Q&A with

Monica Regalbuto

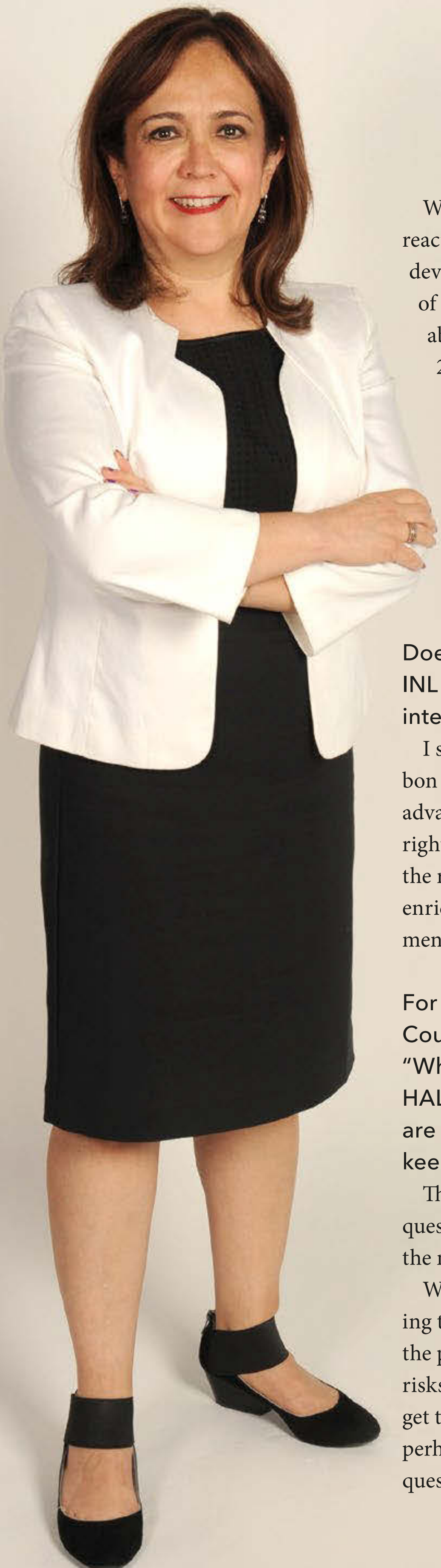
Shaping a sustainable HALEU economy

High-assay low-enriched uranium (HALEU) is the power-dense feedstock of choice for a slew of advanced reactor designs. There's just one problem: It isn't available . . . yet. Downblending high-enriched uranium owned by the Department of Energy to between 5 and 19.75 percent fissile U-235 is a stopgap measure at best, and no U.S. facility can yet produce commercial quantities of uranium above the 5 percent U-235 limit for low-enriched uranium.

The problem is one not of technology, but of economics: Enrichment companies want to see clear market signals that advanced reactors will be deployed in quantity, leading to long-term purchase agreements that will justify investments made today.

ANS Fellow Monica Regalbuto is director of Nuclear Fuel Cycle Strategy at Idaho National Laboratory, tasked with leveraging her more than 30 years of fuel cycle experience to ensure an adequate domestic supply of HALEU. She was invited to speak about her work during the opening plenary session of the 2021 ANS Winter Meeting.

The DOE's Advanced Reactor Demonstration Program (ARDP) and separate Defense Department microreactor awards account for part of the known near-term demand for HALEU, which Regalbuto refers to as the "high-fidelity" market, estimated to reach 20–22 metric tons by the mid-2020s. But demo units alone won't make a sustainable market, and enrichers want to know what will happen next. Unless and until widespread advanced reactor deployments lead to long-term purchase agreements, sporadic deployments are likely to produce "peaks and valleys" of HALEU demand. A sustainable HALEU enterprise must smooth that demand curve.



While the government's use of HALEU—for research reactors, isotope production, and more—isn't new, reactor developers' increasingly urgent calls for an assured supply of HALEU began in 2018. The authority to do something about it was assigned to the DOE in the Energy Act of 2020, and a request for information (RFI) that is now open for responses (see page 66) could be followed by a funding opportunity for a public-private partnership to build a commercial HALEU infrastructure.

