIDITY AND MOBILITY

### 9.5.1. Canada

Neither the Canadian government nor local utilities could be regarded as a notable source of secondary supply to the market. Cameco’s fuel service facilities host third-party uranium accounts that could be liquidated, but only to the extent that surpluses exist and there is a willingness to trade these quantities. The impact of Sprott on a thinly traded market has been noticeable, taking up surplus production into a relatively inaccessible repository. When coupled with primary supply reductions over the last number of years due to the COVID-19 pandemic and mine reductions and closures, the potential for undersupply has increased, a situation that is not restricted to just the Canadian market. Therefore, any secondary supplies in Canada is considered largely immobile for utilities, suppliers and financial institutions alike.

### 9.5.2. Mexico

Based on the available evidence, any nuclear fuel held by CFE is assumed to be a minimal strategic buffer stock of spare assemblies, specifically designed for the Laguna Verde BWRs and therefore not readily transferable or commercially liquid.

### 9.5.3. United States of America

Domestic utilities are mostly operating under a JIT regime for nuclear fuel supply, buffered by contract diversification and commercial lead times. It appears that local fuel cycle suppliers have little in the way of surplus/strategic inventories to go beyond providing a short term buffer to these domestic utilities in the event of a supply disruption. That said, both parties have the logistical opportunity to make liquid large amounts of Japanese inventory that reside in the

USA (also see Section 11). This may be bolstered by Federal Agency stocks, but these are not immediately liquid due to commercial constraints. Irrespective of this, they have the ability to mitigate a limited and predictable supply disruption with at least one year's notice.

# 10. REGIONAL REPORT: SOUTH AMERICA

## 10.1. OVERVIEW OF SOUTH AMERICA

- The South American region exhibits a localization of the nuclear fuel industry (i.e. deconversion/fabrication), such that the supply chain is in effect vertically integrated with the domestic utility in both countries.
- Upstream demands for uranium, conversion and most of the required enrichment are imported into South America, increasing the need for WIP and some buffer stocks.
- Fuel cycle suppliers and utilities reporting on inventories overlap to some degree and so have been evaluated on that basis in an attempt to avoid double-counting volumes.
- As of 31 December 2021, total uranic inventories within South America (including pipeline/WIP material) were valued at some US $534 million, as detailed in Table 12.
- Argentinian inventories are estimated to average the amounts required for annual nuclear fuel production at each component stage (i.e., largely signifying JIT procurement).
- Meanwhile, Brazilian inventories are estimated to equate to up to two years' worth of the components required for annual nuclear fuel production, so point to some strategic holdings in excess of nation policy requirements and working inventory.
- Also, military propulsion and research unit offtake in Brazil may have led to non-civil inventories, although these are beyond the scope of this publication.

TABLE 12: SUMMARY OF SOUTH AMERICAN INVENTORY STATISTICS

| **Country** | **Nuclear entities reviewed** | **Value of inventories** | | **Estimated volumes (tU)** | **Assessed material form [a]** |
|---|---|---|---|---|---|
| | | **(US $ millions)** | **Reported (R) or estimated (E)** | | |
| Argentina | 1 utility/supplier | 16 | R | 202 | $U_3O_8$ |
| | | 24 | | 106 | Nat $UO_2$ |
| | | 92 | | 245 | Fabricated fuel |
| | 1 supplier | 7 | R | 95 | $U_3O_8$ |
| | | 15 | | 65 | Nat $UO_2$ |
| Brazil | 1 utility | 48 | R | 622 | $U_3O_8$ |
| | | 95 | | 44 | EUP/$UO_2$ |
| | | 223 | | 102 | Fabricated fuel |
| | 1 supplier | 15 | E | 188 | $U_3O_8$ |
| Totals | All | 534 | | 1 278 | tU Natural Uranium |
| | | | | 44 | tU as EUP/enriched $UO_2$ |
| | | | | 346 | tU as $UO_2$ (Fabricated fuel) |

[a] Tonnes U (tU), not tonnes U equivalent (tUe) unless otherwise stated

## 10.2. BACKGROUND FOR SOUTH AMERICA

The South American region consists of only two commercial nuclear power countries; Argentina and Brazil. As of 31 December 2021 the region's operators had approx. 3.5GWe (net) of nuclear power in service with an average demand for nuclear fuel products at the levels indicated in Table 13.

TABLE 13: SOUTH AMERICAN REACTOR FLEETS AND NUCLEAR FUEL CYCLE DEMAND

| **Country** | **NPPs** (operating or in temporary shutdown + under construction) **and generating capacity** [a] | **Estimated annual demand in 2021** [b] **(tU)** | **Fuel cycle component (tU as)** |
|---|---|---|---|
| Argentina [c] | 3 PHWR; 1 641MWe (net) | 200 | $U_3O_8$ |
| | | 30 | Slightly Enriched Uranium |
| | | 230 | Fabricated fuel |
| Brazil | 2 PWRs (+1); 1 884MWe (net) | 395 | $U_3O_8/UF_6$ |
| | | 45 | EUP/fabricated fuel |

[a] IAEA PRIS database.

[b] WNA 2021 Nuclear Fuel Report

[c] A CAREM research reactor is also under construction in Argentina

## 10.3. LOCAL INVENTORY POLICY AND STATUS

Both Argentina and Brazil have pursued a policy of relative self-sufficiency for their respective front end nuclear fuel cycle needs. This includes localised deconversion and fabrication in Argentina operated by DIOXITEK and CONUAR respectively and uranium mining, enrichment, deconversion and fabrication operated by Industrias Nucleares do Brasil (INB) in Brazil. These organisations have a symbiotic dependency with their local national nuclear utility, but also engage in sales between the respective markets as well as some military offtake from INB in Brazil.

Irrespective of localisation, both countries rely heavily on imports of uranic material in various forms (natural uranium, slightly enriched uranium and EUP) to meet their domestic needs. DIOXITEK, CONUAR and INB regularly tender for international supplies of $U_3O_8$, $UF_6$ and uranium enrichment. This lengthens the processing times for each fuel reload and necessitates a commercial policy of inventory management to ensure the timely delivery of nuclear fuel to the power stations.

Figure 14 summarises the estimates for South American uranic inventories by form.

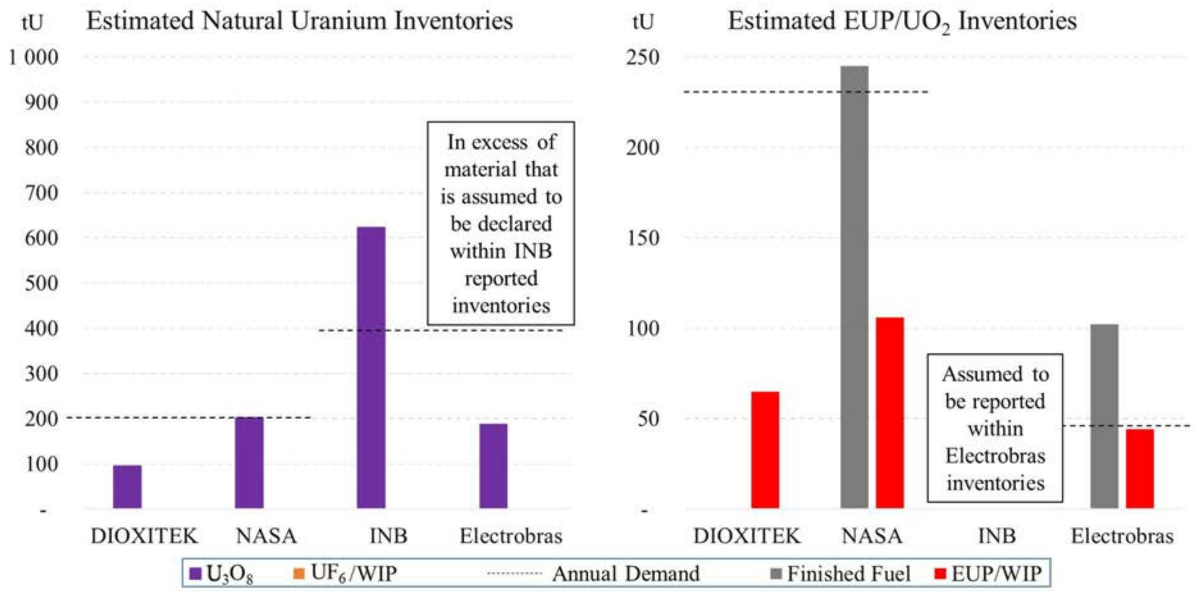


*FIG 14: South American uranic inventories by form*

### 10.3.1. Argentina

Nucleoelectrica Argentina S.A. (NASA) and DIOXITEK hold natural uranium, $UO_2$ WIP and also finished fabricated fuel to ensure supply of approx. 200tU of nuclear fuel every year. Inventories have increased in 2021, after reducing in 2020 due to some drawdown of surplus stocks by DIOXITEK. At the end of 2021 these totalled 9–18 months' worth of stocks at different stages of the fuel cycle (approx. 170tU-300tU), but other than in $U_3O_8$ NASA had no distinct holdings of dedicated buffer stocks or strategic inventories.

