

# Establishing a High Assay Low Enriched Uranium Infrastructure for Advanced Reactors

Prepared by the Nuclear Energy Institute  
January 2022

## Acknowledgements

This document was developed by the Nuclear Energy Institute. NEI acknowledges and appreciates the contributions of NEI members and other organizations in providing input, reviewing and commenting on the document.

NEI Project Leads: Everett Redmond and Nima Ashkeboussi

## Notice

Neither NEI, nor any of its employees, members, supporting organizations, contractors, or consultants make any warranty, expressed or implied, or assume any legal responsibility for the accuracy or completeness of, or assume any liability for damages resulting from any use of, any information apparatus, methods, or process disclosed in this report or that such may not infringe privately owned rights.

## Executive Summary

The need to rapidly develop and deploy carbon free energy sources has never been greater. Nuclear power, through the operating light water reactor fleet and the deployment of advanced reactors, is poised to be an increasing contributor to carbon free energy in the U.S. and internationally. The United States leads the world in technology innovation with more developers of advanced reactors than any other country. Within the last five years significant legislation supporting the development and deployment of advanced reactors has been enacted: the Nuclear Innovation and Modernization Act, the Nuclear Energy Innovation and Capabilities Act, the Energy Act of 2020 and the Infrastructure Investment and Jobs Act. In addition, Congress established and funded the Advanced Reactor Demonstration Program which now supports two advanced reactor demonstrations to be deployed within seven years and eight other advanced reactor projects. Through these federally supported efforts and numerous privately funded efforts the U.S. industry is working to reclaim its historical role as the leading provider of nuclear reactors and fuel. Doing so will support the rapid expansion of carbon free nuclear energy and better position the U.S. to advance nuclear safety and non-proliferation policies around the world, while ensuring a robust domestic commercial industry for decades to come.

Many advanced reactors, including the majority of the Advanced Reactor Demonstration Program awardees, will require High Assay Low Enriched Uranium (HALEU), and fuel forms very different from those manufactured for the current Light Water Reactors (LWRs). For example, the current generation of LWRs uses fuel enriched to less than 5% uranium-235. In contrast, many advanced non-LWR designs require enrichments between 5% and 20% with most above 10%.

The main challenge with HALEU supply is that establishing a commercial-scale production capability requires tremendous upfront capital investment: more than \$500 million for enrichment and deconversion capacity. Therefore, this capacity will not materialize commercially without a sustained customer base and the advanced reactors that need HALEU cannot be deployed without a supply of fuel. In addition, advanced reactor developers are not able to independently finance the required cost of building this infrastructure. In fact, all global commercial enrichment in operation today was deployed with some level of government funding and/or financing.

Currently it is not possible to purchase HALEU between 10% and 20% from a commercial enricher in the United States. The length of time it takes to establish the funding, obtain the necessary regulatory approvals, and then construct the necessary fuel cycle infrastructure creates special challenges for bringing advanced reactors to market.

Global competition is intensifying to design and build advanced reactors. Establishing a domestic HALEU fuel production capability in the near future is critical to U.S. leadership in this emerging market sector and to advancing vital strategic interests. This white paper is focused on specific actions the U.S. government can take to facilitate the rapid deployment of domestic HALEU enrichment production and the associated transportation and deconversion infrastructure and ensure a supply of HALEU for commercial advanced reactors.

In 2020, the Department of Energy (DOE) selected two companies for awards under the Advanced Reactor Demonstration Program (ARDP) Pathway 1: Advanced Reactor Demonstrations. Both reactor designs require HALEU and can be operational in about seven years. Today, it is estimated that the companies selected for the demonstration pathway will require HALEU for their reactors beginning in 2024 to support fuel fabrication ahead of reactor startup. In addition, one of the companies under

Pathway 2: Risk Reduction for Future Demonstrations will require HALEU in the 2024-2025 timeframe and other companies in Pathway 2 and 3 of the ARDP will also require HALEU. Privately funded companies are also working to deploy HALEU fueled reactors by the mid-2020s. These projects emphasize the urgency of demand for HALEU. Unfortunately, it is virtually impossible for HALEU to be provided to these companies in the needed quantities and timeframes from DOE inventories or commercial enrichers located in the U.S or Western Europe. Therefore, acquiring HALEU from other international suppliers will be required in the near term to support the larger goal of deploying advanced reactors in the U.S. in a timely manner. Deploying these reactors before 2030 will support climate goals and position the U.S. to be a strong exporter of advanced reactor technology. A robust domestic HALEU infrastructure is necessary to support both the domestic deployment of advanced reactors and the export of U.S. advanced reactor technologies requiring HALEU.

The following recommendations would support the rapid establishment of a robust domestic HALEU fuel supply chain and the demonstration of advanced reactors before 2030.