Regalbuto is eager to shift from talk to action, but she made time to speak with *Nuclear News* staff writer Susan Gallier about her work and what it will take to site, fund, and build fuel cycle facilities to support an emerging HALEU economy.

Does your work as the lead of Nuclear Fuel Cycle Strategy at INL focus on fuel housed or required at INL, or does it include interfacing with other DOE sites that hold HEU?

I support the nation's needs to combat climate change by reducing carbon emissions, and nuclear power is set to play a key role in that. Many advanced reactor designs will operate with HALEU fuel, so in my job right now I support having a domestic supply of HALEU, both through the recovery and downblending of DOE-owned HEU stocks and through enrichment operations. We support both—downblending and enrichment—and at any site. This is not an INL thing—it's a national thing.

For two years running, in 2020 and 2021, the U.S. Nuclear Industry Council has surveyed advanced reactor developers and asked: "What issues keep you up at night?" And for two years running, HALEU availability has topped the list of concerns. Now that you are responsible for making the HALEU economy a reality, what is keeping you up at night?

That is really funny, because nothing keeps me up at night! Maybe the question I'd like to answer instead is, "What makes you want to get up in the morning?"

What makes me want to get up in the morning and get to work is knowing that we've got this! We can start this enterprise. We can start priming the pump. We know what this high-fidelity market is, we know what the risks are. It's almost like the Nike slogan—let's just do it, okay? We want to get this done, and that's what motivates me. If we needed a new technology, perhaps that would keep me up at night, but no—we're good. So I love your question, but no, I don't want to stay up at night!

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In 2018 and 2019, the DOE started taking a hard look at expected HALEU needs. While most of the heavy lifting still lies ahead, what progress would you say has been made in the past few years?

Several things come to mind. One thing that I think is very important is that we have a much better understanding of what the HALEU market could look like. The ARDP awards from the DOE and other awards from the Department of Defense have facilitated our ability to quantify the projected commercial needs, at least within the next five to seven years.

We have much more definition of what type of fuel forms we're going to be looking for, and what we are looking for near term, which is very important because we need to inform the supply chain and have deconversion services to support fuel fabrication. Also, we know more about how we can use recovered HEU in the near term. If we don't use recovered materials, the only options are importing or waiting until HALEU enrichment capability comes on line. Finally, work to develop HALEU transportation containers has progressed, and, in fact, Orano USA just submitted a license application to the NRC for a HALEU transportation container. Those are all areas where we have really advanced the needle in the past 12 to 24 months.

You have said that meeting high-fidelity government HALEU needs and a percentage of projected commercial demand could "prime the pump" for private investment in HALEU capacity. Estimates of commercial demand are broad. How can you determine what commercial demand will need to be met?

To me, it's really a question of "What is the risk that investors are willing to take?" Building the initial capability to support the high-fidelity market, which is the known and enduring market, is important because it reduces investment risks.