### 10.3.2. Brazil

INB has an obligation to maintain a minimum stockpile of enriched uranium and also holds uranium inventories, which tend to vary with the Caetité mine output. Electrobras also declares a mix of inventories (which may overlap with INB's statements, so they have only been counted in certain circumstances) including $U_3O_8$, WIP and finished fuel equating to 1–2 years of stocks at each stage of the nuclear fuel cycle.

This also applies to finished fuel held as strategic stock (approx. 57tU as EUP) that is not destined for the next scheduled reload[46]. However, the pre-fabrication of Angra unit 3 fuel in anticipation of commercial operation seems to have led to a quantity of surplus material that is available for units 1 and 2. This has proved opportune, given the recent fuel oxidisation issues suffered by Angra unit 2 fuel that meant early replacement of part-burned fuel.

All nuclear material inventory management in Brazil will soon be assumed by the Brazilian National Nuclear Security Authority from the Brazilian National Nuclear Energy Commission, so may lead to a restatement of national inventories and policies.

[46] Annual requirements average 45tU as EUP

### 10.4. SOUTH AMERICAN INVENTORY LIQUIDITY AND MOBILITY

Localised processing of uranium dedicated to in-country demand has provided reasonable assurances to both NASA and Electrobras in terms of security of supply for their ongoing nuclear fuel needs. As finished fuel and work-in-progress is exclusively for domestic use, the ability of the end user to treat the inventories as liquid or commercially mobile is currently limited to trades between Brazil and Argentina. Consequently, the stocks held in both countries are not considered to be available to the global market.

## 11. REGIONAL REPORT: SOUTH AND EAST ASIA

### 11.1. OVERVIEW OF SOUTH AND EAST ASIA

- South and East Asia is seeing positive developments for nuclear power, with installed capacity growth in India and China plus the reversal of a phase-out policy in the Republic of Korea. Consequently, the reduction in nuclear capacity seen in Japan and Taiwan, China since 2010 has been more than offset.
- Generally, a conservative approach has been taken to ensuring security of nuclear supply, either through asset ownership or supply chain management. In particular, the localisation of fabrication and enrichment technologies and the expanding ownership/acquisition of foreign front end suppliers compensates for a lack of domestic uranium resources in the region.
- Prescribed stock policies and/or strategic inventory levels vary. Current inventories held by utilities and fuel cycle entities in the region are the highest globally. Significant accumulations have taken place over the last decade, some unintended.
- Over-purchasing that resulted from operating suspensions and local shutdowns/phase-outs will lead to a progressive drawdown of uranic inventories in the Republic of Korea, Japan and Taiwan, China. Any third-party resales will be governed by market conditions and regulatory constraints. Meanwhile, China and India continue to bolster their sizeable reserves.
- As of 31 December 2021, total inventories within South and East Asia (including pipeline material and some reprocessed material) are valued at some $42.3 billion, as detailed in Table 14.
- Major strategic inventories are held in India, the Peoples Republic of China and the Republic of Korea in support of growing nuclear fleets.
- The significant surpluses of material across the front end are owned by Japanese and Taiwanese entities due to phase-out and operational outages. In the case of Japan, these may be inflated due to the inclusion of reprocessed fuels, but irrespective they represent a significant overhang to the market that cannot readily be consumed despite planned unit restarts.
- The liquidity and mobility of the Japanese inventories is governed not only by location but also by commercial constraints. Therefore, resale may be considered as a last resort, particularly in the face of geopolitical and market uncertainty as well as the Japanese Government’s recommitment to nuclear power.

TABLE 14: SUMMARY OF SOUTH AND EAST ASIAN INVENTORY STATISTICS

| Country | Nuclear entities reviewed | Value of inventories | | | Assessed material form [a] |
|---|---|---|---|---|---|
| | | (US $ millions) | Reported (R) or estimated (E) | Estimated volumes (tU) | |
| Peoples Republic of China | 3 utilities [b] | 2 188 | R | 1 215 | Fabricated fuel |
| | 2 suppliers | 17 102 | E | 132 500 | $U_3O_8$ |
| | | | | 906 | EUP |
| India | 1 utility [b]/supplier | 1 056 | E | 17 465 | $U_3O_8$ and $UO_2$ |
| | | 37 | | 25 | EUP |
| Japan | 11 utilities | 19 181 | R [c] | 37 953 | $U_3O_8$ and $UF_6$ |
| | | | | 2 368 | EUP |
| | | | | 2 183 | Fabricated fuel |
| | 4 suppliers | 86 | E | 463 | $UF_6$ |
| Republic of Korea | 1 utility | 2 136 | R | 9 409 | $U_3O_8$ |
| | | | | 878 | EUP |
| | | | | 441 | Fabricated fuel |
| | 1 supplier | 241 | E | 134 | $UO_2$/Fabricated fuel |
| China [d] | 1 utility | 262 | E | 2 889 | $UF_6$ |
| | | | | 324 | Fabricated fuel |
| Totals | All | 42 290 | | 200 679 | tU Natural Uranium |
| | | | | 4 176 | tU as EUP/Enriched $UO_2$ |
| | | | | 4 297 | tU as $UO_2$ (Fabricated fuel) |

[a] Tonnes U (tU), not tonnes U equivalent (tUe) unless otherwise stated

[b] One utility had no publicly available statistics on inventories

[c] Values include reprocessed materials

[d] Taiwan

## 11.2. BACKGROUND TO SOUTH AND EAST ASIA

The South and East Asia region consists of five commercial nuclear power countries: India, Peoples Republic of China, Japan, Republic of Korea and Taiwan, China[47]. As of 31 December 2021 the region operators had approx. 119GWe (net) of nuclear power in service with an average demand for nuclear fuel products as indicated in Table 15.

[47] New nuclear countries have not been considered until fuel policies are established and the first reactors are commissioned (i.e., Bangladesh)

TABLE 15: SOUTH AND EAST ASIAN REACTOR FLEETS AND NUCLEAR FUEL CYCLE DEMAND

| Country | **NPPs** (operating or in temporary shutdown, and under construction) **and generating capacity** [a] | **Estimated annual demand in 2021** [b] **(tU)** | **Fuel cycle component (tU as)** |
|---|---|---|---|
| China | 1 FBR/1 HTGR/47+14 PWRs/2 PHWRs/4+4 VVERs | 9 563 | $U_3O_8$ |
| | | 8 345 | $UF_6$ |
| | 52 170MWe (net) | 1 077 | EUP |
| | | 1 267 | Fabricated fuel |
| India | 2 BWRs/18+4 PHWRs/ 2+4 VVER-1000s; | 977 | $U_3O_8/UO_2$ |
| | | 344 | $UF_6$ |
| | 6 795MWe (net) | 126 | EUP |
| | | 678 | Fabricated fuel |
| Japan | 17+2 BWRs/16 PWRs | 2 844 | $U_3O_8/UF_6$ |
| | 31 710MWe (Net) | 150 | EUP/fabricated fuel |
| Republic of Korea | 22+3 PWRs/3 PHWRs; | 4 750 | $U_3O_8$ |
| | 24 431MWe (net) | 4 500 | $UF_6$ |
| | | 470 | EUP |
| | | 810 | Fabricated fuel |
| Taiwan, China | 2 PWRs/1 BWR | 414 | $U_3O_8$ |
| | 2 859MWe (net) | 414 | $UF_6$ |
| | | 57 | EUP/fabricated fuel |

[a] IAEA PRIS database.

[b] WNA 2021 Nuclear Fuel Report

Given the symbiotic relationships between country utilities and their domestic fuel cycle suppliers, the two sectors have been considered from an integrated point of view in the following sections.

## 11.3. LOCAL INVENTORY POLICIES AND STATUS

### 11.3.1. China

The rapid growth of nuclear power in China has been accompanied by an increasingly mature domestic nuclear fuel industry, accompanied by a clear strategic policy towards security of supply. For the first time in 2007, the National Defence Science, Technology and Industry Commission announced that the ‘Eleventh Five-Year Plan for the Development of the Nuclear Industry’ will include the formation of a national strategic reserve and a commercial reserve system for natural uranium [68]. Consequently, each stage of the nuclear fuel cycle has attempted to establish an appropriate level of domestic self-sufficiency, while also engaging with the global industry of primary suppliers in uranium, conversion, enrichment and fabrication. This has ensured the coverage of existing needs, but is also directed at providing for suitable levels of work-in-progress (WIP) and strategic stockpiles under the guidance of

China National Nuclear Corp./China Nuclear Energy Industry Corp. (CNNC/CNEIC) and the Chinese nuclear utilities (China Nuclear Power Co. Ltd. (CNP), China General Nuclear Power Co. Ltd. (CGN) and the State Power Investment Corp. Ltd. (SPIC).