- DOE should expeditiously establish the Advanced Nuclear Fuel Availability Program as authorized in the Energy Act of 2020 and immediately begin the funding opportunity or request for proposal process while expediting any required environmental reviews so that the deployment of HALEU infrastructure can begin without delay. Congress should fund DOE at a level of \$200 million a year to execute this program.
- DOE should incentivize the licensing, construction, and deployment of two commercial HALEU enrichment facilities in the U.S., through a competitive procurement process, with the first facility to be operational by 2027 and the second one soon thereafter. Each facility should be able to produce a minimum of 10 metric-tons of HALEU per year at competitive prices. DOE could accomplish this through cost-sharing private-public partnerships or by directly contracting for a bank of HALEU through multi-year contracts or by guaranteeing contract performance by HALEU customers.
- The DOE and other government agencies should not impede the acquisition of HALEU by industry from international suppliers within the framework of existing trade agreements. In addition, DOE should consider assisting with transportation and storage of HALEU. Some of the advanced reactor projects under way will be delayed without access to the international market which will endanger climate goals and U.S. competitiveness in nuclear energy.
- DOE should support and incentivize the development and deployment of deconversion facilities to be operational when the enrichment facilities are operational.
- DOE should support the certification and manufacturing of new shipping packages for the safe transport of: uranium hexafluoride with enrichments from 5% to less than 20% uranium-235, deconverted HALEU forms (e.g., oxide or metal) in commercial quantities, and the manufactured fuel being transported from the fabricator to the reactor site.
- The processing of EBR-II fuel should continue and be expedited to ensure that it is available when needed. Before processing of additional DOE stocks is pursued, DOE should determine if that approach is the best utilization of limited funding towards the goal of establishing a domestic commercial enrichment capability.

## Table of Contents

1	Introduction .....	1
2	HALEU Infrastructure in the United States .....	2
2.1	Enrichment.....	2
2.2	Enrichment Licensing.....	3
2.3	Deconversion .....	4
2.4	Transportation .....	4
2.5	Summary of HALEU Infrastructure Needs .....	4
3	International HALEU Supply.....	5
4	Fabrication of Reactor Fuel Utilizing HALEU.....	5
5	Industry HALEU Needs .....	5
6	Alternate Sources of HALEU from DOE.....	6
6.1	Stocks currently being processed .....	6
6.2	Near-term stocks .....	6
6.3	Longer-term stocks .....	6
6.4	Summary.....	7
7	Legislation .....	7
7.1	Implementation .....	8
8	Projected Timelines .....	9
8.1	Industry.....	9
8.2	Enrichment Capacity in the United States.....	10
8.3	HALEU from DOE.....	10
9	Conclusion and Recommendations .....	12
10	Definitions.....	13
11	References .....	13

## 1 INTRODUCTION

The need to rapidly develop and deploy carbon free energy sources has never been greater. Nuclear power, through the operating light water reactor fleet and the deployment of advanced reactors, is poised to be an increasing contributor to carbon free energy in the U.S. and internationally. The United States leads the world in technology innovation with more developers of advanced reactors than any other country. Within the last five years significant legislation that supports the development and deployment of advanced reactors has been enacted: the Nuclear Innovation and Modernization Act, the Nuclear Energy Innovation and Capabilities Act, the Energy Act of 2020 and the Infrastructure Investment and Jobs Act. In addition, Congress established and funded the Advanced Reactor Demonstration Program which now supports two advanced reactor demonstrations to be deployed within seven years and eight other advanced reactor projects. Through these federally supported efforts and numerous privately funded efforts the U.S. industry is working to reclaim its historical role as the leading provider of nuclear reactors and fuel. Doing so will support the rapid expansion of carbon free nuclear energy and better position the U.S. to advance nuclear safety and non-proliferation policies around the world, while ensuring a robust domestic commercial industry for decades to come.

Many advanced reactors will require HALEU and fuel forms very different from those manufactured for the current LWRs. In addition, many advanced fuels now being designed for the existing LWR fleet will utilize enrichments slightly above 5% with some advanced fuels requiring enrichment above 10%.

Currently, it is not possible to purchase HALEU between 10% and 20% from a commercial enricher in the United States or Western Europe. Therefore, acquiring HALEU from other international suppliers will be required in the near term to support the larger goal of deploying advanced reactors in the U.S. in a timely manner. The main challenge with developing the domestic HALEU supply chain is market risk. The commercial industry will not finance the enrichment capacity without a substantial market for HALEU fuel, e.g., a significant number of firm contracts for HALEU or a substantial number of advanced reactors under construction or firm commitments to build them. Unfortunately, that well developed customer base does not currently exist. The length of time it takes to establish the funding, obtain the necessary regulatory approvals, and then construct the necessary fuel cycle infrastructure creates special timing challenges for bringing advanced reactors to market.

It is of strategic importance for the United States to develop, deploy, and export reactor technology. U.S. nuclear suppliers give the nation a stronger voice on nuclear safety and nonproliferation issues and the opportunity to forge long-term strategic and commercial relationships with other nations. In the absence of U.S. nuclear suppliers, other nations who are aggressively competing to win long-term supply contracts will dominate the market. U.S. advanced reactor companies that utilize HALEU currently find themselves at a disadvantage when exporting their technology because the U.S. is unable to ensure a supply of HALEU for U.S. based designs. Meeting this challenge will require government support for deploying domestic HALEU fuel cycle infrastructure in order to provide the required fuel for those advanced reactor technologies.

In 2018 NEI issued the white paper, “Addressing the Challenges with Establishing the Infrastructure for the Front-End of the Fuel Cycle for Advanced Reactors.”<sup>1</sup> This 2018 paper provided descriptive background information on enrichment technologies, which is not repeated here, and also provided recommendations related to a few regulatory issues: safeguards, security, and criticality benchmarks.

---

<sup>1</sup> Reference 1

Since that paper was issued the industry has addressed safeguards and security with the Nuclear Regulatory Commission (NRC) on a case-by-case basis and is proceeding ahead with pre-application interactions and licensing activities for fuel fabrication facilities. In addition, the industry has determined that additional criticality benchmark data is not essential for licensing activities. However, additional data would be beneficial to reduce conservatism in designs.

