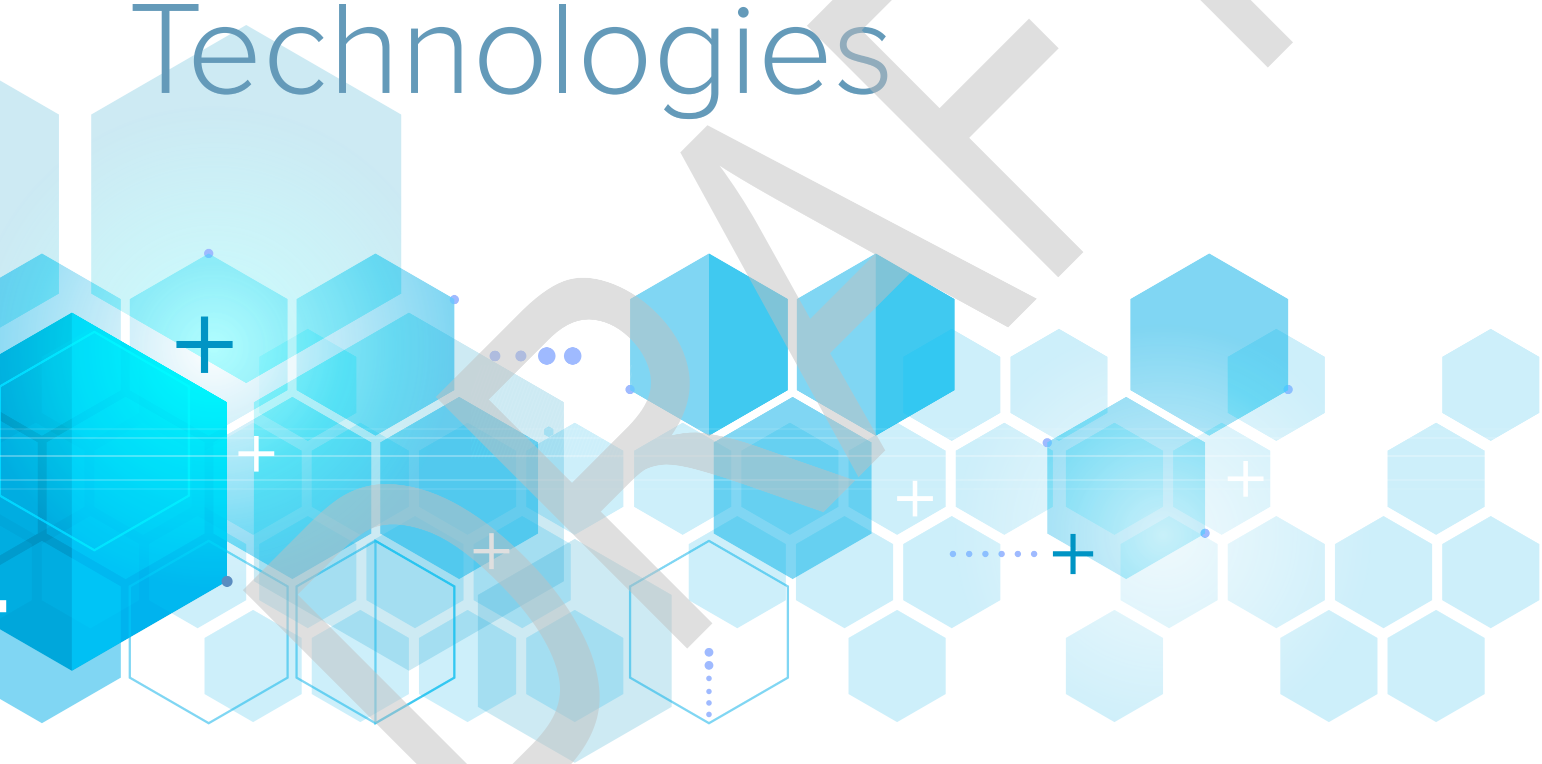
# Draft Blueprint for Consideration of Advanced Nuclear Technologies



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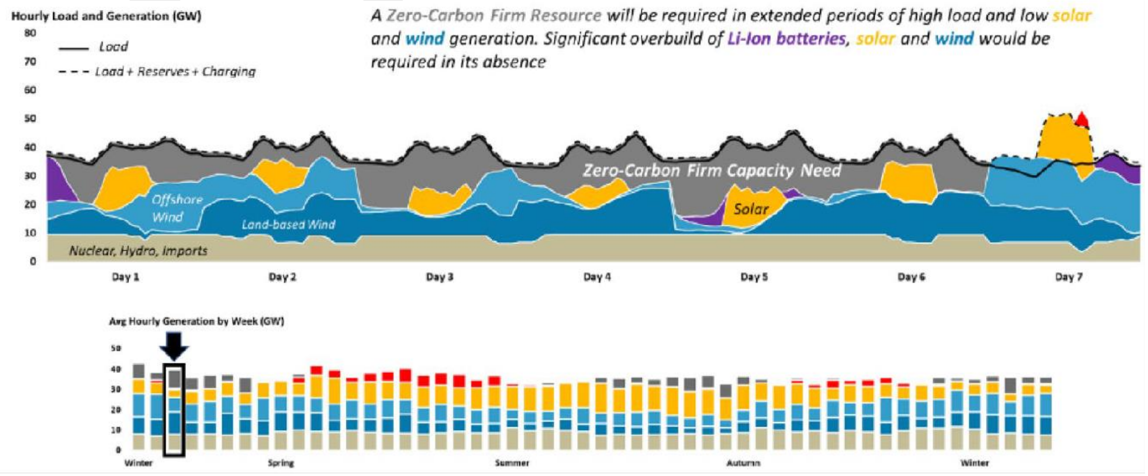
# 1 Introduction: Potential Role of Advanced Nuclear Technologies in New York's Energy Future

A clean, reliable, and affordable energy system is critical to the future of New York's economy and the health and prosperity of all its citizens. To realize that future, the Climate Leadership and Community Protection Act (CLCPA) directs the Public Service Commission (Commission) to ensure that the statewide electrical demand system is "zero emissions" by 2040 (0×40) and directs all State agencies to pursue a carbon-neutral economy by 2050.[1] The state is on its way to meeting these objectives through increases in distributed and centralized solar energy, wind power, energy storage and other measures, through ongoing proceedings before the Commission which also provide opportunities for public input into future decision making. The Commission has not adopted a definition of "zero emissions," but, in the 2016 order through which it established the Zero Emission Credit (ZEC) program, the Commission characterized existing nuclear generation as a zero-emission technology.

Nonetheless, studies identify a critical need in the path to a zero emissions grid in New York: controllable clean electricity technologies that can reliably meet the demand for power throughout the year, even when onshore and offshore wind and solar energy are less available. The New York Independent System Operator (NYISO) refers to these technologies as Dispatchable Emissions Free Resources (DEFRs). Figure 1 from the Climate Action Council's analysis of a fully decarbonized electric system illustrates this need across several simulated days; the need is most pronounced during prolonged periods of low solar and wind output.

### Figure 1. Need for Zero-Carbon Firm Capacity in a Decarbonized New York Grid in 2050

*Sources and Notes: Figure is from the New York State Climate Action Council Scoping Plan Appendix G: Integration Analysis Technical Supplement New York State Climate Action Council Scoping Plan, Section I - Page 50.*



New York's need for DEFRs will increase as demand grows, as fossil-fired dispatchable resources are phased out, and as the 2040 and 2050 deadlines approach. The Climate Action Council's analysis shows that the state will need approximately 20 GW of dispatchable clean power to complement the wind and solar resources on the system by 2050.[2] Similarly, the NYISO forecasts even larger requirements for decarbonized firm resources, identifying needs that extend beyond 25 GW statewide by 2040 and exceed 40 GW in some scenarios.[3]

Along with increased energy efficiency and load flexibility, a number of technologies are advancing to meet this need. A partial list of these options includes advanced geothermal power, long-duration storage, and hydrogen. This is highly positive, as it is unlikely that a single technology will emerge to meet this large, critical need.

In addition to other options, a growing and innovative group of advanced nuclear energy technologies has recently emerged as a potential source of dispatchable carbon-free power.[4] The potential is highlighted in the U.S. Department of Energy's Pathways to Commercial Liftoff: Advanced Nuclear report and federal support for new nuclear development, with the passage of the ADVANCE Act in 2024, which reduces licensing fees and streamlines NRC regulatory processes with the goal of accelerating deployment timelines.[5]

The term advanced nuclear represents a suite of technologies, a description of which is provided in subsequent sections of this document. Advanced nuclear technologies could offer attractive possibilities for New York, with its scalability, economic development, low land use, and potential applications of process heat. It may represent an opportunity for additional grid capacity to support an electrifying economy, that can complement New York's buildout of renewables. Yet advanced nuclear technologies raise a host of questions that would have to be addressed before planning on it, regarding technological readiness, costs and cost risks, environmental justice, among other factors.