The key element for the domestic nuclear fuel supply chain for China is access to natural uranium. Chinese mines have limited reserves, so the international market has been a focus of Chinese investments and contracting, particularly in Africa and Kazakhstan. The importation of material has pre-empted the ability of the domestic conversion industry at Hengyang and Diwopu to process the material into $UF_6$, so national stockpiles have emerged in the form of $U_3O_8$, primarily stored at Hengyang. Levels of 85 000tUe in 2015 [69] are estimated to have now increased to more than 130 000tUe, as shown below, which is equivalent to more than 10 years of current demand. Chinese sources have indicated that the level of inventories will need to almost double to 250 000tUe to support the country's growth of nuclear power.

Figure 15 provides estimates of Chinese inventories of $U_3O_8$ from 2010 to 2021.

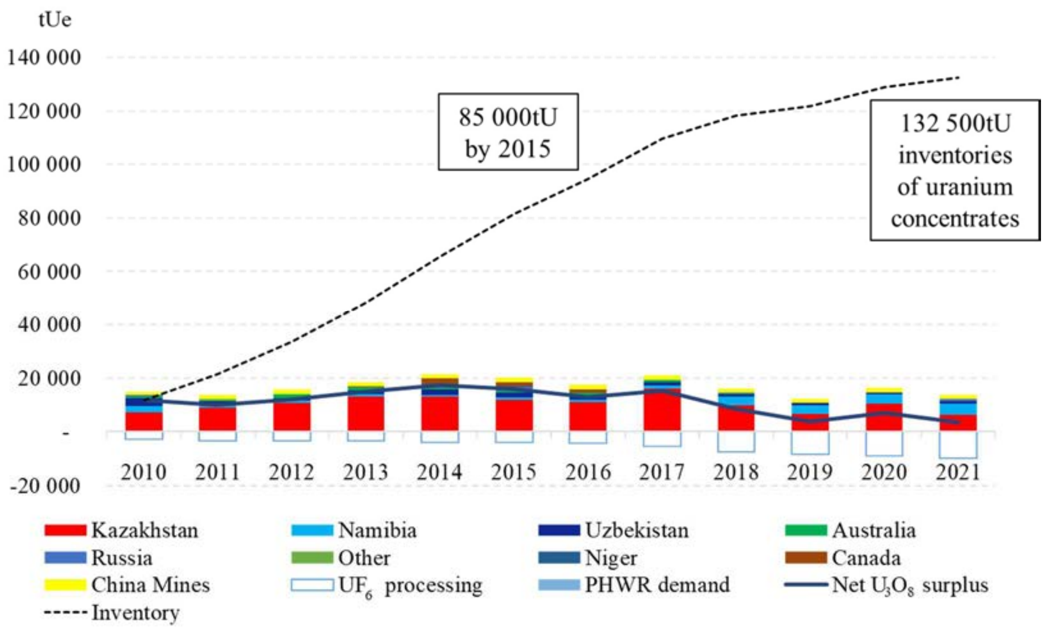


*FIG 15: Estimates of Chinese inventories of $U_3O_8$*

In terms of EUP, initial strategic inventories were believed to have already been in place before 2010. Since then, China has continued to be a net importer of EUP between 2010 and 2021, generating a trade surplus of 1 730tU as EUP. With an estimated demand over the same period of 8 700tU as EUP and domestic production (based on available $UF_6$ supply) of 7 900tU as EUP, the maximum net inventories increase is estimated at 910tEUP. Clearly this represents only a fraction of what is needed to achieve the same level of strategic coverage that is targeted for natural uranium. Consequently, in 2021 there was a call from local enrichment industry management for action to increase the inventory quantities in China, in order to backstop the expansion of domestic processing capacity [70].

Figure 16 illustrates Chinese trade flows in enriched material from 2010 to 2021. It is worth noting that some of the trade is circular, for instance:

— Some exports to the US were for fabrication by Westinghouse Columbia and re-import for the Sanmen/Haiyang AP1000s;
— Until recently Kazatomprom was a destination for Chinese EUP that was pelletised and then reimported by CGN.

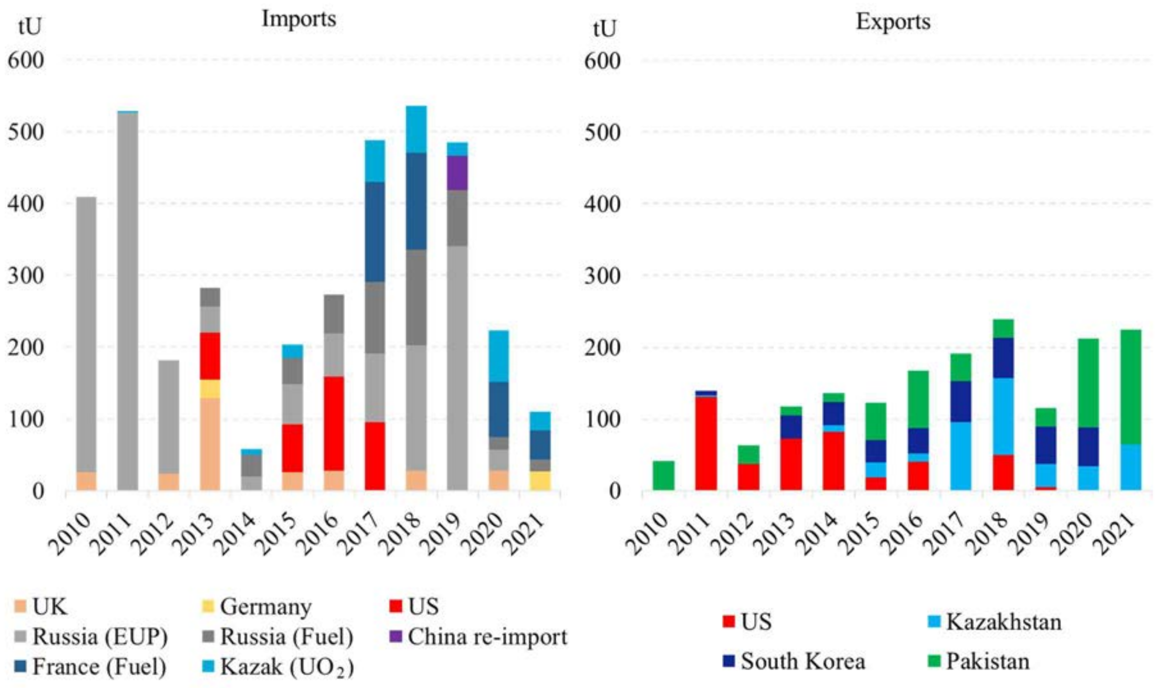


*FIG 16: Chinese trade flows in enriched material*

Insights into fabricated fuel stocks are provided by the two largest nuclear utilities, CNP and CGN. Each makes reference to inventories in their financial accounts, with CNP declaring ¥6.1 billion in nuclear fuel assets at the end of 2021 and CGN's reporting nuclear fuel inventories of ¥8.1 billion (US $940 million and US $1.25 billion respectively). Assuming such inventories are held as fabricated fuel, they could equate to a minimum of 520tU as EUP and 690tU as EUP respectively. However, it is worth noting that first cores add disproportionately to reported inventory levels and also that one third of the first core is often retained as inventory under Chinese accounting rules throughout the first operating cycle. Therefore, and given current demand levels of approx. 600tU of fuel for CNP and approx. 500tU for CGN, these quantities appear likely to be referring to immediate reload demands, rather than a significant strategic inventory. Stocks may therefore be limited to small backup quantities to replace failed fuel at individual stations.

### 11.3.2. India

Historically, reactors operated by Nuclear Power Corporation of India Ltd (NPCIL) have experienced operational availability problems due a shortage of domestically mined uranium and a lack of access to international commercial markets. However, since 2008 when the Nuclear Suppliers Group lifted the sanctions imposed upon India, international suppliers have been able to conclude contracts with the Indian Department of Atomic Energy (DAE) and export uranium to the country's safeguarded reactor fleet. Consequently, uranium required for

PHWRs under IAEA safeguards has been imported from Canada, France, Kazakhstan, and the Russian Federation. Additionally, the enriched fuel requirements of the Tarapur BWRs and Kudankulam VVERs have been fulfilled through imports from Russia (as $UO_2$ pellets and fabricated fuel bundles respectively) in bulk shipments. According to India's government officials, the country has also entered into forward uranium purchase agreements with Canada, Kazakhstan, the Russian Federation and Uzbekistan. India's domestic uranium production is being carried out by the Uranium Corporation of India Limited, a Public Sector Enterprise under the DAE. This material is used for the reactors that are not covered under the IAEA safeguards. Access to global markets has also allowed India to build buffer inventories for its reactors under the Government's strategic policy to guarantee operational availability.