This document is focused on specific actions the U.S. government can take to facilitate the rapid establishment of a robust domestic HALEU fuel supply chain (enrichment, deconversion and transportation), ensure a supply of HALEU for commercial advanced reactors, and support the demonstration of advanced reactors before 2030. This document does not address the HALEU needs of DOE for research reactors, medical isotopes, space applications, or defense related needs or the potential synergies between DOE's HALEU needs and the commercial industry's HALEU needs.

## 2 HALEU INFRASTRUCTURE IN THE UNITED STATES

In the U.S., the infrastructure for the front-end of the fuel cycle for the utilization of low enriched uranium up to 5% U-235 is well defined. The U.S. has mining, conversion, enrichment, fabrication, and transportation capability. However, the infrastructure for producing and utilizing HALEU, in particular enrichments above 10%, is not established in the U.S. The mining and conversion infrastructure are common to all enrichment levels. The areas of focus for HALEU are enrichment, transportation and deconversion.

### 2.1 Enrichment

Enrichers in the United States do not currently produce HALEU, although a demonstration plant is under construction in Ohio and should begin producing a limited amount of HALEU in 2022. A capability to produce significant quantities of HALEU in the U.S. will not likely be available before 2027, contingent upon level and timing of investment and/or placement of long-term orders, as discussed in Section 8. As a result, acquiring HALEU from international suppliers will be required in the near term to support the larger goal of deploying advanced reactors in the U.S. in a timely manner. The issue for deploying HALEU enrichment capability in the U.S. is not the technology; it is a financial challenge. Any of the enrichment technologies, centrifuge or laser enrichment, can produce HALEU. It is a matter of installing new equipment configured specifically to produce HALEU, an upgraded security profile, and an amended (or new) NRC license. The main challenge in establishing this capability is market risk. The commercial industry will not finance the enrichment capacity without a substantial market for HALEU fuel, e.g., a significant number of firm contracts for HALEU or a substantial number of advanced reactors under construction or firm commitments to build them. Unfortunately, that well developed customer base does not currently exist and is unlikely to manifest without assurances that fuel will be available when needed and for as long as it is needed.

In the longer-term the desired supply option is HALEU enrichment capability within the U.S. in addition to international suppliers thereby providing diversity of supply which the commercial industry requires. This could be provided by a current enricher or a new enricher. Having two enrichers in the U.S. supplying HALEU would reduce supply chain risk, reduce costs through competition and offers the opportunity to deploy innovative technologies. This will also enable the United States to increase its leadership role in advanced reactors and compete with Russian and Chinese State-Owned Enterprises (SOE) as a global HALEU supplier. In all cases, investment will be necessary to build out the capacity and

infrastructure and it is unlikely that the enrichers will make that investment without long-term orders, either from the commercial sector or the DOE, and/or other government financial assistance.

The following is a brief overview for the four HALEU enrichment options in the U.S.

### URENCO

The URENCO LES facility in Eunice, New Mexico is currently the only operating enrichment facility in the United States and is licensed to produce 5.5% enriched uranium. URENCO is currently engaging in pre-application activities with the NRC to increase their enrichment limits to 10% enriched uranium. URENCO utilizes centrifuge technology. URENCO has stated that capacity could be brought online after securing the necessary funding and/or offtake commitments.

### Centrus

Under a 2019 contract with the DOE's Office of Nuclear Energy, Centrus is constructing a cascade of sixteen AC100M centrifuges to demonstrate production of HALEU in Piketon, Ohio. This demonstration project is a three year, \$115 million, cost-shared contract that runs through mid-2022. Centrus is currently the only enricher in the U.S. licensed to enrich HALEU up to a 20% enrichment level. The demonstration project will produce less than 1 MTU of HALEU before it concludes in 2022 but could be expanded modularly in the future. Centrus has stated that the next 12 MTU/yr capacity could be brought online within four years of securing the necessary funding and/or offtake commitments, and that it could bring at least 12 MTU of additional capacity online each year after that, subject to market conditions.

### GLE

Global Laser Enrichment in Wilmington, NC has an NRC license for an enrichment facility using laser enrichment technology. NRC issued a license amendment in May 2008 for a test loop. A full-scale facility was licensed in September 2012, but at present it is not being built due to market conditions.

### Orano (previously AREVA)

AREVA Enrichment Services submitted a license application to the NRC in December 2008 and a license was issued in October 2011. In 2017, AREVA requested that NRC terminate the license for the Eagle Rock Enrichment Facility due to market conditions.

## **2.2 Enrichment Licensing**

The NRC licensing process for a new enrichment facility is expected to take 24-36 months. Obtaining regulatory approval to modify an existing license to enrich uranium to HALEU levels would be expected to take 18-24 months and require an environmental review. The most significant factor affecting the licensing of a HALEU enrichment facility – regardless of the technology used – would be the criticality safety aspects of increasing enrichment up to 20%. Licensing facilities for enrichment to that level would not require revisions or changes to the existing regulations.