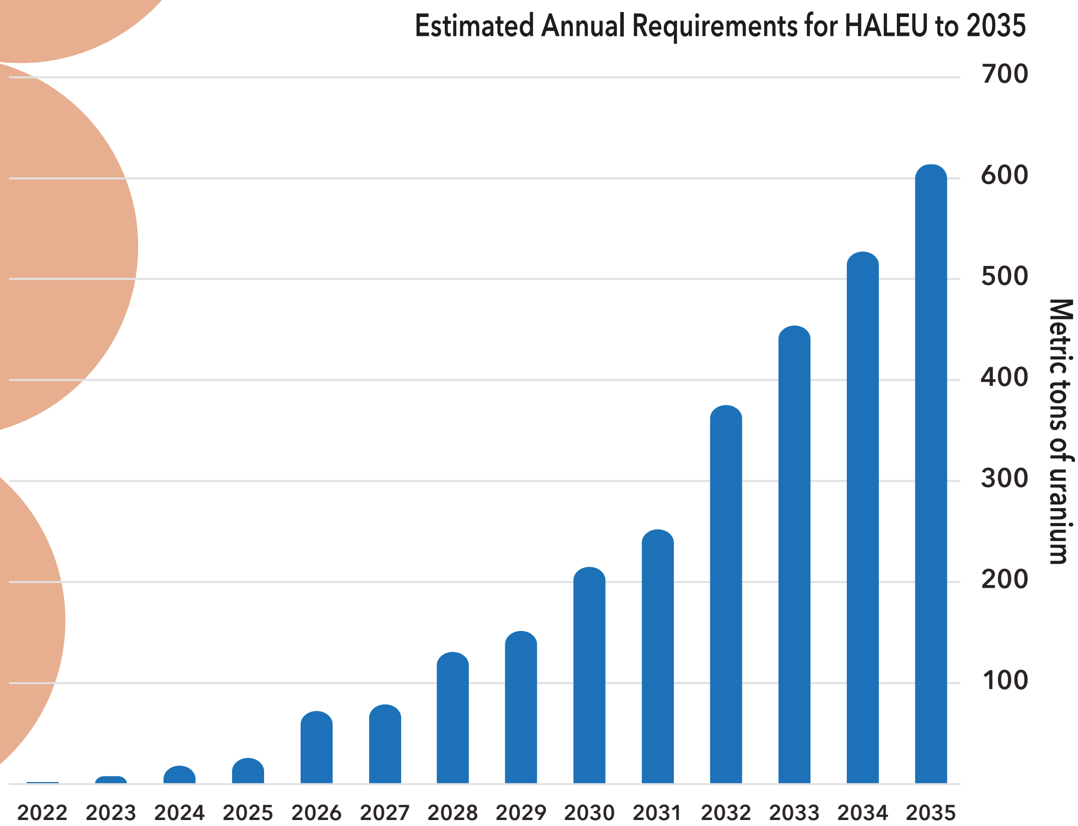
If you're building capability between five and seven years, how many of these companies that anticipate demand do you forecast will bring reactors on line or will need at least an initial core within that period of time? That will determine the percentage. But it is up to the investors that are building the capability. Investors have to decide how much risk they want to take, by predicting, "X, Y, and Z are going to come on line." I do want to emphasize that in addition to the DOE and DOD demonstrations, there are vendors of advanced reactors that are not necessarily using government funds, and they're also part of the mix.

Are you saying that the HALEU Availability Program will meet projected needs to the extent that investors are willing to put their own money on advanced reactor deployments?

Correct. If you look at the Nuclear Energy Institute's annual survey forecasting HALEU needs (see graph), by mid-2026, I think it's over 50 metric tons that they forecast will be needed. The actual demand will depend on how much of that capacity is really going to be on the market and how much is already counted in the high-fidelity market—the government investments that we know are there. It's an exercise of investment risk management.

The Energy Act of 2020 and the RFI now open to responses suggest that a consortium should be developed to act as a wholesale buyer or fuel reserve manager of commercial HALEU. Would that be a physical HALEU reserve? How might that work?

I think it's important to recognize that we need a working inventory because of the peaks-and-valleys nature of the HALEU market. You need to smooth that market. The International Atomic Energy Agency's LEU fuel bank that is just coming on line is a very good model, and that is a



The Nuclear Energy Institute surveyed advanced reactor developers and fuel designers about their estimated annual requirements for HALEU between 10 and 19.75 percent U-235 and submitted the results to energy secretary Jennifer Granholm in December 2021. This graph reflects total estimated annual requirements for fuel fabrication in each year through 2035. (Data: NEI, https://www.nei.org/resources/letters-filings-comments/updated-need-for-haleu)

physical inventory. The inventory, or the bank if you want to call it that, could be housed in various locations in the United States, and it could be operated by the consortium members.

I think what's important to understand in this enterprise is that this inventory has to be housed in a Category II facility with all necessary safeguards and security. DOE has facilities that meet those Category II requirements, and commercial entities have facilities—in fact, some commercial entities have Category I facilities—so there are a number of facilities available. Building a new facility is an option too—it is not a large footprint.

