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CLIMATE 2023

A Preview of the Year Ahead

Clean Baseload Power: Opportunities for Nuclear Energy

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Clean Baseload Power: Opportunities for Nuclear Energy

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Summary

Assistant Secretary at Office of Nuclear Energy Kathryn Huff joins this session to detail the future of nuclear energy envisioned by the US Biden-Harris administration and the works that are in place at the Office of Nuclear Energy. **Watch the full discussion here**.

Key takeaways

- US nuclear policy is all about large light water reactors providing Baseload Electricity Generation. 20% of baseload electricity is produced with nuclear power, with 93 nuclear reactors across 28 states. At the moment, it is just a complicated way to boil water, but the future is about so much more.
- Large light-water reactors, small modular reactors, advanced Gen IV reactors, new chemical processes, clean water, flexible electricity generation, hydrogen production, industrial applications: these are all part of the plan for a wide-ranging nuclear rollout over the next several decades.
- Four priorities of the US Office of Nuclear Energy:
  - Keeping existing reactors safe and open: Many struggle for profitability, and therefore we have seen an array of subsidies from the Bipartisan Infrastructure Law and the Inflation Reduction Act (IRA): 30% investment tax credit for new reactors constructed after January 2025. The production tax credit also applies when built (before 2032).
  - Building advanced reactors: From microreactors that can fit on a truck (under 20MW) to large-scale reactors similar to what are currently operating, all have a role to play, especially in industrial processes for heat or dedicated energy sources from hospitals to chemical plants
  - Secure and Sustain nuclear fuel sources, reliable supply chain, and sustainable spent fuel processes. This is not a stated policy, but there is a need to diversify away from Russia.
  - Diverse employment opportunities.

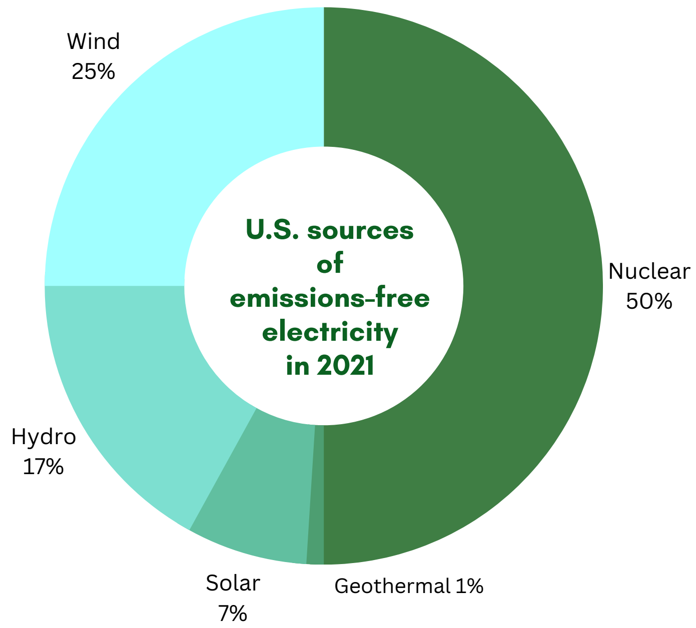
Paul's observations

After listening to Dr. Huff, it is difficult not to get excited about the prospect of nuclear energy in the United States. Between the support packages of the Bipartisan Infrastructure law, the array of investment and production tax credits from the IRA, and the dedication of the Department of Energy to foster innovation amongst the brightest minds in nuclear energy, it does appear that the US is on track for nuclear to play a dominant role over and above the 20% baseline electricity generation it currently produces. It is undeniable that the policy agenda is moving in the right direction.

That said, a decade is not a long time in the world of nuclear energy and despite the array of subsidies that exist for both the current stock of reactors and next-generation facilities, industrial use of nuclear energy, i.e., using heat for industrial processes like hydrogen and chemical production versus electricity generation, is a long way from being cash flow generative. Even today, the existing stock of 93 light-water nuclear reactors is not profitable due to spiking safety costs.