## 2.3 Deconversion

For today's LWR reactor fleet, fuel fabricators receive  $UF_6$  and convert it to uranium oxide and then fabricate it into pellets and fuel assemblies. Many of the advanced reactor designs will utilize different fuel forms: TRISO, metallic, and salts. As a result, many of the advanced reactor fuel fabricators do not plan to receive  $UF_6$  but would prefer to receive uranium metal or oxide for fuel fabrication. Enrichers in the U.S. currently only produce enriched  $UF_6$  and are not set up to deliver the other forms of enriched uranium that the advanced reactor market desires. To produce the desired product, uranium metal or oxide, will require the deployment of commercial deconversion capabilities in the U.S. Deconversion capabilities must be deployed concurrently with HALEU enrichment capacity and could be co-located with an enricher, combined with a fabrication facility, or deployed as a stand-alone facility. A deconversion facility will also have to be licensed by the NRC. The main challenges to deployment of a deconversion capability are scaling up conversion processes and market risk. The commercial industry will not finance the deconversion capacity without a substantial market for HALEU fuel.

## 2.4 Transportation

Currently, 5% enriched  $UF_6$  is transported from the enrichers to the fuel fabricators using the 30B cylinder. However, the existing 30B cannot be relicensed for enrichments up to 20%. New transport packages for shipping  $UF_6$  in commercial quantities up to 20% are being developed and Orano submitted a license application to the NRC in June of 2021 for a modified 30B cylinder, DN30-X, that can accommodate either enrichments up to 10% or up to 20%. These packages, if approved, are expected to be commercially available by early 2024. These new package designs utilize burnable absorber rods to address criticality control issues. As a result, the capacity is reduced. A standard 30B cylinder can accommodate 2,277 kg of  $UF_6$  at 5%. The DN30-X is expected to accommodate 1,460 kg of  $UF_6$  at 10% and 1,271 kg of  $UF_6$  at 20%.

Packages for shipment of uranium metal and uranium oxide are available but these packages have limited capacity compared to the 30B cylinder. Three available packages are:

- The ES-3100, owned by the National Nuclear Security Administration, has a capacity of approximately 35 kg uranium metal or approximately 18 kg of oxide enriched to 20% U-235 and greater.
- The TN-BGC1 has a capacity of 40 kg of uranium metal or oxide enriched up to 20% U-235.
- The Versa-Pac VP-55 has a capacity of 1.215 kg of uranium metal or oxide enriched up to 20% U-235.

## 2.5 Summary of HALEU Infrastructure Needs

The following summarizes the infrastructure needs in the U.S. to support HALEU production.

1. Enrichment facilities capable of producing HALEU up to 20% U-235.
2. Deconversion facilities capable of converting  $UF_6$  enriched up to 20% U-235 to either uranium metal or oxide.

3. UF<sub>6</sub> transportation packages for enrichments up to 20% U-235. Orano is currently licensing a package with the NRC.
4. Transportation packages for uranium metal and oxide that can ship 100's of kilograms of material per package.

### 3 INTERNATIONAL HALEU SUPPLY

The market supply for uranium enriched below 5% is diverse with the U.S. LWR reactor fleet purchasing LEU from several international suppliers, including about 20% of their LEU needs from TENEX in Russia. HALEU can also be purchased today in the international marketplace from TENEX in Russia. TENEX has stated that it can readily increase capacity and can provide HALEU in either metal or oxide form as desired by the purchaser.

The quantity of enriched uranium, including HALEU, that can be imported from Russia is limited by the U.S. Government under the Russia Suspension Agreement (RSA), which was codified in the Energy Act of 2020. However, the RSA does provide an exemption from the import limits for initial cores and allows for exemptions if there is insufficient supply to meet U.S. demand.

To import Russian HALEU, the industry will have to identify transportation packages (discussed above) and storage facilities in the U.S. or Canada. HALEU is an NRC Category II material and will require special security measures for storage. The DOE is in a unique position to assist with this effort. The DOE complex has transportation packages that can be used, until commercially sized packages are licensed, to ship HALEU in uranium metal and oxide form. Additionally, the DOE complex has storage capacity that could be used until such time as the industry begins fuel fabrication.

### 4 FABRICATION OF REACTOR FUEL UTILIZING HALEU

Reactor fuel containing low-enriched uranium is fabricated at three U.S. facilities that sell to the commercial LWR community world-wide. There are also two U.S. facilities licensed to fabricate highly enriched fuel from existing HEU inventories, primarily for the U.S. defense industry. These two facilities also produced fuel for reactors requiring greater than 5% uranium-235 (e.g., test, medical isotope, and research reactors).

At least three advanced reactor companies will be pursuing NRC licensing of fuel fabrication facilities to support production of fuel for their reactors. These facilities will utilize HALEU and will be licensed as an NRC Category-II facility. All three fabricators prefer to receive HALEU in either metal or oxide form depending on their specific processes.

### 5 INDUSTRY HALEU NEEDS

NEI has surveyed the HALEU requirements for the U.S advanced reactor industry for U.S. and Canadian deployments. The information has been provided via letters to DOE in 2018<sup>2</sup>, 2020<sup>3</sup>, and 2021<sup>4</sup>. These letters can be found on NEI's website with links provided in the reference section. It is estimated that approximately 20 MTU of HALEU will be needed between 2024 and 2027 for the first reactor cores to

---

<sup>2</sup> Reference 2

<sup>3</sup> Reference 3

<sup>4</sup> Reference 4

support the projects in the U.S. that have publicly announced a site for their reactor. Additionally, approximately 6 MTU annually will be needed beginning around 2028 to support reloads for these reactors. These quantities are only for reactor projects that have publicly announced a site; the total amount of HALEU needed to support future projects is considerably higher. The December 2021 NEI letter to Secretary Granholm estimated that the cumulative HALEU need by 2026 will be 125 MTU and 700 MTU by 2030.