Accordingly, this discussion paper examines a number of advanced nuclear technology options from the standpoint of technological readiness and systemic challenges and issues. The objective is to surface the most important opportunities, issues, and questions associated with these options to create a platform for additional analysis and stakeholder input on these options that moves New York forward towards its energy, economic, climate, and equity goals.

# 2 Profile of Advanced Nuclear Technologies

The profile of advanced nuclear technologies covers issues and considerations including performance profile, land use, modularity, workforce, economic development, and other applications. Considerations can also extend beyond the electricity system to include supporting communities and other economic sectors within the state.

## 2.1 Performance Profile

Nuclear energy does not produce direct emissions. From a lifecycle perspective, nuclear reactors have demonstrated the lowest lifecycle emissions of any generation technology.[6] Existing vintage nuclear plants operate continuously today when not in a refueling or other outage; the existing U.S. nuclear fleet has been able to operate as "baseload" capacity with over 90% capacity factor. Advanced nuclear technology could similarly serve as baseload duty but is designed to be controllable, thus serving as a dispatchable clean resource to complement wind and solar resources. In addition to its controllability, advanced nuclear technologies have minimal susceptibility to weather-related events, adding resilience to the electric system.[7] It also adds stability to the grid by virtue of its large, synchronized steam turbines.[8] Thus, as a firm resource, advanced nuclear technologies could serve a role as a balancing and regulating resource in a deeply renewable electric grid. Advanced nuclear technologies as a co-located resource to a large commercial, industrial, or manufacturing facility could support significant new economic development due to their potential as a resource to supply continuous power able to support such facilities.

## 2.2 Low Land Use and Modularity

In New York, where land is often at a premium with competing demands for limited space, advanced nuclear technology resources have a very small geographic footprint. For example, nuclear generation uses only about 1% of the land that solar panels would require for a similarly sized system.[9] Such density enables siting plants near existing grid infrastructure even if land is constrained.

In addition, advanced nuclear reactors are designed to be "modular" with smaller units that are easier to site and construct, or to expand into larger multi-unit plants. Modular design allows more of the plant to be built in a factory. This could better leverage economies of learning and standardization, reducing the amount of on-site work required and resulting in shorter construction times and lower capital cost and risk.[10]

## 2.3 Workforce and Economic Development

Although the workforce and economic impacts of advanced nuclear technologies are likely to vary based on the technology type, size and application, these plants have the potential to provide substantial direct and indirect economic benefits. The construction of advanced nuclear plants has been estimated to potentially create large numbers of high-wage jobs, with a potential for a plant's construction to employ more than a thousand workers[11]. Thereafter, construction of subsequent plants could extend such employment opportunities over a worker's career span.

In each advanced nuclear plant's operating phase, it is estimated that several hundred jobs would persist, with high median salaries for energy industry workers.[12],[13] In addition to providing higher average salaries than at other electric generating facilities, nuclear plant workers are typically drawn from the existing labor pool in surrounding communities. Nuclear plants also typically support job creation in the surrounding communities. The Nuclear Energy Institute (NEI) has estimated that "for every 100 nuclear power plant jobs, 66 more jobs are created in the local community for people from a wide range of fields and backgrounds."[14]

If sited as replacement for fossil-fired plants that will be closing, it has been suggested that new advanced nuclear plants could leverage pre-existing transmission connections and replace lost jobs.[15] In one case study, the possible replacement of a 650 MW coal plant with a 925 MW nuclear plant was estimated to create a net increase of 650 full time jobs.[16]

Advanced nuclear technologies may also create opportunities for indirect economic benefits through supply chains, some of which may locate and grow in New York. New York is already home to 32 companies in the nuclear industry, 31 of which also supply the nuclear naval fleet, and hosts nation- leading nuclear education programs.[17],[18] New development in the supply chains would lead to the creation of several hundred additional ongoing jobs and community development in the State.[19]

## 2.4 Potential Supplemental Applications

Beyond providing firm electric energy and capacity, advanced nuclear plants have the potential to provide other benefits, including waste heat that could be used for district heating.[20] Some advanced nuclear reactors operate at temperatures that enable them to supply high-quality heat for industries such as chemical manufacturing, steel production, hydrogen production, and other high-energy-demand sectors that are difficult to electrify.[21] While these use cases could be promising, their applicability to New York's industrial sector would have to be explored and would require extensive coordination among stakeholders.

# 3 Overview of Advanced Nuclear Technologies

The technologies discussed in this blueprint are known as advanced nuclear technologies, which are distinct from conventional reactors operating in the United States today. Today's fleet consists entirely of large light water reactors (LWR), which use boiling water or pressurized water as the coolant (to transfer heat for the steam generator and act as a moderator) and which generate in the hundreds of megawatts (MW).[22] The exact definition of "advanced" nuclear reactors varies, but all advanced options have features that substantially improve on current operating reactors, incorporating passive safety systems and other improvements in safety features, modular construction, or versatility in operation.[23]

A significant design change in many advanced reactors is the use of non-water coolants, which allows safer lower pressures even at higher operating temperatures that increase the efficiency of electricity production, and which changes the nuclear reaction conditions. Water moderates, or slows down, the neutrons in the reactor, which (counterintuitively) increases the likelihood that more fission reactions will occur when neutrons collide with uranium atoms. Consequently, water-cooled reactors require less uranium. In the absence of water, sustaining the nuclear chain reaction requires either (1) adding an alternative moderator, such as graphite;[24] or (2) increasing the concentration of uranium in the reactor core, in what is called a "fast" reactor. Fast reactors can utilize more of the uranium and extract up to 70 times more energy per unit of fuel than in moderated reactors.[25]

Table 1 summarizes the many advanced nuclear plant options under development today. In this table, new technologies are classified by the coolant cycle they use (top row of Table 1) and by three size ranges for the reactors shown in the rows: large scale (above 300 megawatts of electric output or MW), small modular reactors (SMRs, 51 to 300 MW), and microreactors (1-50 MW).[26] Some of the terms such as "SMR" and "microreactor" lack fully uniform definitions across the industry. For example, some may use "SMR" to refer to only light water reactors, while others include all reactors that are small and modular. Modularization and standardization are industry-wide goals and are not exclusive to reactors with under 300MW of capacity.

Turning to the columns, all of them in Table 1 refer to nuclear fission technologies except the final column, which is devoted to fusion reactors. The final row in the table indicates the form of nuclear fuel associated with the coolant cycle in that column. Nuclear technology discussions also often refer to "generations" of nuclear designs, with current operating reactors referred to as "Gen III" and the newer technologies in Table 1 as Gen III+ or Gen IV.[27]

In many of these combined technology/size categories, there are a number of innovative new companies and designs being developed, each with its own unique features. Recognizing these differences, the categories in Table 1 are nevertheless helpful for grouping the issues that merit further consideration when evaluating these technologies. For example, applications for reactors in the same size classes are typically similar. Large-scale reactors or combinations of co-located smaller reactors are expected to be used for grid electricity and very large industrial sites, including large hydrogen generation sites or data centers. Microreactors could be advantageous for their ease of transport, load-following capabilities, no requirement for water, and flexibility to operate either on or off the electric grid.[28]

**Table 1. Advanced Reactor Technology Types and Example Company Technologies**

| | **Water-Cooled Light Water** | **Non-Water Cooled** | | **Fusion** |
|---|---|---|---|---|
| | | **Sodium/Molten Salt** | **High Temp Gas** | |
| **Large Scale ( >300 MW)** | Westinghouse AP-1000 | TerraPower Natrium | | Commonwealth Fusion SPARC |
| **Small Modular (<300 MW)** | NuScale VOYGR | Advanced Reactor Concepts ARC-1000 | X-Energy Xe-100;<br>General Atomics EM2 | |
| **Micro-Reactors (1-50 MW)** | | Oklo Aurora | BWXT Advanced Nuclear | |
| **Form of Fuel** | Conventional LEU | HALEU, TRISO, or other non-traditional forms of uranium-based fuels | | Forms of Hydrogen and Helium |

## 3.1 Light Water Reactors

The first column in the table is for advanced water-cooled, light water reactors (LWRs), which, like the prior generation of reactors, use water as the coolant and uranium fuel rods as their fuel. Yet advanced LWRs incorporate inherently safer designs with passive control systems that reduce reliance on external power supply or operator intervention for essential accident mitigation functions.[29]

Large-scale advanced LWRs are the only category of reactors on this table that are now fully commercial; Georgia Power has just completed the installation of two units in this category, Vogtle 3 and 4, and is now operating them. Unlike all other reactors in Table 1, the next AP1000s to be built will therefore not be “first-of-a-kind” (FOAK) and so can leverage learnings from the first units, but neither would they be “Nth-of-a-kind” (NOAK) plants that are fully down the learning and cost curve.