Another thing to keep in mind is that you need to maintain this inventory in what we call a prolonged low-maintenance storage form. There's certain guidance for low-maintenance storage of uranium in oxide or metal form. LEU can be stored as UF_6 because the inventory is constantly cycling in and out of storage. But if we will need to store HALEU when demand is in a valley, so to speak, we want to make sure that it's in a more robust form.

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Centrus Energy is currently demonstrating enrichment to 19.75 percent on a small scale, using U.S.-origin technology. Could other enrichment companies operating in the United States also enrich to 19.75 percent on a relevant timescale?

Can other facilities be up and running in the same time frame? The answer is yes. At a HALEU workshop in April 2020, we had presentations from all three of the enrichment enterprises in the United States—Centrus Energy, Global Laser Enrichment, and Urenco USA. All three can use their current technology to enrich to 19.75 in the same relative timescale—you don't need new technology. But there is a need to operate as a licensed Category II facility, and that requires investments and market-favorable conditions.

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Category II facilities are required for enrichments above 10 percent. Could some enrichers choose to—or be asked to—enrich uranium to the LEU+ level of 10 percent U-235 at a Category III facility, and then send it on to a Category II facility?

I think it's up to the enrichers to decide if they want to partner. If you feed higher enrichments to your Category II facility, you can shrink the footprint of that facility. If you want to, you can feed 5 percent, you can feed 7 percent, or whatever you have, but the higher the enrichment you feed to your Category II facility, the smaller the footprint and the more economical it is. Companies can partner, of course, but it's up to them if they want to do that. It's not necessary. Perhaps some companies will just do everything themselves, which can be done too.

Deconversion is currently handled by LWR fuel fabricators. Co-locating HALEU enrichment and deconversion facilities could be economical and avoid the costs of producing transport packages specifically for HALEU UF_6. What are the potential advantages and disadvantages of co-locating those facilities?

I personally don't see any disadvantages. The HALEU market is very tiny compared to the LWR market, so there is not a great benefit to having deconversion added to your fuel fabrication facility. The advantage comes in being co-located, making it economical, taking advantage of your safeguards and security, and not having to move the material. To me, that's the advantage, and if you opt for an alternative, you'll have to pay a price for it. You will have transportation needs, for example.

It may require some joint ventures between enrichers and deconversion services operators, but you don't need new technology for deconversion. You do have to address the fact that it requires a Category II facility and will hold a larger inventory. It's not like we're deconverting depleted uranium tails. We are deconverting HALEU, so you need to meet criticality and safety and security requirements.

Somebody is going to have to deconvert! What I would say is, put it in a centralized location, because that way more fuel fabricators can use it. However, if somebody is willing to put deconversion in the front end of their HALEU fuel fabrication facility, that's up to them.

"Fueling Our Nuclear Future" was the theme of the 2021 ANS Winter Meeting opening plenary, moderated by Amir Vexler of Orano USA (far left) and featuring presentations by the DOE's Kathryn "Katy" Huff, Regalbuto, and NEI's John Kotek. (Photo: Justin Cox)

If deconversion services are shared, could it make sense to have shared facilities for HALEU fuel fabrication as well? Could a consortium build one or two Category II fuel fabrication facilities where different reactor developers set up fuel production lines, while protecting their intellectual property?

In theory, yes. In practice, who pays for this? Who will fully utilize this type of facility?

Some advanced reactor developers are using fuel that is already qualified, and they may have no desire to have a common facility. They may benefit, but their needs are different. Others are more at the fuel development stage, iterating between fuel development and the reactor, and so developers in those categories may be more interested in a centralized facility.

Remember, we expect peaks and valleys, so are we going to set up a production line for somebody to come and make fuel and not come back for 10 years or 15 years? Or maybe they decide not to continue their pursuit of an advanced reactor and the line sits idle? Those are hard questions.

Given that different reactor types have very different fuel needs, could we see one fuel cycle facility with co-located services dedicated to producing metallic HALEU fuels, for example, while another site focuses on producing HALEU as U_3O_8 to feed into TRISO fabrication?