## 6 ALTERNATE SOURCES OF HALEU FROM DOE

### 6.1 Stocks currently being processed

DOE, at INL, is currently processing spent Experimental Breeder Reactor-II (EBR-II) driver fuel to recover high enriched uranium and downblend it to just under 20% enrichment. This material is ideally suited for use in fast spectrum reactors. For thermal spectrum reactor applications, the material will require further polishing to remove radiological and elemental contaminants. This material is currently available through DOE and is limited to use at the INL site. At least one advanced reactor company was awarded access to this material in 2020. A total of approximate 10 MTU of 19.75%<sup>5</sup> enriched will be available from EBR-II with approximately 5 MTU available by 2025 and the remainder available by 2028.

### 6.2 Near-term stocks

Savannah River Site (SRS) currently has high enriched uranium solution in storage from the processing of spent research reactor fuels. This solution could be processed to produce approximately 2 MT of HALEU at 19.75% enrichment.<sup>6</sup>

In addition to the material at SRS, there is other HEU material that could be processed to produce approximately 1-2 MTU of HALEU at 19.75%.

Neither one of these efforts is currently funded and once funded NEI estimates it would take approximately 2 years before HALEU would start becoming available at a rate of about 1-2 MT per year.

### 6.3 Longer-term stocks

Research reactor used fuel (e.g., High-Flux Isotope Reactor, university research reactors, Advanced Test Reactor) could be processed and the HEU recovered and downblended. Processing spent fuel located at the Savannah River Site could yield approximately 19 MTU of 19.75% enriched HALEU<sup>7</sup> and Advanced Test Reactor spent fuel at INL could provide an additional 20 MTU of 19.75% enriched HALEU.<sup>8</sup>

The processing of this additional spent fuel would require future funding from Congress and if sufficient funding is provided it would take several years before HALEU would be produced at a rate of approximately 1-1.5 MTU/yr at SRS<sup>9</sup> and about 1 MTU/yr at INL.<sup>10</sup>

---

<sup>5</sup> Reference 5

<sup>6</sup> Reference 6

<sup>7</sup> Reference 6

<sup>8</sup> Reference 5

<sup>9</sup> Reference 6

<sup>10</sup> Reference 5

## 6.4 Summary

Downblended and reprocessed stocks from the DOE may be potentially useful for some projects. However, because they are inherently finite, they do not provide the long-term fuel supply assurance that utilities will require. Only HALEU enrichment capability can provide that assurance. Therefore, these short-term options should not come at the expense of an aggressive effort to deploy domestic HALEU enrichment, and DOE should take care that downblended or reprocessed stocks do not effectively displace or delay commercial HALEU enrichment capacity, to the detriment of the entire industry.

The finite quantities available from processing DOE spent fuel inventories will be subject to the uncertainties of annual appropriations and in any event will not be sufficient to address the first core and reload needs of the advanced reactor projects currently underway and therefore will not obviate the need for some companies to purchase HALEU in the international market until the domestic market provides HALEU. In addition, processing this material may be more expensive than purchasing HALEU from the international market and will do little to encourage the establishment of domestic enrichment market.

HALEU derived from previously irradiated fuel is expected to contain some impurities that may make it unsuitable for a particular reactor design or fuel fabrication facility. If the DOE chooses to process this material, the isotopic specification for the resulting HALEU should be reviewed with the customers/developers to determine if the material will be acceptable for use in their fuel fabrication facilities and reactors. Depending on the impurities in the HALEU, a fuel fabrication facility may have to utilize alternate procedures for handling and disposal that would increase fabrication costs and there may be a performance penalty in the reactor.

The processing of EBR-II fuel should continue and be expedited to ensure that it is available when needed for the company that plans to use it. Before processing additional DOE stocks, DOE should determine if that approach is the best utilization of limited funding given that the ultimate goal is to establish a domestic commercial enrichment capability.

## 7 LEGISLATION

In December 2020, the Energy Act of 2020 was enacted. This law contains an “Advanced Nuclear Fuel Availability” section that instructs DOE to establish a HALEU program with the following provisions:

- DOE shall develop, in consultation with the NRC, criticality benchmark data to assist the Commission in the licensing and regulation of fuel and enrichment facilities
- By January 1, 2024, DOE shall support commercial submission of HALEU transportation package designs to the NRC
- DOE shall consider options for acquiring or providing HALEU from a stockpile of uranium owned by the Department or using enrichment technology. Potential sources include:
  - High-enriched uranium that is downblended to become HALEU
  - HALEU that is produced by DOE research, development, and demonstration activities

- HALEU that is produced in the United States by either 1) a United States-owned commercial entity operating United States-origin technology; 2) a United States-owned commercial entity operating a foreign-origin technology; or 3) a foreign-owned entity operating a foreign-origin technology
- Not later than 1 year after the date of enactment of this Act, and biennially thereafter, DOE shall conduct a survey of stakeholders to estimate the quantity of HALEU necessary for domestic commercial use for each of the 5 subsequent years
- DOE shall establish a consortium with entities in all parts of fuel cycle
- Not later than 3 years after consortium is formed DOE shall have the capability to acquire or provide HALEU in order to make such HALEU available to members of the consortium beginning not later than January 1, 2026
- The program shall expire on the earlier of a) September 30, 2034; or b) 90 days after the date on which HALEU is available to provide a reliable and adequate supply for civilian domestic advanced nuclear reactors in the commercial market

## 7.1 Implementation

The Energy Act of 2020, enacted in December of 2020, authorized the Advanced Nuclear Fuel Availability Program. However, funding to implement this program was not provided in Fiscal Year 2021. Therefore, the earliest that DOE will begin this program is in Fiscal Year 2022. Execution of the provisions related to acquiring and providing HALEU will require long term stable funding from Congress.