Water-cooled Small Modular Reactors (SMRs) share many design elements with advanced larger LWR reactors.[30] SMRs are a size class typically understood to produce less than 300 MW and are capable of being deployed and operated in multiples at a single site.[31] One water-cooled SMR design in the U.S., NuScale’s US600,[32] has received design approval from the Nuclear Regulatory Commission (NRC), making it the closest to commercial operation of all options other than advanced full-scale LWRs. Several other light water SMRs are in pre-application engagement processes with the NRC, including water- cooled designs by Westinghouse, Holtec, and GE-Hitachi Nuclear.[33] The GE-Hitachi design has been selected by the Darlington project in Ontario, which also features a collaboration with Tennessee Valley Authority to develop a reactor design ultimately certified and installed in the U.S., Canada, and in Europe.[34]

## 3.2 Sodium and Molten Salt Reactors

The second column of Table 1 refers to reactors that use some form of chemical salt as the coolant. Sodium-cooled reactors use liquid sodium metal as the coolant. This coolant enables certain advantages, such as improved energy production efficiencies due to higher operating temperatures, increased safety due to much lower operating pressures (less than one atmosphere compared to 150 atmospheres in LWR reactors), and the potential to store energy thermally as molten salt, but also introduces new challenges discussed in Section IV.[35],[36]

Molten-salt reactors typically use molten fluoride or chloride salt as the primary coolant. The use of molten salt enables dissolving the fissile materials into the coolant so the salt can be heated directly by the fission reaction. Additionally, “fast reactor” designs increase the energy yield from the uranium fuel.[37]

TerraPower’s Natrium reactor technology is one example of a sodium-cooled fast reactor.[38] According to the NRC, its safety and environmental reviews are each 8% complete. Until these reviews are complete, no actual nuclear plant construction can begin, but TerraPower has begun site preparation at the site of an abandoned coal plant in Kemmerer, Wyoming.[39]

Molten-salt SMRs and microreactors (column 2, rows 2 and 3) are also under development, and several appear to be on track for commercial operation in the 2030s. To cite one example, Kairos Power has submitted a pair of applications for test reactors to the NRC, which are used to verify reactor safety and provide additional experience with new technologies.[40] In December of 2023, Kairos received NRC approval for its first 35 MW test reactor in Oak Ridge, Tennessee.[41] This unit, which will not produce electricity, is currently under construction with a targeted completion date of 2027.[42] Smaller (15 MW) liquid metal-cooled, metal-fueled fast reactors are also under development by Oklo and aim to achieve commercial operation in the 2030s.[43]

The molten salt and liquid sodium reactors in column 2 differ from LWRs not only by their coolants and presence of a moderator, but also by the form of nuclear fuel they consume. Nearly all proposed non- LWR designs use a different type of fuel than the low-enriched uranium-235 fuel rods used in LWRs. While the forms of these fuels vary, most use a form of uranium that is enriched to higher levels of the U- 235 isotope called High-Assay Low-Enriched Uranium, or HALEU. The different types of reactors use HALEU in different forms, including zirconium fuel rods and a pebble-like fuel form known as TRISO.[44] These new forms of fuel raise a number of supply chain, nonproliferation, nuclear waste, and safety issues which are discussed in the next section.

## 3.3 High-Temperature Gas Reactors (“HTGRs”)

The third column of Table 1 refers to reactors that use gas rather than water, sodium, or molten salt to cool the reactor, but otherwise operate similarly to sodium and salt-cooled designs. Gas reactors operate at higher pressures than sodium and molten salt reactors, but still lower than LWRs (approximately 70 atmospheres). They reach higher reactor temperatures, (hence “HTGR”), enabling applications for high- temperature industrial heat or for more efficient electricity generation than LWRs.[45],[46] HTGRs can also be designed to act as fast reactors when a moderator material is not added in the reactor core. Most of these technologies use HALEU fuel in the same variety of forms as sodium-cooled or molten-salt reactors, with the same attendant fuel supply, waste, nonproliferation, and safety considerations.

One SMR-sized model as well as a number of microreactors that use gas coolants are under development. The timelines for commercializing these technologies are uncertain. X-Energy plans to deliver a commercial four-unit generation facility using its Xe-100 reactor by the “early 2030s”.[47]

The 320 MW plant has pre-selected Seadrift, Texas as the location; however, the plans are still in the pre-application process with the NRC. Also in the pre-application process is the EM2, a 265 MW helium-cooled fast reactor from General Atomics Electromagnetic Systems.

## 3.4 Fusion Reactors

Fusion power plants (Table 1, column 4) use a fundamentally different type of nuclear reaction from all prior and existing nuclear plants, which rely on nuclear fission. Fusion is a nuclear reaction that releases atomic energy by fusing two atoms (typically forms of hydrogen) into a larger, non-radioactive atom such as helium. This process can release large amounts of energy sufficient to make steam for electrical turbines or heat for other uses.

The main technical challenge with fusion is that the fusion reaction can only occur when the gaseous fuel atoms are compressed together with enormous force. The energy to create this compression can come from magnets, lasers, or other energy sources.[48] Because enormous energy is required to contain and compress fusion fuel to cause the reaction to occur, thus far no commercial company has been able to gain more energy out of a fusion reaction than they put in to cause and contain the reaction.[49] Fusion could become a viable option for New York's energy supply only if and when a company can demonstrate the ability to achieve net positive power generation from fusion at a competitive cost.

Nevertheless, several companies are pursuing commercial fusion and making progress towards the goal of net positive power output. Some of these companies aspire to commercialization timelines that make them relevant for the state to consider as part of its further energy planning. For example, Commonwealth Fusion Systems claims that it will have a commercial power generator operating "within the next decade."[50]

This and other claimed fusion reactor timelines may be unrealistic, but even with a longer commercialization period some consideration of this technology may be warranted. If commercially successful, fusion power has the potential to unlock enormous amounts of carbon-free heat and power ideal for supplementing wind and solar energy. Fusion plants use no uranium-based fuels and therefore eliminate the need for a complex and environmentally difficult fuel supply chain as well as geopolitical and national security issues associated with fission fuels. Although the fusion reaction itself produces high amounts of radiation when operating, the reaction leaves behind relatively short-lived nuclear waste products that decay to safe levels within decades and do not require long-term storage like fission wastes. In addition, fusion power plants are considered to be “inherently safe” from local accidents because any disruptive incident (loss of power, explosion, etc.) would stop the nuclear reaction and risk only the release of short-lived, low level radioactive waste.[51]

# 4 Issues for Consideration

The emergent state of advanced nuclear technologies gives rise to the need for discussion of several considerations. Deciding to pursue deployment of nuclear energy in the State would require further inquiry into each issue, stakeholder engagement, and participation in a coordinated, sustained, national, and industry-wide strategy. Potential topics for stakeholder discussions are included in this chapter.