During the period from 2010–2021 India imported approx. 19 900tU and the cumulative inventory change is estimated to be approx. 17 500tU. These estimates of annual and cumulative inventories of natural uranium in India account for domestic mining and imports of EUP, less the uranium consumed, and are shown in Fig. 17.

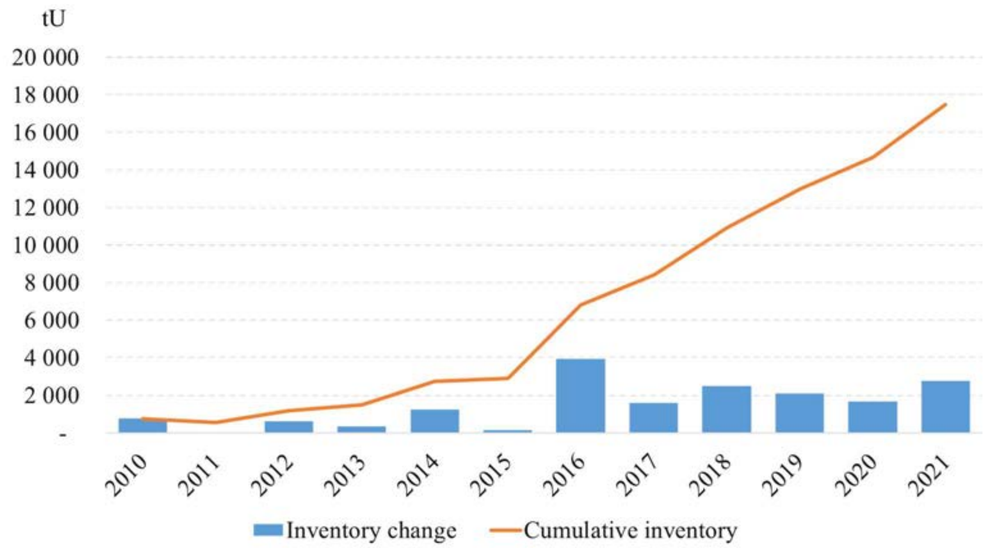


*FIG 17: Indian inventories of natural uranium*

The rise in inventory has largely occurred since 2015 and is in line with DAE targets to build a 15 000tU stockpile to achieve supply security of fuel for its plants. Furthermore, the Indian Government plans to build on this strategic uranium reserve to ensure that there is no shortage of fuel for its expanding fleet. NPCIL is not believed to hold any inventory with respect to nuclear fuel and relies on purchases and inventories accumulated by the DAE [71].

### 11.3.3. Japan

Prior to the accident at the Fukushima Daiichi nuclear power plant, the Japanese government undertook the decision to sponsor the accumulation of a national inventory of 120tU as enriched uranium for the purposes of contributing to the stable supply of international uranium fuel and domestic emergency measures[48]. Some 30tU had been accumulated at Mitsubishi Nuclear Fuel Co., Ltd. by 2015, by which point the programme was curtailed to only 60tU and its

[48] https://www.nikkei.com/article/DGKDASFS15017_V10C11A1MM8000/

implementation suspended as the government had accepted that early restarts were unlikely and inventories were not an urgent priority[49].

The upstream security of supply still largely falls to the Japanese utilities. The Japanese nuclear fleet consists of both PWRs and BWRs, with all but one of the 11 utilities (i.e., JAPC) concentrating on one or other technology. This focus has led to very different inventory policies being pursued by the respective utility groupings; a distinction that has been highlighted by the accident at the Fukushima Daiichi nuclear power plant in 2011.

Following to the accident at the Fukushima Daiichi nuclear power plant and the subsequent stand-down of the entire fleet, domestic holdings of nuclear materials reached site operating limits at GNF-J, MNF and NFI very quickly as reactors stopped accepting fuel. Consequently, upstream international supply chains for uranium, conversion, enrichment and deconversion were also backed-up with partly processed material. For BWR utilities, the quantities affected were largely related to short to medium term deliveries, due to the necessity for relatively near-term planning for bespoke assay BWR reloads. Therefore, surplus inventories were initially low. Meanwhile, standardised assay reloads for PWRs allowed for a much longer supply chain (up to 4–5 years in advance of requirements), so volumes of material held up in the PWR utility's supply chain were high. That said, the suspensions and shutdowns enacted since the accident at the Fukushima Daiichi nuclear power plant have disproportionately impacted BWR utilities (particularly TEPCO and Tohoku), resulting in a large proportion of stranded material both inside and outside of Japan. The result is that inventory values for almost all Japanese utilities have been persistently high.

The Japanese Nuclear Regulatory Authority (NRA) and the Japanese Atomic Energy Commission (JAEC) safeguards declarations for nuclear material holdings inside Japan [72] provide an insight into the current domestic situation. Figure 18 shows that end users have dramatically slowed imports since 2010 to the match reactor operating requirements and the inability to process material. They have consequently achieved a net decrease in domestic inventories of approx. 220tU as EUP. This is in part due to approx. 134tU as EUP of fuel exported for processing (defabrication) and eventual re-use. Irrespective, the NRA declared that the domestic fuel cycle still holds 1 368tU as EUP as WIP. Additionally, the remaining fleet of 33 operable reactors plus those undergoing decommissioning have stocks of fresh fuel equivalent to a further 2 185tU as EUP. This gives a minimum total of some 3 700tU as EUP.

[49] https://judgit.net/projects/4019

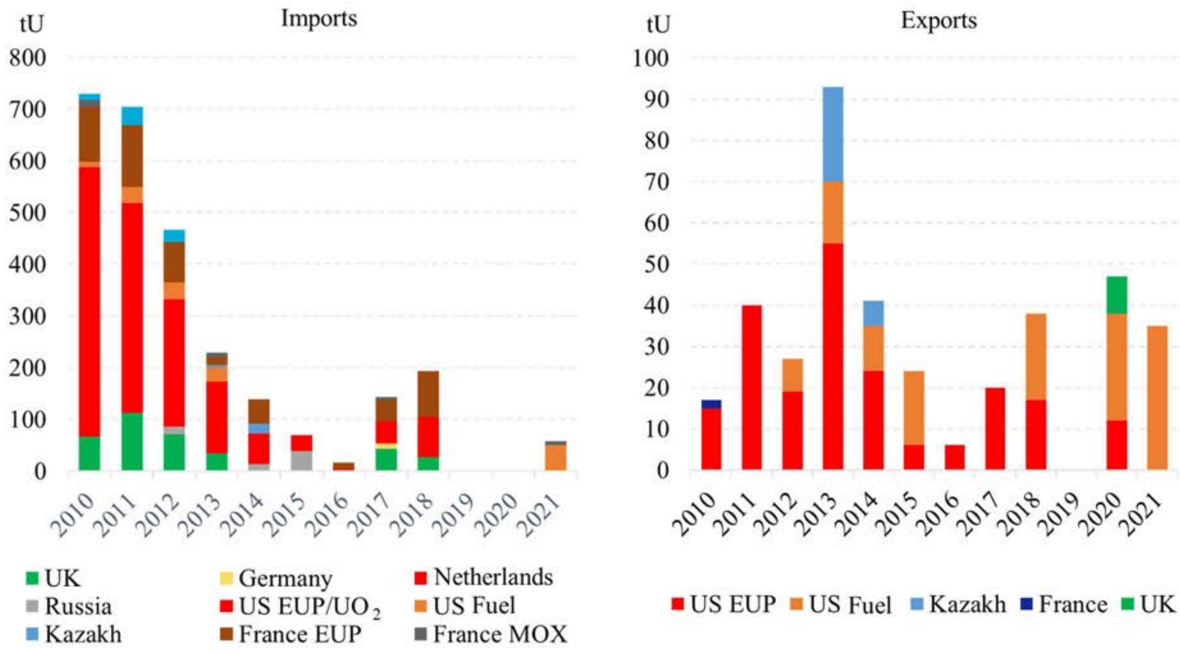


*FIG 18: Japanese trade flows in enriched uranium from 2010–2021*

However, the above statements only reflects a proportion of the global inventories belonging to Japanese entities. Figure 19 demonstrates that in-process inventories remain high. Most utilities continued to add to front end inventories through 2015 due to contractual commitments. Much of the drop since then has been the result of asset write-downs as reactor retirements were announced. Buildups then continued, as few utilities were able to consume fuel due to limited restarts. Third-party sales have occurred [73], but for many they were effectively precluded due to the potential for a recognition of book losses on low mark-to-market values.