It's up to the market to determine how people will assemble. But it would make sense to have deconversion services that can address both an oxide and a metal market. Producing one doesn't prevent you from getting to the other, it just takes more steps. At the end of the day, it's about how many customers somebody has. If there are a lot of customers for, let's just pick one and say oxide, the deconversion service may choose to invest only in oxides, because you can still go from oxide to metallic fuels at the fuel fabrication facility. On the other hand, if there is a huge interest in metals, the commercial service may just produce metal, or UF_4, and then you can get to the oxide at the fabrication facility. Or they may choose to produce both.

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The cost of building these facilities, reaching higher enrichments, and in some cases developing new fuel fabrication techniques are likely to make advanced reactor fuel costs a larger share of the levelized cost of electricity, as compared to today's LWRs. What are the implications?

You're going to require a larger upfront investment, because not only do you have to support your capital investment, which is traditionally building the reactor, you also have to account for fuel costs, especially for reactors designed to refuel once, twice, or maybe never, where you load all your fuel on day one. You're not constantly cycling into refueling cycles, so that will impact your financial models compared to LWRs. When you're buying your fuel all at once, and because HALEU fuel is not a commodity today, you're going to pay a little more. At the start, it is going to be a heavier lift.

Certainly, the costs are going to vary depending on what fuel you're using, and if it is already a qualified fuel, if there is already a commercial entity that can produce it, that will influence the price. At the end of the day, just as with LWR fuel, those costs are borne by the ratepayers or end users. It's part of making your design attractive. You can't make it cost prohibitive or the end users are going to say, "Well, I'm going to go with something else."

Limited Near-Term Domestic HALEU Options

RECOVERY AND DOWNBLENDING

INL
1 metric ton of HALEU per year until 2035. HEU downblending from EBR-II and ATR origin yields 10 metric tons and 20 metric tons, respectively.

Savannah River Site
20 metric tons potentially available from fuel take-back processing.

BWXT
Potential for 10 metric tons by 2022 and 40 metric tons by 2025 from downblending excess/surplus HEU.

ENRICHMENT

Centrus Energy/American Centrifuge Operating LLC
900 kg per year of UF_6 from ongoing 16-machine cascade demonstration.

URENCO USA
Commercial enrichment facilities for HALEU enrichment between 5 percent and 10 percent.

Staff research scientist Colt Heathman performing HALEU processing work at INL. (Photo: INL)

You have suggested that fuel leasing models could help amortize the cost of fuel over a reactor's lifetime. Under a leasing arrangement, would the DOE own the fuel "from cradle to grave" and take it back for reprocessing or disposal?

You can use leasing models for any type of reactor, small or large. Those are just financing mechanisms that fuel providers can enter into with a reactor vendor or a utility, so they've been available all the time.

Who owns the fuel is a question that has not been answered. As you know, in the current LWR fleet, the responsibility for spent fuel is under the Department of Energy, and they have contracts with the utilities. For advanced reactors, those agreements or responsibilities have not yet been defined. Are they going to do it in a similar fashion? That's an important question. But I have not seen any guidance on that.

How long would it take to build a HALEU economy sustained by long-term purchase agreements? The HALEU Availability Program defined in the Energy Act of 2020 will sunset in 2034. Do you think that's realistic?

This question makes me think, but if I do the math, I say yes, it is realistic.

If you have reactor demonstrations starting in 2027, which is what we're targeting, and you have deployment of a commercial unit starting in 2031, about four years after, and if we say for the sake of argument that advanced reactors using HALEU are 25 percent of the new nuclear builds that are needed to reach net zero by 2050, then we will reach a sustainable market by 2034.

What outcome do you expect from the HALEU Availability Program RFI issued in December, and what's the next step?

The DOE will get the responses—I don't participate in the RFI process. But it's an important first step needed to start building these facilities. The longer we take to start building, the more we're going to delay the availability of an enrichment capability for HALEU that we already know we need now. The sooner we get it up and running, the more we can save some of the HEU materials that we're currently downblending, and I think the better off we will be. My desire and aspiration at the end of this RFI is that a funding opportunity will be issued, and we will build a public-private partnership.

But again, let's start yesterday! We have to build this capability. We do not want to cede the HALEU market to a foreign entity. That's the motivation, and that's what I would like to see, the sooner the better.