## 4.1 Technological Readiness

All new energy generation technologies face questions of technical readiness: does the technology work in commercial applications? As noted by experts at the Oak Ridge National Laboratory, the underlying fundamentals of nuclear technology have been largely unchanged for some time.[52] LWRs have been operated commercially for decades. As for non-LWR approaches, the United States has developed, tested, and even operated molten salt reactors, sodium-cooled fast reactors (SFRs), and HTGRs for over five decades, but never on a commercial basis.[53]

In the heavily regulated nuclear industry, final stages of readiness are determined by the NRC. This determination is very specific to each reactor design, so each new option moves on its own path and timetable. Historically, technology milestones in nuclear technologies have often been extended due to technical challenges that take longer to resolve than expected. For example, reactors using non-light water coolants require fabrication of new materials and acceptance of manufacturing processes for them into codes and standards—a process whose timing is difficult to predict.[54]

In the often-lengthy period prior to a new reactor design entering the NRC licensing process, the stage of technological development and timeline to commercialization is especially difficult to assess. Many developers of new advanced nuclear technology options have predicted near-term commercial readiness. Both projects selected for cost-sharing by the Advanced Reactor Development Program (ARDP) of the U.S. Department of Energy claim that they will be online by 2030.[55] The ARDP also provided five additional U.S.-based reactor development teams with grants to address technical and regulatory issues on designs that they claim could have demonstration projects operational by 2035.[56]

In addition to the readiness of the specific reactor, the readiness of the fuel supply for each new reactor type must also be assessed. As noted in Section III, all advanced nuclear technology options other than fusion use one of several new forms of uranium fuel. The facilities that manufacture these fuels are also not yet licensed by the NRC nor established in commercial operation, and their technological maturity is just as important as reactor readiness. As an example, the Natrium demonstration plant discussed above has delayed its proposed operating date beyond 2028 due to the lack of its particular fuel, zirconium alloy fuel rods filled with HALEU.[57]

Key questions for the State to consider in technical readiness include:

- How can the State and its stakeholders access sufficiently objective and transparent information on technical readiness?
- At what level of technical readiness should the State begin more intensive consideration of new advanced reactors within energy plans?

## 4.2 Licensing, Safety, and Siting

### 4.2.1 Safety Risks and Perceptions

All nuclear reactors must possess safety systems that, in the event of irregular operating conditions, can control (stop) the fission reaction, ensure the adequate cooling of fuel, and prevent the release of radioactivity into the environment. Statistics indicate that the U.S. commercial nuclear industry's safety record has been strong and improving, with the lowest level of overall safety-related impacts of any major energy source.[58] Nonetheless, public concerns about nuclear safety remains high, prodded by the highly visible accidents at Three Mile Island (1979), Chernobyl (1986), and Fukushima (2011).

Advanced reactors offer the promise of safer designs that could reduce both the likelihood and consequences of core damage events.[59] All of the advanced technologies take advantage of passive, "inherent" safety features that cause a reactor to shut down safely without the need for operators to take remedial action after the loss of electrical power or reactor coolant. SMRs have evolved from conventional LWRs to achieve the necessary safety functions through passive systems and their geometric design. Non-LWR advanced reactors (Gen IV) also integrate inherent safety features that are derived from the basic material and chemical characteristics of the design.[60] For example, the negative reactivity coefficient for HTGRs and fast reactors, when designed correctly, prevents a runaway reaction, and automatically stops the fission process when the reactor becomes too hot or loses coolant.

The design to automatically power down safely may not eliminate all operating or accident safety risks. The reactor design must perform as it has been designed to act, including the behavior of many new processes, reactions, parts, and materials that will be new in the advanced technologies. The NRC's current licensing process of all new, advanced nuclear reactors has so far utilized only historical data and may not account for projected environmental conditions resulting from climate change.[61]

While advanced reactor designs do inherently reduce the risk of a meltdown, as with all reactors, their performance could depend on operating conditions. To cite two examples: (1) the success of a sodium- cooled fast reactor's ability to prevent a runaway reaction relies on the temperature of the coolant remaining stable, which is questioned under certain conditions;[62] and (2) for HTGRs, many of the inherent safety features rely on the quality of the TRISO fuel and could potentially be undermined by any defects in the facility that produces the fuel.[63]

Concerns have also been expressed about the NRC's ability to regulate and ensure safety for the large number of very different reactor designs that are likely to enter full-scale licensing in the next several years. These concerns have been expressed by both nuclear opponents, who are concerned that the agency is rushing approvals in response to criticisms that it has been too slow, and nuclear proponents, who believe the NRC is not moving fast enough and does not have sufficient staffing and expertise.[64],[65] The recently-enacted federal ADVANCE Act is aimed at some of these issues by directing increases in the NRC's staff, among other measures.

Key questions for consideration by the State for nuclear safety include:

- How can the State participate in or monitor NRC safety licensing processes for each design that may be built within New York?
- How can the State adopt and improve best practices in nuclear safety?

### 4.2.2 Physical Security

In addition to perceived safety risks from the reactor facility designs, ensuring physical security and non- proliferation of nuclear materials related to advanced technologies are concerns that are the responsibility of the NRC and other national entities.

There are two distinct physical security threats, known as “design basis threats” (DBTs) that the NRC considers when evaluating the safety of a reactor facility: radiological sabotage (e.g., terrorists attacks), and theft or diversion of nuclear materials.[66] The current NRC framework is based on LWRs; however,

SMRs and non-LWRs could require different or additional physical security requirements[67] which the NRC is considering in an ongoing rulemaking process.[68]

Key questions for consideration by the State for security include:

- Do advanced nuclear facilities pose any significant physical security risks for the State, and if so, how can they be managed?
- Do recent cyber security events in other sectors highlight a need to assess potential cyber security risks for advanced nuclear facilities?

### 4.2.3 Siting Challenges and Opportunities

Advanced nuclear technologies possess characteristics that have the potential to serve as grid connected facilities or industrial co-location facilities. Ideally, with the inherent safety design features, advanced designs may allow for units to utilize existing power infrastructure and provide local communities with economic opportunities.

The NRC requires reactor sites to be at least 20 miles away from population centers.[69] In 2023, the NRC proposed guidance to expand potentially available sites for advanced nuclear plants by relying on technology-inclusive, radiation exposure risk-informed, and performance-based metrics when determining siting of advanced reactors, including both light-water SMR and non-LWR technologies.[70]

Consistent and deliberate engagement with communities in areas for potential new nuclear facilities is an essential component of sound energy planning and environmental justice. Siting conversations must engage all community stakeholders early, with the opportunity to state and address concerns, to ensure that any opportunity provided by any new energy resource is fully deliberated.

Key questions for consideration by the State for advanced nuclear plant siting include:

- What process should the State use to engage in siting conversations with stakeholders?

## 4.3 Environmental and Climate Justice

New York is committed to integrating environmental and climate justice into the actions needed to address the transition to a clean energy economy. The Climate Act directs the State to "prioritize the safety and health of disadvantaged communities" and require a minimum of 35% with a goal of 40% of the overall benefits of clean energy and energy efficiency programs, projects, or investments in the transition to be directed to these communities.[71]

The environmental and climate justice dimensions of advanced nuclear options begin with the mining and processing of uranium fuels. Uranium mining occurs in open pit mines that expose miners and nearby communities to elevated levels of radiation and other toxic chemicals used in the initial steps of fuel processing. In the U.S., uranium mining occurs predominantly on Indian Nations/Indigenous Nations land, sometimes disrupting sacred sites and raising strong equity concerns.[72] If new nuclear plants of any size are sited in New York, environmental and climate justice issues will be extremely important to assess and prioritize for the communities surrounding the plant.

Key questions for consideration by the State for environmental and climate justice include:

- What role should the State play in promoting environmental and climate justice in the fuel cycle of advanced nuclear facilities in view of the fact that almost all of this activity will occur out-of- state?
- How should siting advanced nuclear technologies incorporate the environmental and climate justice concerns of surrounding communities?
- How can New York's planning and oversight processes ensure that underserved and historically marginalized populations have equitable access to training and job opportunities in new nuclear projects?

## 4.4 Costs, Supply Chain Development, and Financing

### 4.4.1 Cost and Cost Uncertainty

Nuclear plants in the U.S. have a long history of substantial cost overruns. The most recent commercial reactors to be completed, the Vogtle units, were originally estimated to cost $13 billion ($5,834/kW) but eventually cost $32 billion ($14,362/kW), with a 7-year delay.[73] An analysis of the cost overruns identified some best practices that were not followed, especially emphasizing pre-project planning. Other factors mentioned in the analysis were the bankruptcy of Vogtle's initial EPC contractor due to the fixed- price nature of its contract and increased accrual of interest during construction as delays mounted.[74] In addition, suppliers "lacked experience…to successfully manufacture nuclear components," leading to high rates of manufacturing failure. Finally, reductions in the price of natural gas created supplier commitment risk, as investors and suppliers worried about Vogtle's ability to price its electricity output competitively and thus demanded more assurances.[75] Notably, South Carolina's proposed VC Summer plant (which also used Westinghouse AP1000 Gen III+ reactors), was cancelled under the weight of cost overruns in the billions.[76]

For any new nuclear reactor technology, a FOAK plant's cost will be high and very uncertain. Costs will be high because details underlying the design, construction, and manufacturing remain exploratory and immature, leading to longer construction periods, less efficient execution, costly specialized parts, and more rework. The uncertainties may be even higher than those associated with offshore wind, which sought to replicate already-mature technologies and construction methods from Europe. Costs and cost uncertainties will tend to decrease with learning and supply chain development when progressing toward a NOAK plant.