DOE could accomplish the goals of the Advanced Nuclear Fuel Availability Program through several different mechanisms discussed below.

- DOE could incentivize the licensing, construction, and deployment of two enrichment facilities in the U.S. through a competitive procurement process to acquire a specified amount of HALEU per year through multi-year contracts. The first facility should be operational by 2027 and the second one soon thereafter. Each facility should produce a minimum of 10 metric-tons of HALEU per year at competitive prices. The HALEU purchased by the government could be used by DOE (e.g., to fuel research and test reactors) and serve as a “bank” of HALEU to be sold to the industry when needed. To minimize the government’s role as a HALEU provider for the industry, DOE could reduce its offtake from its contracts with enrichers if the industry purchases directly from the enricher. If industry demand exceeds enrichment capacity in a particular year, DOE could sell some of the HALEU it acquired in previous years to the industry. This “bank concept” differs from the concept of a “strategic reserve” because in the latter case the HALEU would be stockpiled until some event occurs (e.g., supply disruption) requiring the release of the material to stabilize the market. In the “bank concept,” DOE would provide the HALEU it acquires as soon as the market requests it and at the end of the program DOE could either liquidate its stocks of HALEU to the industry or preserve them for ultimate use by DOE for its own purposes (e.g., research reactor use, medical isotope production). DOE’s market pull, added with the market signal from early movers, like the two DOE Advanced Reactor Demonstration Project (ARDP) awardees, should provide a sufficient demand signal to accelerate an investment decision for commercial enrichers.

- DOE could incentivize the licensing, construction, and deployment of two enrichment facilities in the U.S. through a competitive process to award cost-sharing private-public partnerships that support the deployment of two enrichment facilities in the U.S. with the first facility to be operational by 2027 and the second one soon thereafter. Each facility should produce a minimum of 10 metric-tons of HALEU per year at competitive prices.
- DOE could incentivize the licensing, construction, and deployment of enrichment facilities in the U.S. by guaranteeing the performance of long-term contracts by customers of HALEU facilities.
- In addition to enrichment facilities, DOE should incentivize the licensing, construction, and deployment of deconversion facilities and transportation packages. The deconversion facilities should be operational when the enrichment facilities are operational.

Sustained annual appropriations will be required for these activities. However, it is expected that a large portion of the appropriated money will be returned to the treasury, or reinvested in the program, if DOE procures HALEU and it is sold back to the industry.

## 8 PROJECTED TIMELINES

Figure 1 depicts the timelines for a portion of the industry needs and projects, potential deployment of enrichment capacity in the U.S. supported by DOE investment, and potential supply of DOE-supplied HALEU. A description of each timeline is provided below. Comparing the timelines indicates that it is virtually impossible for HALEU to be provided in the needed quantities and timeframe from sources within the U.S. to support the advanced reactor community. Therefore, acquiring HALEU from international suppliers will be required in the near term to support the deployment of advanced reactors in the U.S. in a timely manner. In parallel, the government should expeditiously establish the Advanced Nuclear Fuel Availability Program to support the development of deployment of HALEU enrichment capacity in the U.S.

### 8.1 Industry

Industry will need increasing amounts of HALEU annually for projects both in the U.S. and outside the U.S. It is estimated that approximately 20 MTU of HALEU will be needed between 2024 and 2027 for the first reactor cores to support the projects in the U.S. that have publicly announced a site for their reactor (not including the reactor that will use EBR-II processed fuel). Additionally, approximately 6 MTU annually will be needed beginning around 2028 to support reloads for these reactors. Fuel fabrication must begin about 2 years before the fuel is to be loaded into the reactor.

In addition to the projects in the U.S., there are U.S. companies deploying advanced reactors in Canada that will also need HALEU. For these projects HALEU will be needed between 2022 and 2028. The quantities mentioned above are only for reactor projects in the U.S. that have publicly announced a site, the total amount of HALEU needed to support future projects domestically and internationally is considerably higher. The December 2021 NEI letter to Secretary Granholm estimated that the cumulative HALEU need by 2026 will be 125 MTU and 700 MTU by 2030.

## 8.2 Enrichment Capacity in the United States

The main challenge to deployment of HALEU enrichment capacity in the U.S. is market risk. The commercial industry will not finance the enrichment capacity without a substantial market for HALEU fuel, e.g., a significant number of firm contracts for HALEU or a substantial number of advanced reactors under construction or firm commitments to build them. Currently, that well-developed customer base does not exist. DOE actions, under the Advanced Nuclear Fuel Availability Program, can help jumpstart the domestic market as previously discussed. Initial congressional funding for this program is expected in Fiscal Year 2022. DOE must move expeditiously to implement this program and expedite any required environmental reviews. The DOE Office of Nuclear Energy should use the Advanced Reactor Demonstration program as a model: the program was created by Congress in the FY 2020 appropriations bill enacted in December 2019, DOE issued a funding opportunity announcement in May 2020, announced the Pathway 1 demonstration awards in October 2020, and the Pathway 2 and 3 awards in December 2020. A similar sense of urgency is required to develop a domestic HALEU infrastructure. It will take approximately four years from the time awards are finalized to the time HALEU can be produced from a new or expanded facility. If DOE were to move expeditiously, NEI estimates that DOE could issue a funding opportunity announcement or request for proposals to support enrichment capacity deployment in mid-2022 and finalize awards by mid-2023. HALEU enrichment capacity, 10 MTU/yr or greater, could be on-line four years later in 2027, with HALEU being delivered the following year. If environmental reviews are required, these should be done in parallel and should not delay deploying the domestic HALEU infrastructure.