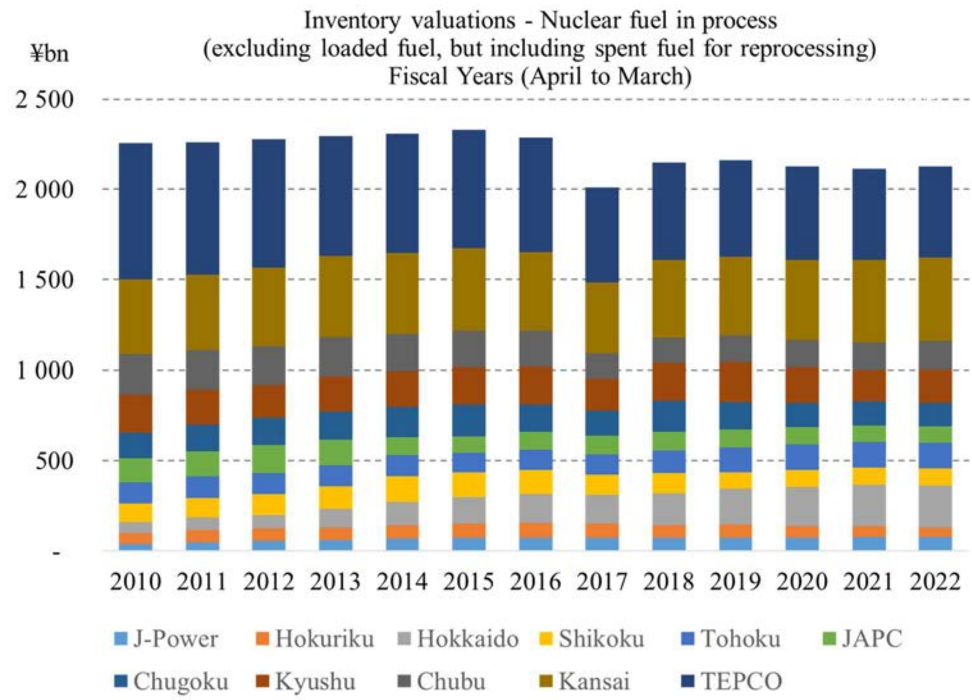


*FIG 19: Japanese utility financial statements on inventories from March 2010–March 2022*

Due to the inclusion of reprocessed material in the above statistics, it is difficult to extract the front end holdings for each utility. Recent pronouncements by the Ministry of Economy, Trade and Industry (METI) and the Federation of Electric Power Companies (FEPC) have indicated that Japanese supply chain inventories excluding the potential ongoing requirements of the operable fleet amount to approx. 2 400tU as EUP and that they could only be drawn down over a protracted period. It implies that approx. 1 000tU as EUP is held outside of Japan (i.e., excluding domestic WIP of 1 368tU as EUP), which may now include the approx. 134tU as EUP material exported for defabrication and re-use. This material is likely held at American and European fabricators, enrichers and converters. It does not however account for large upstream volumes of $UF_6$ and $U_3O_8$ that would likely accompany any portfolio of processing contracts. A gap analysis on the value differences between the aggregated utility statements and NRA/METI declarations points to other front end inventories of up to approx. 38 000tU worth approx. US $7.1 billion, for which there is evidence of quantities approaching 25 000tU in six utility submissions to the NRA. It is presumed that almost all of this front end inventory resides outside of Japan.

### 11.3.4. Republic of Korea

Until 2017, Korea Hydro & Nuclear Power (KHNP) was engaged in a diversified procurement strategy for nuclear fuel that included a policy of building strategic inventories, aligned to its growing nuclear fleet of PWRs and existing PHWRs. This was to ensure enriched and natural uranium supply to the domestic fuel fabricator KEPCO Nuclear Fuel (KNF) at Daejon. However, front-end market surpluses and a change in government policy in 2017 saw the utility end its proactive accumulation of stocks. The premature closure of two nuclear units (Kori 1 and Wolsong 1) and delays in construction of new APR1400 reactors also left KHNP with a significant surplus throughout its supply chain. Nevertheless, KHNP continues to ensure its security of supply through management of supply chain flexibilities, backed-up by various equity interests in uranium mines, a uranium production company and an enrichment plant.

Enriched uranium for KHNP’s 21 PWRs is supplied primarily by Rosatom, Urenco, Orano and (until recently) CNEIC. Natural $U_3O_8/UO_2$ for the three PHWRs has come from Australia, Canada, Kazakhstan and Namibia. Analysis of trade statistics (see Fig. 20) indicates that over the period 2010–2021, from a starting stockpile assumed to be approx. 300tU in 2010, holdings of $U_3O_8$ or $UO_2$ as natural uranium inventories in Korea dipped through 2015, but then recovered to previous levels. Meanwhile, EUP inventories (as $UF_6/UO_2$ or in fabricated fuel) rose during the decade, adding approx. 170tU since 2010 once domestic demand and exports to the United Arab Emirates have been extracted.

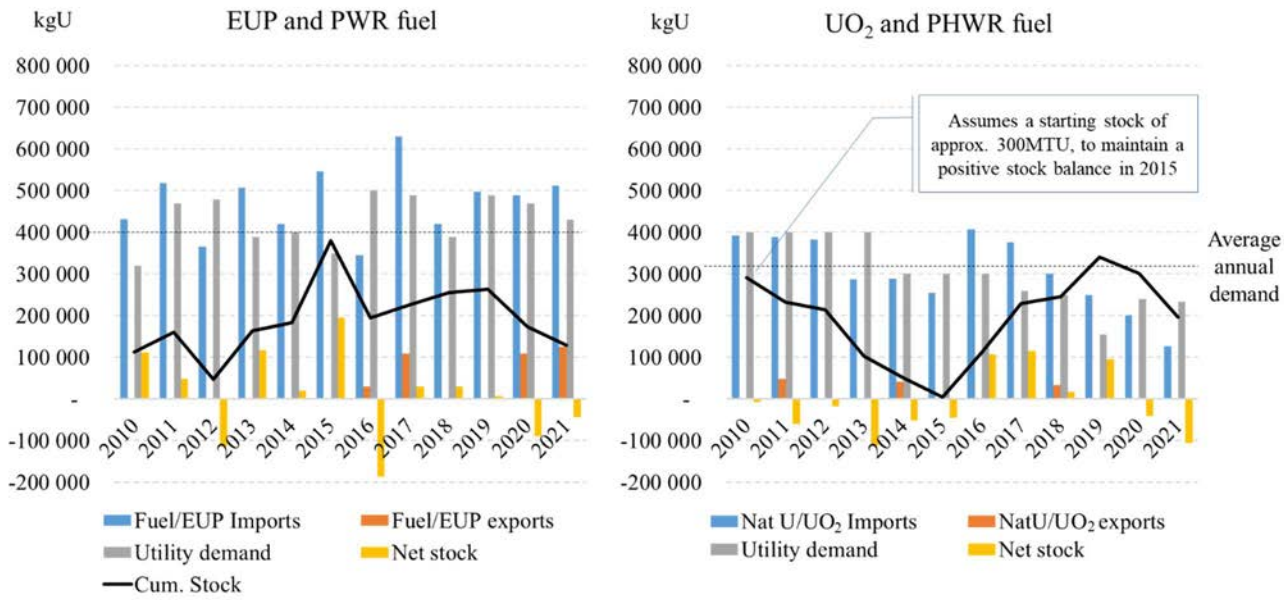


*FIG 20: Korea, Republic of fuel inventory movements by form*

Extracts from KHNP's and KNF's financial reports provides a reasonable indication of total fabricated inventories, albeit not definitively restricted to fresh nuclear fuel. In 2021, KHNP recorded approx. US $2.7 billion in raw materials and supplies plus transfers of nuclear fuel from inventories to stores amounting to approx. US $800 million. A further US $1.8 billion in fabricated fuel is assumed to be loaded and part-burned. Meanwhile, KNF reported approx. US $240 million in inventories, plus fuel in transit.

These combined values equate to between two and three years' worth of reactor requirements, so net of the quantities needed for the next reloads would approach at least one year of strategic inventories as fabricated fuel or EUP. This assessment is supported by recent statements of coverage by the Korea Institute for International Economic Policy (KIEP) [74] and KHNP [75]. As with other utilities, the financial value of supply chain inventories (identified as 'raw materials' and 'supplies yet to be imported') is in line with reactor pipeline/WIP requirements (approx. US $2.7 billion), indicating a PWR nuclear fuel purchasing lead time of 2–3 years which incorporates strategic inventories.