This is where the Bipartisan Infrastructure law and the IRA, again, take center stage. While they are not the panacea to bring forward wide-ranging nuclear adoption from the anticipated 2035, they will enable, when combined with Department of Energy grants, a financial backstop that can hopefully make the nuclear industry eventually profitable. That said, even with these generous government handouts, investors looking for free cash flow in the near term will be disappointed.

"At the moment, nuclear power in the United States is just a complicated way to boil water, but the future is about so much more."



Source: taken from Clean Baseload Power: Opportunities for Nuclear Energy presentation

Presentation: DOE Nuclear Energy Outlook

Maintaining the safe operation of nuclear power stations in the US is a top priority, as these facilities generate a significant portion of the country's baseload electricity, representing 20% of the total and half of the carbon-free electricity. Large light-water reactors produce low-grade heat, which could be useful for desalinization and hydrogen applications, either low or high, or to make electrolysis more effective. Light-water reactors are refueled every 18-24 months and run continuously, providing a reliable source of power. They rarely turn off unexpectedly, which would be due to an automatic safety switch tripping. We can rely on them to generate power all the time, which matches well with the more variable sources of carbon-free electricity. There are currently 92 large-scale light-water reactors in the US, with Vogtle Units 3 and 4 set to be added in 2023.

Nuclear reactors boil water to power turbines to generate electricity, using 3 megawatts thermal (MWt) to generate 1 MW of electricity. The thermal output could be used directly. Although a critical aspect of regular operation is flexible generation, it is not very efficient to lower the output of a nuclear power plant, so storage using hydrogen technology would improve efficiencies. Advanced generation reactors and small modular reactors are part of the future mix, producing higher-quality heat that could contribute to hydrogen storage or direct heat applications. As renewable energy sources continue to become more affordable, there will be a need for nuclear power to make room for them in the energy mix.

"As renewable energy sources continue to become more affordable, there will be a need for nuclear power to make room for them in the energy mix." – Dr. Kathryn Huff

The Civil Nuclear Credit

This Bipartisan Infrastructure Law aims to prevent premature retirements of existing commercial reactors by offering financial support in the form of credits to operators meeting set criteria, which helps them to compete with the price of electricity generated by fossil fuels It is a $6 billion fund in total, where $1.2 billion is appropriated each year from 2022 to 2026. The first round of funding has just been awarded, helping the Diablo Canyon plant to stay open. Future rounds will be distributed more evenly.

Inflation Reduction Act (IRA)

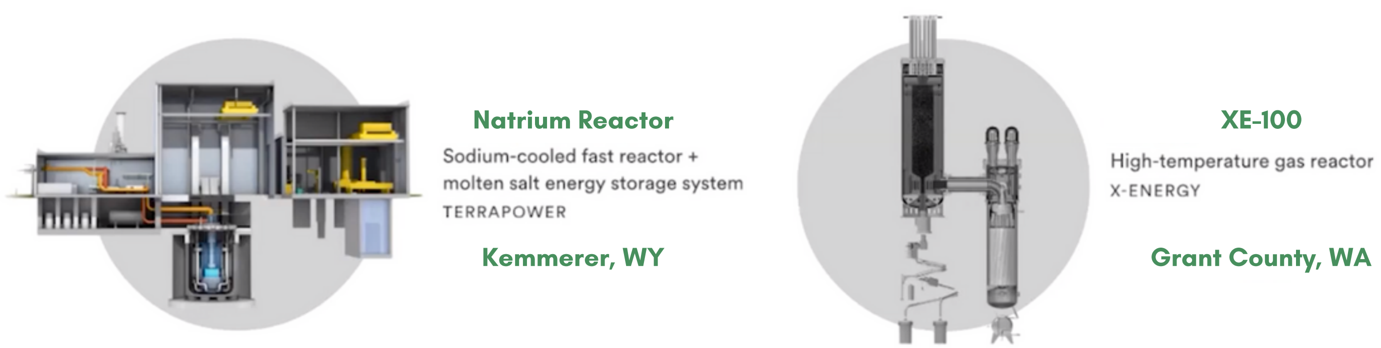
The IRA applies a production tax credit to any plants in service before 2024, which is when the credit starts. They will receive the credit until 2032. The IRA awards them a credit of 1.5 cents per kilowatt-hour (KWh) if they pay their workers fairly, which nuclear power plants generally do, as their staff is highly qualified engineers. They will get much smaller tax credits if they don't meet this requirement.