As previously discussed, Centrus will complete its demonstration project in 2022 and will produce less than 1 MTU of HALEU. With appropriate funding, Centrus could continue producing nearly 1 MTU/yr of HALEU from the demonstration facility while expanding the facility if the necessary funding and/or offtake commitments were secured.

## 8.3 HALEU from DOE

As discussed previously, in addition to EBR-II fuel, DOE could process additional material to produce HALEU. However, the processing of additional material requires funding from Congress. Assuming this funding begins in Fiscal Year 2023, NEI estimates that 1-2 MTU per year could become available beginning in 2025. Since the EBR-II processed material is only useable by a few developers (only one company currently plans to use it), it is not included in the timeline.

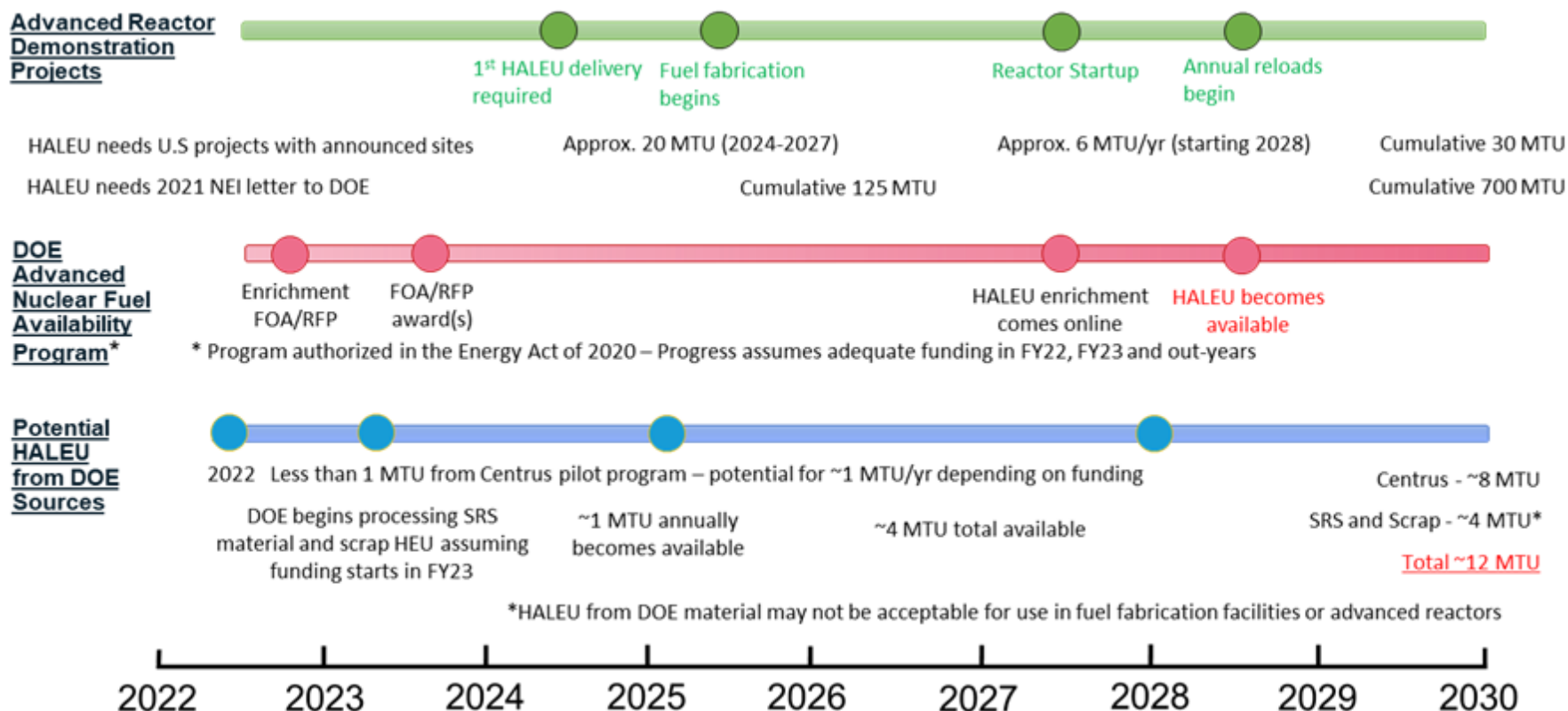


Figure 1: A Comparison of Timelines for Industry and Potential Supply of HALEU from U.S. Sources

## 9 CONCLUSION AND RECOMMENDATIONS

With the announcement of the DOE ARDP awardees in 2020, it is estimated that both companies selected for the demonstration pathway will require HALEU for their reactors starting in 2024. In addition, other companies are working to deploy HALEU fueled microreactors by the mid-2020s. These projects emphasize the urgency of demand for HALEU. Unfortunately, it is virtually impossible for HALEU to be provided to these companies in the needed quantities and timeframe from the U.S. Department of Energy or commercial enrichers located in the U.S or Western Europe and these projects alone are not sufficient for enrichers to begin building capacity. Therefore, acquiring HALEU from international suppliers will be required in the near term to support the larger goal of deploying advanced reactors in the U.S. in a timely manner while a domestic HALEU fuel supply chain is being developed. Deploying these reactors before 2030 will support climate goals of the U.S. and position the U.S. to be a strong exporter of advanced reactor technology.