Given the reversal of the nuclear phase-out programme by the new South Korean government, the likelihood is that new units will be approved and the construction of mothballed projects will recommence. If the fuel security policy of KHNP then reverts to its previous approach, the current levels of inventory will be below those desired and the expectation will be for further inventory accumulation.

### 11.3.5. Taiwan, China

Taipower has maintained a strategic inventory of nuclear fuel in line with its government's policy to mitigate supply interruptions. The quantities involved are equivalent to three years' demand for uranium, plus up to one years' demand as fabricated fuel, with the latter held at each operating unit [76]. In addition, Taipower pre-purchased both the Lungmen units 1 and 2

ABWR first cores, which were on site by 2010[50] [77]. However, Lungmen construction was subsequently suspended in 2014. Taipower paid $260 million for the Lungmen fuel, which in total consisted of 1 744 assemblies/318tU as $UO_2$ [78]. Since the Lungmen fuel was by then out of manufacturer warranty, it was progressively repatriated between July 2018 and December 2020 to the original fabricator (GNF-A, Wilmington) at a cost of US $24 million. It was still in storage at the end of 2022.

The nuclear phase-out policy will result in the various surplus quantities being liquidated. It was expected that a managed drawdown of strategic inventories would transpire, in line with expiring operating licenses. However, early reactor closures due to spent fuel storage capacities being reached have resulted in surpluses of fresh fuel. As a consequence, in early 2021, 121 unused assemblies from shutdown units were sent to Framatome Richland for defabrication (containing approx. 21tU)[51]. In its most recent statements (August 2018) Taipower confirmed that it also held stocks at both Kuosheng and Maanshan, totalling approx. 41tU in fabricated fuel and some 4 550tU of natural uranium [79]. These are assumed to have been progressively run down in recent years so that Taipower is left with approx. 2 900tU as uranium and 6tU as fabricated fuel (not including the Lungmen cores).

## 11.4. REGIONAL SUMMARY

Figure 21 shows estimates for natural and enriched uranic inventories in the five nuclear countries in the South and East Asia region. However, there are a number of caveats to be applied for some countries.

For China, whilst uranium inventory estimates match with anecdotal evidence, the presumed EUP inventories accumulated before 2010 are not included. Therefore, the analysis is likely to have underestimated the strategic stock volumes.

In Japan, reported figures only provide clear visibility on domestically located materials. Estimates of quantities, particularly in the case of foreign natural uranium holdings, are made to complete the analysis but introduce a margin of error[52].

Given the inventory accumulation policy pre-2015, starting stockpiles in 2010 were also likely to exist in the Republic of Korea. They have been estimated using financial statements, but aggregation of KHNP's inventory reporting means that the form of inventories between PWR and PHWR supply chains is indeterminate.

The assumed drawdown of fabricated fuel stocks at the remaining operating units since 2018 may have already depleted local reserves in Taiwan, China. Therefore, the potential exists for an overestimate of Taipower inventories, which cannot be corroborated from more recent financial records.

Regardless of these uncertainties, the nuclear fuel cycle suppliers and utilities in the region are considered to hold the largest inventories across the global nuclear fuel cycle, as shown in Fig. 21. Traditionally this would be expected, due to the lack of access to indigenous uranium resources. However, the levels have been exacerbated in recent years due to the premature

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[50] https://lungmen-info.taipower.com.tw/tc/pages.aspx?mid=48
[51] http://portal.sw.nat.gov.tw/APGA/GA30E_LIST
[52] Note that reprocessed materials are not included in Figure 21.

shutdown of operating reactors, or the slower than expected restart or commissioning of new units.

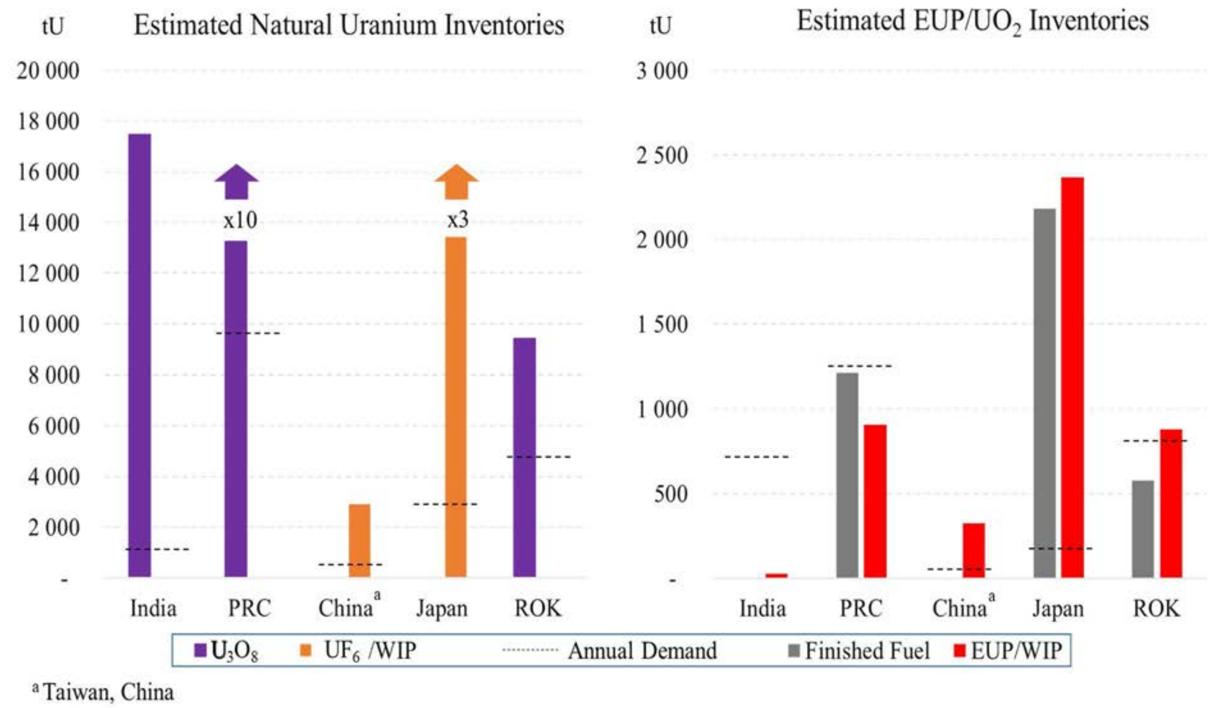


*FIG 21: South and East Asia inventories by form*

In terms of the absolute levels of stockpiles, they represent many multiples of the respective national demand quantities. In China and India, this is due to a national inventory policy. However, for Japan the domestic utilities are faced with over-purchasing under existing contractual commitments at a time when the operable fleet has declined by one-third and the availability of the operating fleet is still low. Meanwhile, in the Republic of Korea and Taiwan, China the national nuclear operators are attempting to adjust stock levels in response to government policies towards nuclear power, albeit that they are now facing differing longer-term outcomes.

## 11.5. SOUTH AND EAST ASIAN INVENTORY LIQUIDITY AND MOBILITY

### 11.5.1. China

The uranic inventories are deemed to be intended for domestic use. However, attempts by CNEIC to expand sales in international markets and the need to ensure supplies for dependent customers (such as in Pakistan) means that some of the uranic material is by definition liquid and mobile. That said, security of supply for the domestic nuclear power sector will inevitably take priority in the event of any supply interruption, so it would be reasonable to assume that the largest share of inventories would backstop the domestic supply chain. A further build-up of WIP and strategic stocks is also likely to represent a significant level of additional demand on the international markets for some years to come, particularly if domestic processing capacity at any stage of the fuel cycle remains at a level below 100% of Chinese utility demand.

### 11.5.2. India

Given the historic circumstances, it is highly unlikely that India will be willing to export its uranium stock, even less so if there is a perceived supply deficit for natural uranium on world markets. That being the case, the stockpile is deemed to be both illiquid and immobile. This is even more applicable to the material destined for NPCIL's unsafeguarded reactors.

### 11.5.3. Japan

The location of materials and end users are important factors when evaluating the liquidity and mobility of Japanese inventories. Firstly, material held in Japan is largely illiquid and immobile, unless there is a defined need to export the material for processing. Even then, the utilities who have so far elected this option intend to re-use the material domestically. Resale has been a last resort for many inventory holders and given that recent geopolitical events have tightened supply to the Western market, this may now be an even less attractive option. Furthermore, much of the identified surplus quantities are believed to have been locked into commercial loan agreements in the intervening 10 years, which may take a reasonable period of time to cease.