It should be straightforward for any plant to achieve the wage and apprenticeship requirement. It will be indexed to $20-23 so that a plant operator gets an extra $60 per megawatt-hour (MWh) and 1.5 cents per watt-hour for almost a decade, from 2024 and 2032. This is a game-changer for some nuclear power plants that are considering retirement. This will keep them open until 2032, contributing to the 2035 goal of establishing a net-zero electric grid. To keep costs down for consumers and avoid operators overly profiting, they won't make extra profit off this tax credit if they receive $25 per MWh. Beyond $25, the credit is phased down by 80% by $1 per MWh, dropping to zero by $43.75 per MWh.

Building Advanced Reactors

There are many advanced reactors being developed, and research and development can support their deployment and demonstration. The National Laboratory System and grants to universities and companies are supporting the research of advanced fuels that are more resistant to accidents, as well as new sensors and instrumentation and modeling and simulation to reduce the testing required for reactor licensing. Advances in 3D printing and materials manufacturing can be leveraged to make reactors more modular so that reactors can be built more like airplanes than airports.
Small modular reactors of 20 to 300 MW scale are appropriate for modular builds at grid scale. Micro reactors are small enough to fit on a truck and are easily transportable, and they generally have between 1 and 20 MW of electric capacity. Large-scale reactors such as the AP1000, similar to the existing plants with gigawatt-scale reactors, are advanced reactors built in the US and other countries. A few are operating already in China.
All of these reactors have a role to play. Microreactors could replace diesel generators at critical infrastructure sites like hospitals, military bases, and remote or austere locations. Likewise, modular reactors could replace coal plants. Many coal plants are approaching retirement as part of a clean energy transition. Large-scale reactors can form the grid's backbone, accounting for almost 20% of US electricity.

The $2.5 billion Advanced Reactor Demonstration Program will support the Natrium and XE-100 reactors



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Natrium is a sodium-cooled, high-temperature fast neutron reactor with a cool, clean molten salt storage system to allow more flexible contributions to the grid.

Xe-100 is a high-temperature gas reactor. This reactor uses tri-structural isotropic fuels, which are extremely robust against accidents. It produces high-quality heat with lots of potential uses in industry.

Natrium and Xe-100 are built with the government at a 50/50 cost share. The awards were made from the Office of Nuclear Energy, and now they have moved into the Office of Clean Energy Demonstrations, which has the infrastructure to support demonstration activities.

The Bipartisan Infrastructure Law further reduces the uncertainty for these projects by fully appropriating their $2.5 billion price tag. The Carbon Free Power Project is an Office of Nuclear Energy project to develop a small modular light-water reactor. It already has a design certification from the Nuclear Regulatory Commission (NRC). It is being built in Idaho as six modules that will be connected on-site and to the grid. The first module should be connected to the grid by 2029.

The Advanced Reactor Demonstration Program also supports a range of other reactor innovations. This includes risk reduction for uses like Kairos and coal tags. Kairos is a high-temperature pebble-bed reactor. In addition, there is also a molten salt reactor experiment on the horizon in 2030. A huge menu of reactors will start to be available in the 2030s for commercialization, but the main focus is on the demonstrations that can be available to switch in this decade. There is an investment tax credit that will help reactor vendors get investors because it provides financial incentives for meeting certain manufacturing requirements. There is also a tax credit for producing electricity for reactors that can be built quickly enough to access it. The Natrium reactor project will be eligible if it hits its timelines and milestones. The production tax credits are tech neutral, applying to all energy technologies, including nuclear.