Several studies estimate the costs of FOAK and NOAK plants, as well as "between-of-a-kind" (BOAK) between FOAK and NOAK, which might be relevant for New York if building on the designs of the FOAK projects identified in Table 1. Table 3 below summarizes overnight capital cost estimates from a recent meta-analysis by Idaho National Laboratory for non-technology specific advanced nuclear technology. [77]

**Table 2. Estimated "BOAK" Overnight Capital Costs for Large Reactors and for SMRs ($2024/rounded)**

*Source: Recreated from p. iv, Idaho National Laboratory, Meta-Analysis of Advanced Nuclear Reactor Cost Estimations, July 2024*

| Advanced Reactor Type | Estimated Costs |
|---|---|
| Large Reactor (>400 MW) | $3,400 - $8,400 / kW |
| SMR (<400 MW) | $2,800 - $9,000 / kW |

NOAK project costs should be lower but are also uncertain and will take more time to be revealed. For example, DOE's liftoff report projects a $3,600/kW NOAK cost for large light water reactors based on experiences in South Korea, estimating at least 10 units to be necessary to realize NOAK costs. SMR Start, an industry group, estimated Light Water SMR NOAK costs to be $2,500/kW with a 10% learning curve and $2,000/kW for a 15% learning curve, assuming NOAK costs are reached after 36 units.[78]

Key questions for consideration by the State for construction cost uncertainties include:

- What is the likely realistic cost range for each technology, and how does this enter into the State's consideration?
- How should the State assess the factors that affect the cost of new plants? The DOE Supply Chain Deep Dive report suggests "nuclear construction costs depend more on overall project management, experience accumulated over multiple units, regulatory interactions, contracting approaches, and local prices for labor and commodity inputs than on the direct costs of the reactor or any other equipment."[79]

### 4.4.2 Construction and Labor Supply Chain Development

Any nuclear plant (or fleet of smaller ones) requires specialized and non-specialized labor all converging in one place to work with several major types of specialized equipment, components, and materials. The interrelated nature of complex nuclear construction means delays or quality problems in one element affects the others and prolongs work crew timing and costs, with the potential to create cascading project delays.

One often-cited challenge for plant builders is a weak U.S. nuclear construction supply chain following a several-decade pause in building new plants. Few domestic manufacturers are "N-stamped" by the American Society of Mechanical Engineers (ASME) to provide nuclear-grade components. Until domestic suppliers obtain this certification, which takes considerable commitment and time, U.S. builders will remain reliant on foreign suppliers for many critical components and compete with overseas plants under construction for limited supplies.

A fairly well-established global supply chain exists for at least the Gen III+ LWR equipment, components, and materials to support the development of early projects, albeit with uncertainties and risks for certain components that are novel or poorly specified by the plant designer. In addition, many developers of new technologies are acutely aware of supply chain issues and have been participating in developing new suppliers for their designs, although more project commitments are needed to solidify the development path. The Department of Energy's Nuclear Supply Chain Deep Dive report offers an extensive look at the new types of factories needed to sustain an advanced nuclear technology component supply chain and the certifications required for both new plants and existing manufacturers.

One uniquely important part of the construction supply chain is construction labor. According to Reuters, large-scale nuclear plant builds require about 1,200 workers, many with specialized trades such as nuclear-certified welders.[80],[81] The DOE Advanced Nuclear Liftoff report projects that about 275,000 construction workers will be needed if advanced nuclear plant construction reaches the levels it believes are necessary for achieving nationwide net zero by 2050, or about 13 GW/year.[82] This raises concerns over the availability of both skilled and unskilled labor for plant construction, but also an opportunity to create many new high-paying construction jobs in the state.

Key questions for consideration by the State for the construction cost supply chain include:

- How should the State consider construction supply chain issues in its consideration of advanced options? If so, what level of plant- or design-specific examination is appropriate?
- How do national supply chain shortages impact economic development of advanced nuclear technologies in the State?
- Can State-level policies influence supply chain improvements?
- Do national supply chain shortages create an opportunity for economic development of supply chain-related business into the State?
- How can the State assess and improve nuclear workforce readiness, and is there an opportunity to export readiness training nationally?

### 4.4.3 Project Development and Financing Concepts

Given the varied state of technology across the current suite of advanced nuclear technologies, it should be acknowledged that the timing for development of any of these technologies will depend on the time for plant designs and construction capabilities to progress on a learning curve, the development of associated supply chains and the successful demonstration of facilities to satisfy safety, performance and scalability considerations. The State has the opportunity to participate in the national activities that are designed to lead to technology demonstrations and supply chain development, which may involve the cultivation of local labor forces and supply chain niches. Even where demonstration projects are potentially uniquely designed, or given construction processes are partly technology specific, consideration of participation in demonstration projects that cultivate labor and supply chain development may be beneficial.

Development concepts for a FOAK plant would have to consider how best to allocate construction cost overrun and cancellation risk between customers, plant developers, plant construction firms, capital providers to all these parties, the State, and the Federal Government. There are a number of potential contractual and financial structures that the State could consider, as well as potential State engagement in current or upcoming federal government technology support programs.

Further federal assistance would be essential for pursuing a FOAK plant, recognizing the public-good value of the learnings that would enable others to build plants further down the cost curve. Federal assistance could include a federal cost guarantee, loan guarantee, or direct federal assistance in aid of construction. In addition, new plants could take advantage of tax credits made available by the Inflation Reduction Act:[83]

- The Clean Energy Investment Tax Credit (ITC) can credit developers 30% of a plant's initial capital cost if meeting wage and apprenticeship requirements, with additional bonuses of 10% each for use of domestic content and location within energy communities.
- The Clean Energy Production Tax Credit (PTC) offers developers credits of up to 2.75 cents per kWh assuming satisfaction of wage and apprenticeship requirements, with similar bonus categories to the ITC, except with a 3 cent per kWh addition per criteria met.

Non-taxable entities such as state and local governments or rural electric cooperatives can elect to receive the value of the tax credits as a direct payment from the IRS. Developers of microreactors could also seek assistance from a variety of federal customers. For example, the Department of Defense's Project Pele recently awarded contracts to two microreactor developers.[84]

Key questions for consideration by the State regarding development include:

- What is the nature of and level of development and cost risk that the state can consider in advanced nuclear technology projects?
- What policies and policy levers does the State have to reduce or allocate these risks?
- How can the value of federal incentives be maximized?
- Beyond workforce and supply chain opportunities, what could be the potential value in advancing demonstration sites?

### 4.4.4 Fuel Supply Chain Development

Fuel production involves a several-step process, from mining uranium ore and refining it into $U_3O_8$ "yellowcake powder," to converting $U_30_8$ into $UF_6$ gas, to enriching to higher concentration of the radioactive U-235 isotope, to processing into $UO_2$ and fabricating fuel rods or pellets.[85]

New water-cooled reactors use the same low enriched uranium (LEU) fuel that is used in current reactors and can draw on the same supply chain. Although the U.S. has some uranium reserves and used to have processing capability, it has almost entirely been relying on more cost competitive supplies from Canada, Australia, Russia, Kazakhstan, and Uzbekistan.[86] If the U.S. increases its reliance on nuclear, energy security concerns may require re-onshoring part of the fuel supply chain.

Nearly all of the non-water-cooled reactors will need new supply chains to produce HALEU fuels. Currently the world's only commercial HALEU production comes from the Russian company Tenex. As mentioned previously, the supply of HALEU is a bottleneck for advanced nuclear reactors coming online and proving their technological readiness. A new U.S. fuel supplier, Centrus Energy, delivered its first 100 kilograms of HALEU to the DOE in late 2023, as part of the DOE's plan to acquire 290 MT of HALEU needed to establish domestic demand.[87] Centrus used funds from the $700 million released by the Inflation Reduction Act to "help establish a reliable domestic supply of fuels for advanced reactors using HALEU."[88] While commercialization of HALEU production is still being developed, the DOE has been using "downblending" of high-enriched uranium (HEU) stockpiles to produce HALEU, but the surplus stockpiles of HEU may only produce 15 MT of HALEU.[89]

Key questions for consideration by the State regarding the nuclear fuel supply chain include:

- What level of assessment of fuel supply chain issues do stakeholders think is appropriate for further consideration of advanced nuclear technology options?
- What form and level of fuel supply assurance should be part of future state considerations of specific advanced nuclear technology options?