That said, certain end users without a confirmed requirement due to decommissioning commitments may elect to liquidate international holdings as market prices recover. It is assumed that BWR operators are in this category, given that recent financial reports have indicated a drop in upstream nuclear fuel inventories.

### 11.5.4. Republic of Korea

The major part of KHNP's inventory is believed to be enriched uranium with a range of assays specific to their reactors. Their inventory, plus those of KNF, are largely dedicated to meeting domestic requirements or to backstop KNF's relatively small export contractual commitments. Therefore, the liquidity and mobility of this stock is relatively low and may become even more so, if renewed expansion of nuclear power is promoted.

### 11.5.5. Taiwan, China

Taipower's residual natural uranium inventories are being drawn down in lieu of new purchases and some of the surplus fuel is being recycled for the remaining three operating units. Strategic stock use for the final reloads at each unit (assuming Kuosheng unit 2 and Maanshan units 1 and 2 still have such stocks in hand) will be completed under the nuclear power phase-outs in 2023 and 2025, respectively. However, Lungmen fuel re-use may be more problematic and protracted. Direct resale is not possible; there are currently no new ABWRs planned where the first core has not already been purchased (and the fuel is out of warranty). Also, defabrication was (prior to 2022) considered uneconomic (at a cost of approx. US $90 million [80]), potentially leading to an asset write-down. The market price recovery seen in 2022 may alter the results of that financial evaluation, but bilateral constraints may still preclude its resale beyond the USA. Any final stocks of natural uranium that remain after the shutdown of the last domestic units will presumably be resold.

In conclusion, from available evidence, the South and East Asia region holds the greatest quantities of inventory material and some stocks are potentially beyond domestic needs to ensure a security of supply. Material from Japan and Taiwan, China could therefore re-enter the commercial market for re-use, if considered commercially attractive to its owners.

# 12. SUMMARY AND CONCLUSIONS

## 12.1. VOLUME AND LOCATION OF SECONDARY SUPPLIES

The global nuclear fuel market is evaluated to hold significant front end inventories, with an aggregated value of almost US $72 billion at the end of 2021, as summarised in Table 16. Gross coverage of demand is shown in terms of months, as well as the coverage period net of one year's worth of demand. This is used to represent WIP for the next reloads at each stage of the fuel cycle, which maintains the integrity of the supply chain. It demonstrates that, while natural uranium volumes exceed annual demands by a number of multiples, the enriched materials and fabricated fuels segments hold insufficient amounts to buffer against a disruption in the immediate supply chain. Furthermore, this research suggests that natural uranium is predominantly held as $U_3O_8$, representing the lowest form in the nuclear fuel processing chain and situated before a bottleneck in the conversion stage of the fuel cycle.

TABLE 16: GLOBAL INVENTORIES SUMMARY

| | **Estimated Value** | **Uranium volumes by form (tU)** | | |
|---|---|---|---|---|
| | **US $ millions** | **Natural** | **Enriched** | **Fabricated** |
| Inventory (tU) | 72 451 | 324 315 | 11 055 | 9 513 |
| 2021 Demand (tU) | 36 249 | 64 076 | 7 472 | 10 281 |
| First cores in hand (tU) | | | | 1 719 |
| Months' Cover | | 61 | 18 | 11 |
| Years' cover (gross) | | 5.1 | 1.5 | 0.9 |
| Years' cover (net WIP/next load) | | 4.1 | 0.5 | 0.0 |

This global picture also hides a spectrum of varying inventory quantities at a regional level, from South and East Asian entities who hold 58% of stocks by value, to South American and African and Middle East countries that hold much lower amounts (<1% each). A mixture of private and government inventories in North America and the application of Euratom edicts for EU-utility stock planning in Western Europe indicate that these regions are somewhat better covered, with 17% and 21% of inventories respectively. However, the relative sizes of those nuclear power markets would contradict that conclusion, in that the inventories are insufficient to cover a significant proportion of their respective needs. In Eurasia, strategic holdings of Russian fuel represent 3% of global inventories, but also signal a dependence upon one supplier due to reactor technology and geopolitical influence. Table 17 breaks down the global uranium inventories by region.

TABLE 17: REGIONAL INVENTORIES SUMMARY

| | Estimated Value | Uranium volumes by form (tU) | | |
|---|---|---|---|---|
| | **US $ millions** | **Natural** | **Enriched** | **Fabricated** |
| Africa and Middle East | 612 | 0 | 5 | 338 |
| Eurasia | 2 043 | 14 943 | 281 | 502 |
| Europe | 14 895 | 50 918 | 3 879 | 2 424 |
| North America | 12 076 | 56 497 | 2 670 | 1 605 |
| South America | 534 | 1 278 | 44 | 346 |
| South and East Asia | 42 290 | 200 679 | 4 176 | 4 297 |
| | 72 451 | 324 315 | 11 055 | 9 513 |

From the research, distinct types of strategic inventory and secondary supply reliance at a regional level have emerged. These are due to a number of factors:

1. The diversity of nuclear fuel purchasing;
2. The local abundance or lack of uranium resources;
3. The proximity of downstream stages of the nuclear fuel processing supply chain;
4. The growth or decline of a country's nuclear power programme;
5. Whether the local industry (supplier or end user) is nationally owned and financed.

These characteristics have played a significant role in forming specific country inventory policies since 2010 (the last time that the fuel cycle approached an equilibrium state that saw the need for proactive strategic inventory management and policy making).

Africa and Middle Eastern utilities have long lead time fuel supply chains, which makes them vulnerable to supply interruptions as shown in Table 18. Without provisioning for strategic reserves, they are effectively procuring fuel on a just-in-time basis.

TABLE 18: AFRICA AND MIDDLE EASTERN INVENTORIES SUMMARY

| | Estimated Value | Uranium volumes by form (tU) | | |
|---|---|---|---|---|
| | **US $ millions** | **Natural** | **Enriched** | **Fabricated** |
| Inventory (tU) | 612 | 0 | 5 | 338 |
| 2021 Demand (tU) | 866 | 1 494 | 216 | 216 |
| First cores in hand (tU) | | | | 190 |
| Months' Cover | | 0 | 0 | 19 |
| Years' cover (gross) | | 0.0 | 0.0 | 1.6 |
| Years' cover (net WIP/next load) | | 0.0 | 0.0 | 0.0 |

Table 19 is a summary of Eurasian uranium inventories. Eurasian utilities are heavily reliant on one fuel cycle supplier, Rosatom's TVEL. For utilities outside of Russia, strategic inventories of finished fuel have been put in place, further backstopped by regional and international fuel banks. Meanwhile the integration of the domestic nuclear fuel and power industries means that Russian stockpiles (where they exist) are governed federally.

TABLE 19: EURASIAN INVENTORIES SUMMARY

| | Estimated Value | Uranium volumes by form (tU) | | |
|---|---|---|---|---|
| | **US $ millions** | **Natural** | **Enriched** | **Fabricated** |
| Inventory (tU) | 2 043 | 14 943 | 281 | 502 |
| 2021 Demand (tU) | 3 194 | 6 333 | 772 | 772 |
| First cores in hand (tU) | | | | 355 |
| Months' Cover | | 28 | 4 | 7 |
| Years' cover (gross) | | 2.4 | 0.4 | 0.6 |
| Years' cover (net WIP/next load) | | 1.4 | 0.0 | 0.0 |

Table 20 presents a summary of European uranium inventories. It reflects that there is a mix of well-stocked State-owned utilities and other utilities who hold reserves due to national regulations: however, few privately held entities have permanent stocks of any significance. As such, inventories are unevenly distributed, both across the region and the supply chain.

TABLE 20: EUROPEAN INVENTORIES SUMMARY

| | Estimated Value | Uranium volumes by form (tU) | | |
|---|---|---|---|---|
| | **US $ millions** | **Natural** | **Enriched** | **Fabricated** |
| Inventory (tU) | 14 895 | 50 918 | 3 879 | 2 424 |
| 2021 Demand (tU) | 9 751 | 17 801 | 2 304 | 2 489 |
| First cores in hand (tU) | | | | 341 |
| Months' Cover | | 34 | 21 | 12 |
| Years' cover (gross) | | 2.9 | 1.7 | 1.0 |
| Years' cover (net WIP/next load) | | 1.9 | 0.7 | 0.0 |

In the USA and Mexico, few private utilities hold material beyond WIP/pipeline and are reliant on supplier's commercial backups and modest Federal reserves. In contrast, Canadian utilities make provisions to a greater extent. Table 21 is a summary of North American inventories.