"A huge menu of reactors will start to be available in the 2030s for commercialization, but the main focus is on the demonstrations that can be available to switch in this decade." – Dr. Kathryn Huff

Advancing environmental and social justice

Another cross-cutting priority in the nuclear energy industry is getting more diverse voices from underrepresented minorities and genders. This is done largely through university funding and funding traineeships in community colleges. Advancing environmental justice is a key theme in developing this consent-based siting for interim storage endeavors. For example, communities should be part of deciding where to store spent fuel, as well as the siting of demonstration reactors and other infrastructure. There is a risk that coal communities are left behind in this transition, so there is consideration about a coal-to-nuclear transition that will bring those communities along with the clean energy transition. The nuclear industry has a lot of good-paying, clean energy jobs; it takes thousands of people to build and run plants. Fossil fuel communities can represent some of the job savings that can be achieved in this transition so that no one is left behind.

Questions & Answers

Ever since nuclear power plants were built, there was the possibility to utilize heat directly for industry or hydrogen production. Why are we only now talking about this function, and why should we trust that it will finally happen?

Electricity was the market's main focus when nuclear power plants were built. There was a lot more money to be made in producing electrons for the grid, and there was no incentive to decarbonize the things that were so easy to do with fossil fuels. So, the market for nuclear reactors focused on electrons, and fossil fuels took care of many of these direct heat applications. Both of those things change when you start to worry about the climate. The electric grid is not the only thing we have to decarbonize. Companies see the pattern of present and future incentives, which will help us achieve our 2050 net zero goals. Unmitigated fossil fuels will have to go, so we are seeing that climate goals drive nuclear toward these other applications.

Does this represent an alternative income stream for the owners of nuclear programs?

Yes, for existing power plants. Look at the changing markets on the electric grid: there are nuclear power plants that have experienced negative pricing moments where they had to pay to put their electrons on the grid because it is too costly to bring a power plant offline and turn it back on. At times there are so many electrons on the grid that the grid operator might, as it has in Texas and elsewhere, say they simply do not want electrons at that time. Worse than that, there have been times when a supplier had to pay a fee to put their electrons on the grid. Those negative pricing moments could be avoided.

"Unmitigated fossil fuels will have to go, so we are seeing that climate goals drive nuclear toward these other applications." – Dr. Kathryn Huff

What is the baseload percentage when it comes to the US electricity mix?

It depends on the region. Some regions do not have a lot of renewable generation, so much of their electricity is baseload. You have a little peak in the morning when people are both at work and home. You have a much bigger peak in the evening when people are both at work and home. In some regions, this can double the grid in the evening. The dot curve in California is fairly well recognized now, where energy demand shifts by an entire half of the grid from midday to the afternoon. That would be the electricity required just as a baseload. The sun shines in the middle of the day, so it would be good to very efficiently hold half the grid's worth of electricity for six hours, then make it available at 6 pm. We generally do not have power storage at that scale.

Is that baseload around 30%?

In most regions, it is probably about 30%, though, in others, it may be 10% or 50%.

Is the plan to scale up nuclear to provide a baseload rather than flexibility to work well with renewables?

Yes, you still have to replace all the natural gas-peaking plants which are not carbon-free. We sometimes use coal to smooth out grid peaks, so we need to decarbonize all of that. Some of that can be done with renewables. There is a great paper from the State Department and the White House about our pathways to net zero. It clearly shows that you could get away with just 90 to 100 gigawatts (GW) of nuclear on the grid if every other clean energy technology ramps up to its maximum. However, if any other technology does not quite meet their goals in that model, you need up to twice as much nuclear as we currently have. Several existing nuclear power plants are nearing retirement, so we need to consider the replacement rate, and we will need to build new nuclear. The Office for Nuclear Energy is preparing for that sort of maximum amount to achieve decarbonization so that we will be doubling nuclear power by 2050.

How does the replacement rate fit with the priority to keep nuclear power plants open for as long as possible?

While some plant lifetimes can be extended to 80 or 100 years, many plants are aging. We cannot expect all plants to receive lifetime extension requests from the NRC, so we need to be prepared for some of those to shut down.