## 4.5 Fusion Reactors

Fusion power generators raise questions and issues that are quite distinct from many of the considerations affecting fission-based plants. Fusion plants use various forms of hydrogen or helium as fuel, where hydrogen is widely available from many domestic as well as international sources.[90] The absence of uranium fuel removes the need for uranium mining and milling, which have environmental considerations, as well as fuel enrichment and fabrication, which imply radiation safety, proliferation, and further environmental and waste considerations. In addition, as mentioned in chapter 3, fusion plants are inherently safe, with no possibility of heavy radiation-release accidents, and create no long-lived radioactive wastes. Together these attributes have led the NRC to use a comparatively modest and rapid permitting process for fusion plants, with an approximate single-permit timeline of about 2 years.

While these advantages may make fusion an attractive option, all forms of fusion are still in early demonstration. No fusion researcher or aspiring reactor manufacturer has created a sustainable fusion reaction that lasts more than a few milliseconds nor creates multiples of the energy used by the process. Demonstrating sustained technical feasibility is therefore the first critical issue for further consideration of fusion as a resource for the State.

After technical feasibility is established, the second critical threshold fusion power must clear is economic. There is too little information available today to determine the cost of building or operating a commercial fusion power plant and the resulting competitiveness of such a plant against other options. Accordingly, while it is fully appropriate for New York to closely monitor technical developments in fusion power, there is simply not enough information to give it full consideration as a potential supply option in the State's near-term energy roadmaps.

Key questions for consideration by the State regarding nuclear fusion include:

- What steps are appropriate for monitoring the progress of fusion power plants?
- At what point should further steps be taken by the State either to promote fusion as an option or to consider how fusion would fit into its energy planning and permitting processes?

## 4.6 Waste Generation and Disposal

Waste generated by nuclear fission remains radioactive for many years after it is produced, with some elements remaining radioactive for thousands of years. Although the volume of this waste is not large— all the waste generated by U.S. commercial reactors since 1950 could fit on a 100-yard football field with a depth of less than 10 yards[91]—proper handling, storage, and disposal of the fuel is critical to ensuring public safety.

Currently, nearly all nuclear waste is managed on-site at the generation facility in the form of solid spent fuel rods stored in deep pools of water for approximately 10 years after generation, and then placed in steel-lined concrete casks on the reactor site. While on-site storage is intended to be temporary (the NRC licenses on-site storage in pools and dry casks for 120 years from the plant's initial startup),[92] there are no available permanent disposal sites in the U.S.,[93] and virtually all nuclear fuel used for electricity generation still sits at the facilities where it was generated.[94] While this approach has been successful in preventing waste leakage, as dry casks approach their maximum licensing period, the risks of their failure increase. The federal government has paid over $7 billion to nuclear utilities and reactor owners in legal settlements for failing to take possession of their fuel waste and therefore requiring owners to continue to store the waste onsite.[95]

Advanced nuclear reactors produce similar types of waste to their conventional counterparts, but many designs incorporate increased fuel efficiency and waste reduction. The increased amount of uranium-235 in HALEU leads to longer fuel cycle times and, therefore, less waste production.[96] Other examples of waste-reducing measures could come from technology and fuel choice, such as the use of "fast breeder" reactor technology, which as already noted produces more fuel as waste than it uses for generation, and the use of alternative fuels such as thorium.[97],[98]

Ultimately, the responsibility for building a waste disposal plan for advanced nuclear technologies rests with the federal government. Spent fuel storage is regulated nationwide by the NRC; should a national repository become a reality, the federal government will be responsible for its management.

Key questions for consideration by the State regarding nuclear waste disposal include:

- How can the State evaluate and prioritize advanced nuclear technologies based on their waste management capabilities and overall environmental impact?
- How can the State work with the federal government to manage nuclear waste?

# 5 Next Steps

The immediate next step is for the State to provide this draft to the public. Public input will help the State form and shape the next steps for advanced nuclear technology development and technologies.

As the State considers longer term policies and strategies, current federal policies and programs may provide valuable opportunities for demonstrations supporting economic development or supply chain growth. The State may consider such opportunities as individual projects may be organized.

# Endnotes

[1] New York State Senate. 2019. S6599 – Climate Leadership and Community Protection Act. Page 17, lines 34–47. https://legislation.nysenate.gov/pdf/bills/2019/S6599

[2] New York State Climate Action Council. 2022. "New York State Climate Action Council Scoping Plan." Appendix G: Integration Analysis Technical Supplement New York State Climate Action Council Scoping Plan, p. 50. Climate.ny.gov/ScopingPlan. See also NYISO, 2023–2042 System Resource Outlook (July 23, 2024) at 8–9 ("Today, the grid largely relies on fossil generators to provide the aforementioned reliability attributes. To achieve a zero-emissions grid, a collection of generation technologies, referred to as DEFRs, must be developed and deployed throughout the State to provide, in the aggregate, sufficient grid services to maintain reliable electric service for all New Yorkers. The importance of DEFRs continues to be a critical factor as identified in the prior Outlook. In the Outlook, DEFRs are added to the postulated future resource mix to supply essential characteristics, such as dispatchability and flexibility capabilities to support a high renewable system … The results in this Outlook, however, show an increased reliance on [DEFRs] to provide both peak capacity and hourly energy to support a highly renewable system. This increased reliance is driven by the forecasted hourly profile of demand and the limitations on the duration of energy storage resources").

[3] See NYISO, 2023–2042 System Resource Outlook (July 23, 2024) at 10, State Scenario Policy Case. Note that two alternate scenarios identify DEFR needs exceeding 40 GW by 2040.

[4] See pg. 92-95, J. K. Nøland, M. Hjelmeland, L. B. Tjernberg and C. Hartmann, "The Race to Realize Small Modular Reactors: Rapid Deployment of Clean Dispatchable Energy Sources," in IEEE Power and Energy Magazine, vol. 22, no. 3, June 2024. DOI: 10.1109/MPE.2024.3357468.

[5] See Newly Signed Bill Will Boost Nuclear Reactor Deployment in the United States. Department of Energy Office of Nuclear Energy (July 10, 2024).

[6] See p.42, United Nations Economic Commission for Europe, "Carbon Neutrality in the UNECE Region: Integrated Life-cycle Assessment of Electricity Sources," 2022.

[7] See p.14, EPRI, "Nuclear Plant Resilience to Weather-Related Events Between 2011 to 2020," September 23, 2022. Report ID 3002025519.

[8] U.S. Department of Energy Office of Nuclear Energy, "What is Generation Capacity?" May 1, 2020. https://www.energy.gov/ne/articles/what-generation-capacity

[9] Lovering J, Swain M, Blomqvist L, Hernandez RR (2022) Land-use intensity of electricity production and tomorrow's energy landscape. PLoS ONE 17(7): e0270155. https://doi.org/10.1371/journal.pone.0270155

[10] Office of Nuclear Energy, "Benefits of Small Modular Reactors (SMRs)." https://www.energy.gov/ne/benefits-small- modular-reactors-smrs

[11] According to 2021 estimates by NuScale, construction of their SMR would create over 1,600 jobs (https://www.nuscalepower.com/-/media/nuscale/pdf/publications/nuscale-smr-technology-an-ideal-solution-for-coal-plant-replacement.pdf) This is aligned the Idaho Policy Institute's Economic Impact Report for the "Construction and Operation of a Small Modular Reactor Electric Power Generation Facility at the Idaho National Laboratory Site, Butte County, Idaho," in 2019.

[12] Solan, David, et al., "Economic and Employment Impacts of Small Modular Nuclear Reactors," Energy Policy Institute, June 2010. https://www.nrc.gov/docs/ML1802/ML18023A166.pdf

[13] According to the Wages, Benefits, and Change Supplement to the Annual U.S. Energy and Employment Report (pg. 58), individuals working in utilities in the nuclear industry receive the highest median hourly wage at $47/hr (25% above the average utility worker in the US).

[14] Nuclear Energy Institute, https://www.nei.org/news/2021/nuclear-in-the-neighborhood

[15] Study by Abdussami et al, 2023. https://www.sciencedirect.com/science/article/pii/S2352484724002993

[16] Hansen, Jason K., Jenson, William Dunkley, Wrobel, Anna Marie, Stauff, Nicolas, Biegel, Katie, Kim, T. K., Belles, Randy, and Omitaomu, Femi. Investigating Benefits and Challenges of Converting Retiring Coal Plants into Nuclear Plants. United States: N. p., 2022. Web. doi:10.2172/1886660. See page 72.