The following recommendations would support a robust U.S. advanced reactor industry for domestic and international deployment and the rapid establishment of a robust domestic HALEU fuel supply chain.

- DOE should expeditiously establish the Advanced Nuclear Fuel Availability Program as authorized in the Energy Act of 2020 and immediately begin the funding opportunity or request for proposal process while expediting any required environmental reviews so that the deployment of HALEU infrastructure can begin without delay. Congress should fund DOE at a level of \$200 million a year to execute this program.
- DOE should incentivize the licensing, construction, and deployment of two commercial HALEU enrichment facilities in the U.S., through a competitive procurement process, with the first facility to be operational by 2027 and the second one soon thereafter. Each facility should be able to produce a minimum of 10 metric-tons of HALEU per year at competitive prices. DOE could accomplish this through cost-sharing private-public partnerships, by directly contracting for a bank of HALEU through multi-year contracts, or by guaranteeing contract performance by HALEU customers.
- The DOE and other government agencies should not impede the acquisition of HALEU by industry from international suppliers within the framework of existing trade agreements. In addition, DOE should consider assisting with transportation and storage of HALEU. Some of the advanced reactor projects under way will be delayed without access to the international market. Delaying these projects will endanger climate goals and U.S. competitiveness in nuclear energy.
- DOE should support and incentivize the development and deployment of deconversion facilities to be operational when the enrichment facilities are operational.
- DOE should support the certification and manufacturing of new shipping packages for the safe transport of: uranium hexafluoride with enrichments from 5% to less than 20% uranium-235, deconverted HALEU forms (e.g., oxide or metal) in commercial quantities, and the manufactured fuel being transported from the fabricator to the reactor site.

- The processing of EBR-II fuel should continue and be expedited to ensure that it is available when needed. Before processing of additional DOE stocks is pursued, DOE should determine if that approach is the best utilization of limited funding towards the goal of establishing a domestic commercial enrichment capability

## 10 DEFINITIONS

Low Enriched Uranium (LEU): Low-enriched uranium has uranium-235 content greater than 0.7% and less than 20%.

High Assay Low Enriched Uranium (HALEU): Currently, light water reactors utilize LEU with a uranium-235 level of less than 5%. Uranium enriched above 5% is defined as HALEU. In this paper, HALEU refers to enrichments between 10% and 20% U-235.

LEU+: Uranium enriched between 5% and 10% is typically referred to as LEU+

Category I, II, and III Special Nuclear Material (SNM): SNM is separated into three categories. A Category I quantity of SNM material, which is also referred to as strategic SNM, is any SNM with uranium enriched to 20 percent or more uranium-235, uranium-233 or plutonium. A Category II quantity of SNM material is referred to as SNM of moderate strategic significance and is 10,000 grams or more of uranium-235 enriched to 10 percent or more but less than 20 percent uranium-235. Category III SNM material, also referred to as SNM of low strategic significance, is defined as 10,000 grams or more of uranium-235 contained in uranium enriched above natural but less than 10 percent uranium-235.

## 11 REFERENCES

Reference 1. NEI White Paper, Addressing the Challenges with Establishing the Infrastructure for the front-end of the Fuel Cycle for Advanced Reactors, January 2018.

<https://www.nei.org/resources/reports-briefs/infrastructure-for-the-front-end-fuel-cycle>

Reference 2. NEI Letter to DOE Secretary Perry on Need for High-Assay Low-Enriched Uranium, July 2018. <https://www.nei.org/resources/letters-filings-comments/nei-letter-perry-need-haleu>

Reference 3. NEI Letter to DOE, Secretary Brouillette, Updated Need for High-Assay Low-Enriched Uranium, July 2020. <https://www.nei.org/resources/letters-filings-comments/updated-need-for-haleu>

Reference 4. NEI Letter to DOE, Secretary Granholm, Updated Need for High-Assay Low-Enriched Uranium, December 2021. <https://www.nei.org/resources/letters-filings-comments/2021-doe-updated-need-for-high-assay-low-enriched>

Reference 5. Regalbuto, Monica, "Independent Report GAIN/EPRI/NEI April 2020 Virtual HALEU Workshop," National Academies of Sciences, Merits and Viability of Different Nuclear Fuel Cycles and Technology Options and the Waste Aspects of Advanced Nuclear Reactors: Meeting #10, September 28-29, 2021. <https://www.nationalacademies.org/event/09-28-2021/merits-and-viability-of-different-nuclear-fuel-cycles-and-technology-options-and-the-waste-aspects-of-advanced-nuclear-reactors-meeting-10-september-28-29-2021-public-sessions>

Reference 6. Bates, Bill, "HALEU Production at the Savannah River Site (SRS)," GAIN-EPRI-NEI High-Assay Low Enriched Uranium (HALEU) Webinar, April 28-29, 2020.

[https://gain.inl.gov/HALEU\\_Webinar\\_Presentations/09-Bates,SRNL\\_Capabilities-28Apr2020.pdf](https://gain.inl.gov/HALEU_Webinar_Presentations/09-Bates,SRNL_Capabilities-28Apr2020.pdf)