Is there any financial incentive to close or dismantle a nuclear power plant?

Companies that do the decommissioning earn from doing that work. The NRC requires that the operators maintain a fund for decommissioning so that the money is already there if there's a need to decommission. On decommissioning, the NRC would release that money, but not generally to the operator, but to a separate entity to which the reactor has been sold, allowing them to do the decommissioning.

Has the US government set the goal of a 50% reduction in carbon emissions by the end of the decade?

Yes, and 100% clean electricity by 2035.

Could the US meet that goal by 2035? It takes a long time to get permits and construction, so how do we get there?

The Biden administration's approach is to be as aggressive as possible with economic incentives because we have seen the American industry construct an incredible amount of infrastructure when incentivized

economically. We have big incentives in the Inflation Reduction Act and the Bipartisan Infrastructure Law. Some of our models indicate that we can get close to some of these goals with these, but industry and private investors will have to step up. It is not going to be government dollars and loans that make this happen. It can only happen if private investors get on board with our aggressive goals.
Zero carbon on the electric grid by 2035 means that all natural gas is carbon mitigated, no natural gas at all, and all coal is replaced by a clean source—that is hundreds of coal plants. We will have to build as much as possible, as quickly as possible. We will get some of these demos built by the end of the decade, and hopefully, they will not just build one in 2030 and then one in 2035, but we'll see one built in 2030 and then six in 2031.

Are we expecting any change in regulation that will ease the process of opening a nuclear power plant?

Take the NuScale reactor, the only small modular reactor with a design certification, as an example. It took 42 months to submit applications to the NRC and get their design certification. That was the fastest conceivable process, and they had support from Congress to streamline some of their processes. NuScale had been well-researched for almost a decade before submitting that application, indicating that it takes a while. I think the NRC is serious about streamlining its processes. I will not speak for the NRC, but I have seen that they would like to lower the barrier but not the standards. They would like to simplify their processes and make the way they conduct the evaluations more agile without changing the regulations. In particular, they do not want to lower the standards for which the United States is trusted.

Can we get better at building things on time and budget if we are constantly innovating new versions so that reactors are different for each project?

South Korea is a good example of a country with a good track record of building things on time and budget, and at a low cost for nuclear. They do so by building the same plan in pairs. There is a lot to learn from nations that have done this well. We also think that this more modular approach with smaller units should reduce the on-site build's complexity and the number of people that need to be on site.

Can we efficiently build lots of alternative new reactors and technologies?

I think we can manage a couple of different designs, but I would like a few of those companies to find a way to maximize a single success. The United States government is not generally in the business of picking winners, and it is critically important that we allow private industry to find solutions that make sense economically and to move those forward. We want to incentivize the ends rather than the means. Companies can offer contributions to decarbonization goals by developing different technologies, and we want to support them until they filter themselves out.

"We want to incentivize the ends rather than the means." – Dr. Kathryn Huff

Does the US have any plans to match its old rate of nuclear build, when in the early 1970s it added 5 GW of nuclear per year to its grid?

Between 1970 and 1990, the United States deployed 95 GW of electric nuclear power, which is more than we currently have on the grid today. We did it with GW-scale plants. A variety of different designs, but mostly just light-water reactors in the minor GW -scale. It was a different time from a regulatory and permitting perspective, but I think if we want to get to net zero by 2050 I think is possible, we would need to ramp up the amount of nuclear power that we build and do it more efficiently. If they're modular, we construct them at a factory, and assemble them when they arrive on-site rather than build bespoke every single time, like we have been doing with our GW-scale reactors. I think we will gain efficiencies in modular construction and, hopefully, economies of scale once we get into production. I hope that some of these companies proposing smaller modular designs see a future of economies of scale and construction speed. We have done this and have about 27 years between now and 2050. That decarbonization goal feels a little more possible now than zero electricity by 2035. I'm concerned that we will have to work a little faster than we currently are to get there.

How do we reduce the permitting time for new smaller industrial-scale nuclear facilities?