[17] See pg. 2, DOE Nuclear Supply Chain report.

[18] See pg. 11, Energy Futures Initiative, Inc., "The U.S. Nuclear Energy Enterprise: A Key National Security Enabler," August 2017. https://beyondnuclearinternational.org/wp-content/uploads/2021/10/b1dc5-efinuclearreportfinal08.2017.pdf. (Accessed on August 8, 2024).

[19] See pg. 8, Office of Nuclear Energy, "Coal-to-Nuclear Transitions: An Information Guide," April 2024.

[20] Sokka et al, 2024. https://www.mdpi.com/1996-1073/17/13/3250

[21] Foss, A., J. Smart, H. Bryan, C. Dieckmann, B. Dold, and P. Plachnda, "NRIC Integrated Energy Systems Demonstration Pre-Conceptual Designs," April 2021. Report for Project RC-21N020701.

[22] For the purposes of this report, "MW" (megawatt) and "kW" (kilowatt) will be used to represent "MWe" (Megawatt electric) and "kWe" (kilowatt electric), the electrical power output capacity of a plant. This is distinct from a reactor's capacity in MWt (megawatt thermal), which is the thermal capacity of the reactor required to drive the turbine that produces the plant's electrical output.

[23] The 115th US Congress Public Law 115–439 (2019) distinguishes the difference of "advanced nuclear reactors" from commercial reactors in operation today by significant improvements in inherent safety features, significantly lower levelized cost of electricity, lower waste yields, greater fuel utilization, enhanced reliability, increased proliferation resistance, increased thermal efficiency, or the ability to integrate into electric and nonelectric applications. The U.S. Department of Energy's Pathways to Commercial Liftoff: Advanced Nuclear report considers Gen III+ (large light water and light water SMRs) and Gen IV reactors as "advanced" reactors, see DOE at 16. Alternatively, the U.S. Nuclear Regulatory Commission designates advanced nuclear reactors as non-light water reactors, see NRC, Advanced Reactors (non-LWR designs) (Accessed August 2, 2024).

[24] The NRC defines a moderator as, "A material, such as ordinary water, heavy water, or graphite, that is used in a reactor to slow down high-velocity neutrons, thus increasing the likelihood of fission." See https://www.nrc.gov/reading-rm/basic-ref/glossary/moderator.html

[25] Donovan, J., "Shrinking nuclear waste and increasing efficiency for a sustainable energy future," September 2020, IEAE Bulletin, Vol. 61-3.

[26] See 42 U.S. Code § 18751 (a) (3) Micro-reactor.

[27] In Table 1, Gen III+ would largely correspond to first column, light water reactors; the remaining cells would probably be considered Gen IV. With respect to generation labels, the Electric Power Research Institute (EPRI) notes that "[T]hese terms primarily refer to the historical development period of a nuclear reactor design. GEN I refers to the earliest prototype and demonstration reactors, of which there are none left operating today. Most reactors operating globally today are of the GEN II vintage, mostly light water reactors … but also include other coolant designs. GEN III and III+ reactors incorporate evolutionary improvements in design over GEN II, targeting standardization, efficiency improvements, and advances in safety. All GEN III and III+ designs are water-based, and many plants are operating globally, with more under construction or planned. GEN IV specifically refers to a set of [reactors] currently under development and being studied by the Generation IV International Forum with expectations to start operations in the 2030's. GEN IV reactors are expected to cover a broad range of plant sizes. Light water SMRs, while often included in GEN III/III+, offer attributes that bridge the GEN III/III+ and GEN IV classes." EPRI (at § 1.4.1.1)

[28] See eVinci Microreactor – Westinghouse (Accessed on August 5, 2024).

[29] International Atomic Energy Agency, "Passive Safety Systems in Water Cooled Reactors: An Overview and Demonstration with Basic Principle Simulators," Vienna, 2019, Training Course Series 69.

[30] See NRC, Small Modular Reactors (Accessed August 2, 2024).

[31] See EPRI at 1–7, citing 42 U.S.C. § 18751. EPRI also explains that the definition of SMR may be more expansive in various other international countries, see EPRI at 1–7.

[32] See NRC, Design Certification – NuScale US600 (Accessed August 2, 2024).

[33] See NRC, SMR Pre-Application Activities (Accessed August 2, 2024).

[34] See GE Vernova, Tennessee Valley Authority, Ontario Power Generation and Synthos Green Energy Invest in Development of GE Hitachi Small Modular Reactor Technology, Press Release (March 23, 2023).

[35] See Advanced Nuclear Reactor Technology—A Primer ("ANRT"), pp. 15–16, for a brief discussion of the advantages of non-water-cooled reactors. Nuclear Innovation Alliance, July 2023.

[36] U.S. Department of Energy, "Quadrennial Technology Review 2015 Chapter 4: High Temperature Reactors," 2015. https://www.energy.gov/sites/default/files/2016/03/f30/QTR2015-4J-High-Temperature-Reactors.pdf

[37] International Atomic Energy Agency, “Fast reactors,” https://www.iaea.org/topics/fast-reactors. (Accessed on August 12, 2024). It is important to note that fast reactors are not all “breeder” reactors, which are designed to produce more plutonium than the fissile material they consume. In fact, many designs are not breeder reactors and are still net consumers of fissile material.

[38] Although its initial unit will be 345 MW and is therefore small enough to be considered an SMR, added storage technology can boost the output to 500 MW when needed. See https://www.terrapower.com/terrapower-begins-construction-in-wyoming.

[39] See NRC, TerraPower, LLC -- Kemmerer Power Station Unit 1 Application (Accessed August 2, 2024).

[40] See NRC, Pre-Application Activities for Advanced Reactors (Accessed August 2, 2024).

[41] See NRC, Hermes – Kyros Application (Accessed August 2, 2024).

[42] See Gregory Raucoules, Construction of next-gen nuclear reactor ‘Hermes’ begins in Oak Ridge, 6 ABC News (July 31, 2024). The second test reactor, also proposed for Oak Ridge, includes a multi-reactor demonstration project and is currently proceeding through regulatory approvals See NRC, Hermes 2 – Kyros Application (Accessed August 2, 2024).

[43] ANRT, p. 40 and https://oklo.com/energy/default.aspx accessed 8.7.24

[44] TRISO stands for tristructural-isotropic-coated particle fuel.

[45] See U.S. Department of Energy, “Quadrennial Technology Review 2015: High Temperature Reactors.”

[46] Sterbentz, J., et al., “High-Temperature Gas-Cooled Test Reactor Point Design,” April 2016. Idaho National Laboratory, INL/EXT-16-38296.

[47] See Office of Clean Energy Demonstrations, Advanced Reactor Demonstration Projects (Accessed August 5, 2024). Target date is from https://x-energy.com/media/news-releases/x-energy-transalta-partner-to-study-deployment-of-advanced-small-modular-nuclear-reactors-in-alberta-through-emissions-reduction-alberta-award acc. 8/22/24.

[48] There are five major technological approaches to creating fusion reactions for power generation: magnetic confinement, inertial confinement, magnetic or electric pinches, and inertial electrostatic confinement. There are other additional approaches and many sub-approaches within these categories.

[49] The U.S. DOE reported in December 2022 that fusion ignition, meaning more energy was produced than the laser energy used to drive the reaction, was achieved at the Lawrence Livermore National Laboratory. See “DOE National Laboratory Makes History by Achieving Fusion Ignition,” December 13, 2022. https://www.energy.gov/articles/doe-national-laboratory-makes-history-achieving-fusion-ignition

[50] Commonwealth Fusion Systems, “ARC: Commercialization,” https://cfs.energy/technology#arc-commercialization. (Accessed August 7, 2024).

[51] Willis, C. and J. Liou, “Safety in Fusion: An inherently safe process,” International Atomic Energy Agency, May 2021. https://www.iaea.org/bulletin/safety-in-fusion. (Accessed on August 9, 2024).

[52] See Slide 4, Terrani, Kurt, “Nuclear Reactor – Current state, challenges and future needs from materials perspective” (Nov. 21, 2019). Presentation at Oak Ridge National Laboratory. (“Few, if any, technological advanced in design, materials, sensing, and qualification approach have been brought to bear since the 1970s”).

[53] See pp. 14, 18, 23, Congressional Research Service. “Advanced Nuclear Reactors: Technology Overview and Current Issues” (February 2023). https://crsreports.congress.gov/product/pdf/R/R45706

[54] Albert, Marc, “Advanced Manufacturing and Materials.” Electric Power and Research Institute. https://ant.sf.epri.com/research/advanced-manufacturing-materials (Accessed on August 7, 2024).