TABLE 21: NORTH AMERICAN INVENTORIES SUMMARY

| | Estimated Value | Uranium volumes by form (tU) | | |
|---|---|---|---|---|
| | **US $ millions** | **Natural** | **Enriched** | **Fabricated** |
| Inventory (tU) | 12 076 | 56 497 | 2 670 | 1 605 |
| 2021 Demand (tU) | 11 997 | 19 305 | 2 225 | 3 717 |
| First cores in hand (tU) | | | | 169 |
| Months' Cover | | 35 | 14 | 5 |
| Years' cover (gross) | | 2.9 | 1.2 | 0.4 |
| Years' cover (net WIP/next load) | | 1.9 | 0.2 | 0.0 |

In South America, the integrated nature of the fuel cycle industry and utility end users mostly drives a JIT procurement strategy and a policy of limited inventories. Table 22 summarizes the South American inventories.

TABLE 22: SOUTH AMERICAN INVENTORIES SUMMARY

| | Estimated Value | Uranium volumes by form (tU) | | |
|---|---|---|---|---|
| | US $ millions | Natural | Enriched | Fabricated |
| Inventory (tU) | 534 | 1 278 | 44 | 346 |
| 2021 Demand (tU) | 668 | 595 | 75 | 275 |
| First cores in hand (tU) | | | | 0 |
| Months' Cover | | 26 | 7 | 15 |
| Years' cover (gross) | | 2.1 | 0.6 | 1.3 |
| Years' cover (net WIP/next load) | | 1.1 | 0.0 | 0.3 |

Meanwhile, in South and East Asia, Indian and Chinese entities have large national reserves that are a backup to significant domestic nuclear power programmes. The Republic of Korea has followed a similarly approach, albeit interrupted by a nuclear phase-out policy that has only recently been reversed. Meanwhile, in Japan and Taiwan, China, the impacts of 10 years of operational standstill or phase-out of nuclear power has led to purchasing overcommitments and resulted in some of the only genuine surplus stockpiles across the global industry. Table 23 is a summary of these large South and East Asian uranium inventories.

TABLE 23: SOUTH AND EAST ASIAN INVENTORIES SUMMARY

| | Estimated Value | Uranium volumes by form (tU) | | |
|---|---|---|---|---|
| | US $ millions | Natural | Enriched | Fabricated |
| Inventory (tU) | 42 290 | 200 679 | 4 176 | 4 297 |
| 2021 Demand (tU) | 9 774 | 18 548 | 1 880 | 2 812 |
| First cores in hand (tU) | | | | 665 |
| Months' Cover | | 130 | 27 | 18 |
| Years' cover (gross) | | 10.8 | 2.2 | 1.5 |
| Years' cover (net WIP/next load) | | 9.8 | 1.2 | 0.3 |

## 12.2. LIQUIDITY AND MOBILITY OF SECONDARY SUPPLIES

It is evident from the form and regional spread of the estimated inventories that their mobility and liquidity may also not be uniform. Analysis indicates that most inventories have an end user already prescribed, particularly in Western countries. Meanwhile, those countries with available surpluses may find it difficult to readily liquidate their holdings, as any transaction would be a subject to:

- An audit of its financial impact;
- The material form and homogeneity/specification;
- Tangible commercial and operational practicalities (e.g. obligation or origin codes, contractual restrictions, etc.);
- Import and export restrictions;
- National regulatory controls.

For material to be liquid, it needs to be easily transferable (presumably between countries with comprehensive bilateral trade and nuclear regulatory regimes) and in a form that can be readily processed for a different end user. The ability of the nuclear fuel cycle suppliers to disaggregate higher added value material into its component parts for resale is of significant benefit, but certain practical restrictions may still impact the transfer of the material. Similarly, transport swaps and code swaps can facilitate material mobility, providing there are willing counterparties to a transaction.

## 12.3. CONCLUSIONS

Due to the absence of significant liquid inventories in the front end of the nuclear fuel cycle, any policy for strategic fuel management involves prudence and a multi-faceted approach to security of supply. The historical reliance on secondary uranium supplies to supplement the nuclear fuel supply chain is unlikely to continue at the same levels, due to a combination of factors including; potential supply chain deglobalisation, the prospect of renewed inventory building and non-utility (i.e. financial institution) demand. A diversified portfolio of suppliers can only protect the supply chain to a limited degree if a disruption is not localised. Furthermore, the need to have material in higher processed forms to ensure continued operation of a reactor goes beyond holding a limited number of fuel bundles onsite to cover for fuel failures.

There is a spectrum of possible mitigations to guard against supply chain risks; from national reserves of uranic materials to extended fuel cycle lead times and strategically placed material buffers or commercial mechanisms such as loans and flexibilities. The adoption of such measures may well be far more urgent in the current geopolitical environment and regardless may become an emerging trend if the market deglobalizes in the longer term.

To further inform this debate, additional research could potentially improve the analysis of global inventories of secondary uranium supplies. This would include:

- Seeking greater access to northern hemisphere supplier data (particularly disaggregation of consolidated subsidiary information);
- A more comprehensive analysis of locally reported trade statistics, including a more detailed analysis of uranic material types;
- Selectively examining data from before 2010 to establish pre-existing inventories by country;
- Establishing more sophisticated rules for extracting residual values for in-core fuel, spent nuclear fuel and back end reprocessing from financial statistics, thereby providing distinct estimates for nuclear fuel WIP/pipeline inventories;
- Soliciting additional information from regulatory bodies, for example to better ascertain Government policy on inventories and the implementation thereof;
- Recommending to IAEA Member States to provide additional transparency and public access to relevant uranic inventory reporting, including the information provided to the IAEA in Safeguards Declarations or databases such as the Nuclear Material Management and Safeguards System (NMMSS) in the USA.

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## ANNEX: CONTENTS OF THE SUPPLEMENTARY ELECTRONIC FILES

Supplementary electronic excel file with tables of uranic inventories by country and region.

## LIST OF ABBREVIATIONS

| | |
|---|---|
| AECC | Angarsk Electrolysis Chemical Complex |
| AEOI | Atomic Energy Organization of Iran |
| AEP | Atomenergoprom |
| AGR | Advanced Gas-cooled Reactor |
| ANDRA | National Agency for Radioactive Waste Management |
| BWR | Boiling Water Reactor |
| CFE | Comisión Federal de Electricidad |
| CNEIC | China Nuclear Energy Industry Corporation |
| DAE | Department of Atomic Energy |
| DBOT | Down Blending Offering for Tritium |
| EDF | Électricité de France |
| EIA | Energy Information Administration |
| ENEC | Emirates Nuclear Energy Corporation |
| ERU | Enriched Reprocessed Uranium |
| ESA | Euratom Supply Agency |
| EU | European Union |
| EUP | Enriched Uranium Product |
| FBR | Fast Breeder Reactor |
| FIFO | First In First Out |
| HALEU | High Assay Low Enriched Uranium |
| HEU | Highly Enriched Uranium |
| INB | Brazilian Nuclear Industry |
| IUEC | International Uranium Enrichment Centre |
| JAEC | Japan Atomic Energy Commission |
| JIT | Just in time |

| | |
|---|---|
| KHNP | Korea Hydro and Nuclear Power |
| KNF | KEPCO Nuclear Fuel |
| LES | Louisiana Energy Services |
| LEU | Low Enriched Uranium |
| LWGR | Light Water Graphite Reactor |
| LWR | Light Water Reactor |
| MOX | Mixed Oxide |
| NASA | Nucleoeléctrica Argentina SA |
| NEA | Nuclear Energy Agency |
| NEK | Nuklearna elektrarna Krško |
| NFC | Nuclear Fuel Cycle |
| NFP | Nuclear Fuel Plant |
| NPCIL | Nuclear Power Corporation of India Ltd. |
| NPP | Nuclear Power Plant |
| NRA | Nuclear Regulatory Authority |
| OECD | Organisation for Economic Co-operation and Development |
| PAEC | Pakistan Atomic Energy Commission |
| PHWR | Pressurized Heavy Water Reactor |
| PRIS | Power Reactor Information System |
| PWR | Power Water Reactor |
| RepU | Reprocessed Uranium |
| SE | Slovenské Elektrárne |
| SWe | Separative Work equivalent |
| SIU | Slightly Irradiated Uranium |
| SPUT | Sprott Physical Uranium Trust |
| STUK | Finnish Radiation and Nuclear Safety Authority |
| SWU | Separative Work Unit |

| | |
|---|---|
| TENEX | Techsnabexport |
| TVA | Tennessee Valley Authority |
| TVO | Teollisuuden Voima Oyj |
| UAM | Uranium Asset Management |
| US DOE | United States Department of Energy |
| VVER | water-water energetic reactor |
| WIP | Work In Progress |
| WNA | World Nuclear Association |

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### Consultants Meetings

Vienna, Austria: 5–9 July 2021; 18 October –16 December 2021;
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