The NRC is responsible for permitting. In the Department of Energy, we support NRC by doing research and development. As we look towards this modular construction, I can imagine a scenario where the NRC does some of their licensing processes on-site at the factory that they might have otherwise done at the construction site.

"Many reactors being licensed for build this decade are focusing on the existing licensing pathways and are finding some successes." – Dr. Kathryn Huff

What changes in regulations are upcoming?

The NRC is looking at a framework called Part 53, which is a licensing process that targets advanced reactors. It has gone a little more slowly than the NRC intended, but I understand that it is promising for some reactors to be ready by 2030. Many reactors being licensed for build this decade are focusing on the existing licensing pathways and are finding some successes. I think it is very promising that we have a small modular reactor with a design certification. It makes sense to invest in the technologies that have a pathway to licensing, including all reactor technologies, because the NRC has proven that they can license and advance a small modular reactor or at least a light-water one. We have yet to see the NRC successfully license a non-light water advanced reactor in this decade, but I think it is coming.

When we talk about advanced reactors, do you think people may think we should close down those older nuclear reactors and choose the safer ones?

It is tricky to talk about improvements in safety and efficiency on a technology that is already quite safe and efficient. When you talk about deaths per terawatt hour, nuclear is at the bottom of the list, even below most renewables, except for geothermal. The first human-determined fission chain reaction happened 80 years ago, and those 80 years have been incredibly productive. These technologies have advanced, and we have learned a lot from operating them for hundreds of operational hours. We need to maximize the fact that we have improved these technologies so that they are very safe.

Finding new sites for a nuclear facility in Europe is tricky. Will it be any different in the US?

The Office for Nuclear Energy recently published a report on how many of the coal plants in the United States would be suitable sites for nuclear reactors, and that's where we have a lot of promise. These sites are typically utility owned and have connections to high-voltage power lines. The skills needed to work at nuclear power plants are similar to those required at coal plants. You have union boilermakers and welders and electricians and folks who are turbine maintenance engineers. You need all those people in a power plant too, and they will want jobs when that coal plant is decommissioned for a clean energy transition. A nuclear reactor is a natural replacement for those coal plants, and I expect to see many coal plant sites apply for site licenses for small modular nuclear reactor deployments. Those communities will be very excited about those job opportunities and the transition from coal to nuclear if we communicate with them about the ups and downs of being such a community. The utilities also see promise there, as well as the unions that represent those communities and the jobs in those communities. There is a lot of investment potential. You reduce the cost by 15% to 35% when you do something like this because you can leverage that high-voltage power line and don't have to site new cooling water. So ultimately is promising. Some small modular nuclear reactors might be sited alongside existing GW-scale plants owned by nuclear utilities or at existing plants due for decommissioning.

US nuclear power reactors under construction

Site	Technology	MWe gross	Proponent/utility	Construction start	Loan guarantee/ commercial operation
Vogtle 3, GA	Westinghouse AP1000	1250 (1117 net)	Southern Nuclear Operating Company	March 2013	has loan guarantee; Q1 2023
Vogtle 4, GA	Westinghouse AP1000	1250 (1117 net)	Southern Nuclear Operating Company	Nov 2013	has loan guarantee; Q1 2023

Subtotal under construction: 2 units (2500 MWe gross, 2234 MWe net)

Source: World Nuclear Association

Enrichment costs are skyrocketing. What is the fastest path toward the US having an answer?

The Department of Energy has developed the Uranium Strategy that will provide a small number of long-term offtake agreements for industries interested in siting conversion and enrichment facilities in the United States. We only have one commercial-scale enrichment facility and one conversion facility that is not currently operating. The US has nearly 20% of the reactors on the planet, and they need enrichment, not just for advanced reactors, which require even more enrichment, but for existing reactors that need enriched material. We can no longer trust all of the sources of enriched material that we have historically trusted. Some of our material comes from Russia, a weakness in our supply chain that we need to be ready to bolster. So, we are working with Congress to identify the funds necessary to execute long-term offtake agreements.