[55] See X-energy and TerraPower. (Accessed on August 7, 2024).

[56] Office of Nuclear Energy, “5 Advanced Reactor Designs to Watch in 2030” (March 17, 2021). https://www.energy.gov/ne/articles/5-advanced-reactor-designs-watch-2030 (Accessed on August 7, 2024).

[57] Day, Paul, “First TerraPower advanced reactor on schedule but fuel a concern” (May 2024). Reuters. (Accessed on August 7, 2024).

[58] Prof Anil Markandya and Paul Wilkinson, Electricity Generation and Health, the Lancet, September 13, 2007. DOI: https://doi.org/10.1016/S0140-6736(07)61253-7

[59] Reyes Jr., J., F. Southworth, and B. Woods, “Why the Unique Safety Features of Advanced Reactors Matter,” The Bridge Vol. 50 No. 3 (2020). National Academy of Engineering. p. 46.

[60] See MIT at 75.

[61] U.S. Government Accountability Office, “Nuclear Power Plants: NRC Should Take Actions to Fully Consider the Potential Effects of Climate Change” (April 2024). GAO-24-106326.

[62] See pg. 59, Lyman, Edwin, “’Advanced’ Isn’t Always Better: Assessing the Safety, Security, and Environmental Impacts of Non-Light-Water Nuclear Reactors.” (2021) Union of Concerned Scientists. https://doi.org/10.47923/2021.14000

[63] See pg. 77, Lyman, Edwin, “’Advanced’ Isn’t Always Better: Assessing the Safety, Security, and Environmental Impacts of Non-Light-Water Nuclear Reactors.” (2021) Union of Concerned Scientists. https://doi.org/10.47923/2021.14000

[64] For example, the Union of Concerned Scientists has opined that “the NRC--a far weaker regulator today—has apparently changed its position and may proceed with licensing the ARDP demonstration reactors without requiring prototype testing first. But by skipping prototype testing and proceeding directly to commercial units, these projects may run not only the risk of experiencing unanticipated reliability problems, but also the risk of suffering serious accidents that could endanger public health and safety.” See pg. 9, Lyman, Edwin, “’Advanced’ Isn’t Always Better: Assessing the Safety, Security, and Environmental Impacts of Non-Light-Water Nuclear Reactors,” 2021. Union of Concerned Scientists. https://doi.org/10.47923/2021.14000

[65] An example of proponent criticism is Congress Takes Aim at the Nuclear Regulatory Commission: ‘It’s déjà vu all over again.’ Victor Gilinsky, Bulletin of the Atomic Scientists, Feb. 12, 2024.

[66] See NRC, 10 CFR 73.1. https://www.nrc.gov/reading-rm/doc-collections/cfr/part073/part073-0001.html

[67] NRC, “Draft White Paper on Potential Changes to Physical Security Requirements for Small Modular and Advanced Reactors,” November 2017.

[68] See NRC Docket NRC-2017-0227.

[69] In this guidance, population center refers to any density that exceeds 500 people per square mile.

[70] See Appendix A, U.S. NRC, “General Site Suitability Criteria for Nuclear Power Stations,” October 2023. Draft Regulatory Guide DF-4034.

[71] New York State Senate. 2019. S6599 – Climate Leadership and Community Protection Act. https://legislation.nysenate.gov/pdf/bills/2019/S6599

[72] For additional background, see Sustainable and Ethical Uranium Mining: Opportunities and Challenges, Good Energies Collective August 2022.

[73] See p.29, U.S. Department of Energy, Pathways to Commercial Liftoff: Advanced Nuclear (March 2023). Calculated by dividing total cost by 2,234 MW (the capacity of Vogtle Units 3 and 4).

[74] Ibid.

[75] See p.117, MIT Center for Advanced Nuclear Energy Systems, Capital Cost Evaluation of Advanced Water-Cooled Reactor Designs with Consideration of Uncertainty and Risk (June 2022).

[76] Sonal Patel, POWER Magazine, “UPDATED: SCANA, Santee Cooper Abandon V.C. Summer AP1000 Nuclear Units, Citing High Costs,” July 31, 2017. https://www.powermag.com/scana-santee-cooper-abandon-v-c-summer-ap1000-units-citing-high-costs/

[77] See p.iv, Idaho National Laboratory, Meta-Analysis of Advanced Nuclear Reactor Cost Estimations, July 2024

[78] See p.27, SMR Start, The Economics of Small Modular Reactors (March 2021).

[79] See p.27, U.S. Dept of Energy, Nuclear Energy Supply Chain Deep Dive Assessment (February 14, 2022) EERE Technical Report Template (energy.gov).

[80] Paul Day, Finding a workforce may be nuclear's largest challenge | Reuters, Oct 9. 2022

[81] WeldingInfo educational website. https://www.weldinginfo.org/welding-careers/nuclear-welder-job-description/

[82] DOE Pathways to Commercial Liftoff: Advanced Nuclear, March 2023 p. 31.

[83] U.S. Environmental Protection Agency, Summary of Inflation Reduction Act provisions related to renewable energy (October 25, 2023)

[84] U.S. DOD, “DOD Exercises Option on Second Micro Nuclear Reactor Design,” September 13, 2023. https://www.defense.gov/News/Releases/Release/Article/3524458/dod-exercises-option-on-second-micro-nuclear-reactor-design/

[85] See DOE Office of Nuclear Energy nuclear fuel cycle diagram.

[86] DOE Supply Chain report p.22

[87] See pg. 1-15, U.S. DOE Office of Nuclear Energy, "DRAFT Environmental Impact Statement for Department of Energy Activities in Support of Commercial Production of High-Assay Low-Enriched Uranium (HALEU)," Volume 1, DOE/EIS-0559. March 2024.

[88] The White House, "Fact Sheet: Biden-Harris Administration Announces New Steps to Bolster Domestic Nuclear Industry and Advance America's Clean Energy Future," (May 29, 2024).

[89] See pg. 2-21, U.S. DOE Office of Nuclear Energy, "DRAFT Environmental Impact Statement for Department of Energy Activities in Support of Commercial Production of High-Assay Low-Enriched Uranium (HALEU)," Volume 1, DOE/EIS-0559. March 2024.

[90] The forms of hydrogen used by most fusion processes are Deuterium (hydrogen plus one proton) and Tritium (hydrogen plus two protons); helium may also be used. Helium and both forms occur naturally in hydrogen deposits; tritium can also be made by irradiating lithium. If successful, fusion reactors may be able to produce more additional fuel than they consume, thereby creating a highly energy-positive fuel cycle.

[91] U.S. DOE, "5 Fast Facts about Spent Nuclear Fuel," October 2022. https://www.energy.gov/ne/articles/5-fast-facts-about-spent-nuclear-fuel

[92] U.S. NRC, "Spent Fuel Storage in Pools and Dry Casks Key Points and Questions & Answers," February 7, 2022. https://www.nrc.gov/waste/spent-fuel-storage/faqs.html

[93] The U.S. Congress designated Yucca Mountain, Nevada as the only location for a national nuclear waste repository in 1987; however, legal and political opposition to this site have delayed progress on its construction.

[94] U.S. NRC, "Backgrounder on Radioactive Waste," January 2024. https://www.nrc.gov/reading-rm/doc-collections/fact-sheets/radwaste.html

[95] Congressional Research Service, "Nuclear Waste Storage Sites in the United States," April 2020.

[96] Hatch, Cory, "U.S. researchers fabricate commercial grade uranium dioxide HALEU fuel," November 2023. https://inl.gov/feature-story/u-s-researchers-fabricate-commercial-grade-uranium-dioxide-haleu-fuel. (Accessed on August 8, 2024).

[97] See p.148, International Atomic Energy Agency, Near Term and Promising Long Term Options for the Deployment of Thorium Based Nuclear Energy (2022)

[98] Through the Advanced Research Projects Agency-Energy (ARPA-E), 11 projects have been selected to receive part of $36 million to develop technologies that reduce nuclear waste and enable recovery of uranium for fuel reprocessing. This demonstrates the federal government's reignited interest in innovative ways to manage nuclear fuel as the push for advanced reactor technology moves forward. See ARPA-E, "U.S. Department of Energy Announces $36 Million to Reduce Waste from Advanced Nuclear Reactors," March 2022. https://arpa-e.energy.gov/news-and- media/press-releases/us-department-energy-announces-36-million-reduce-waste-advanced. (Accessed on August 8, 2024).