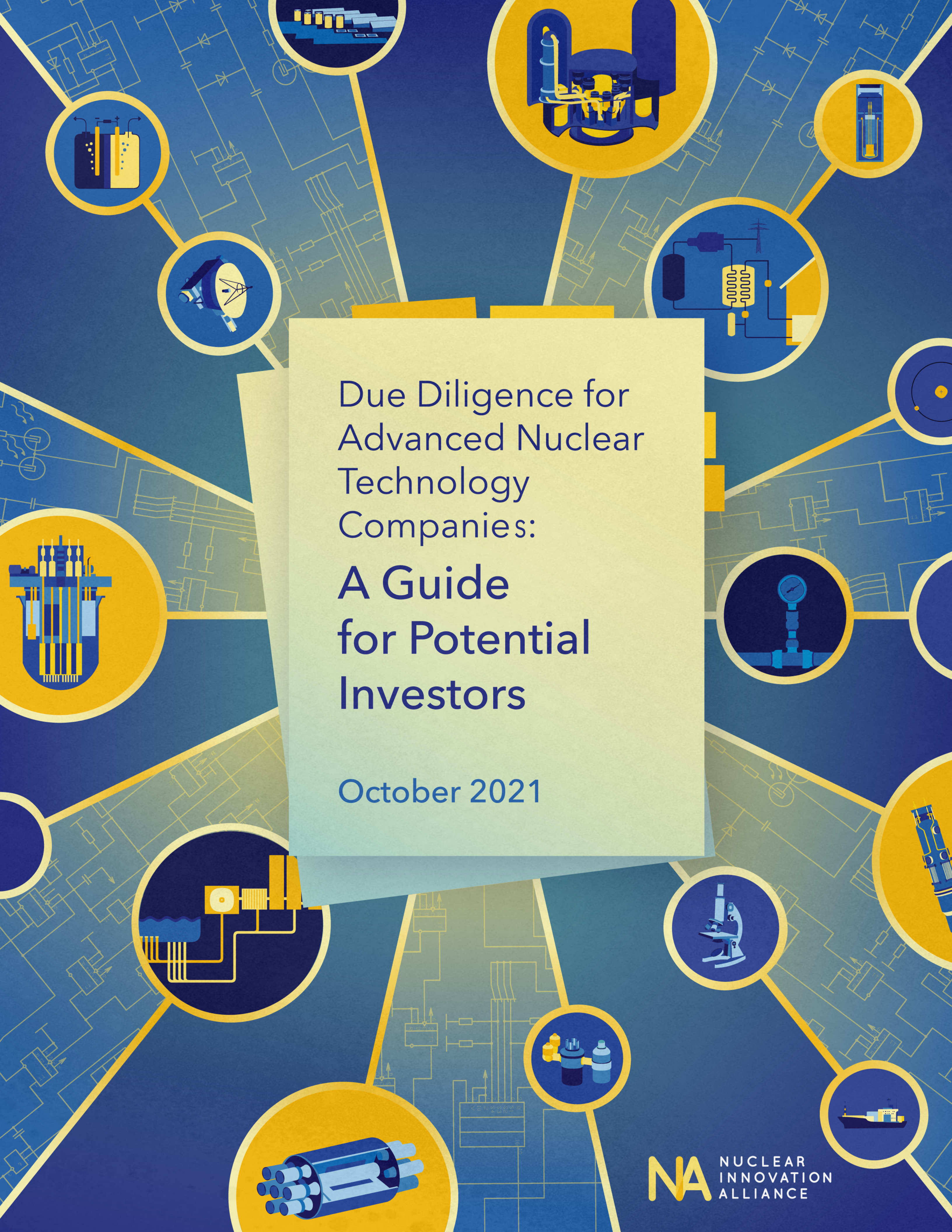

Due Diligence for Advanced Nuclear Technology Companies:

A Guide for Potential Investors

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NUCLEAR INNOVATION ALLIANCE

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Introduction

Investor interest in advanced nuclear energy is growing because it has attributes that can help meet urgent energy and environmental needs, both in the United States and abroad. Advanced nuclear energy is carbon-free, emits no conventional pollution, is highly reliable, and can be applied over a range of applications such as electric power generation, industrial or district heating, hydrogen production, and many others. The Nuclear Innovation Alliance thus created this document as a guide for potential investors in companies developing advanced nuclear technologies. The guide covers advanced nuclear fission, not fusion. The guide describes advanced reactor characteristics and considerations that may be of particular interest for evaluating these investments. For example, developing advanced nuclear technologies is a complex process requiring expertise in several technical disciplines. Development and testing can take time and can be capital intensive. Furthermore, nuclear technologies are highly regulated and regulatory expertise is required to bring products to market.

The guide is designed to provide potential investors with helpful context as they begin to navigate the promising and rapidly evolving advanced nuclear space and to also help advanced nuclear innovators understand what questions to expect from investors. The guide should be treated as a background for potential investor's diligence efforts; not as a comprehensive treatment of issues that should be considered prior to an investment decision. NIA has published the guide as part of our ongoing effort to enable advanced nuclear energy to play a role in helping the United States and other countries reach their zero-carbon emission goals.

Steve Greene, Principal of Green Acres Advisory, was the lead author of this guide, in collaboration with NIA.

The Investment Opportunity

The outlook for advanced nuclear technologies is promising. The worldwide urgency to address the drivers of climate change has created an environment receptive to technologies that can produce energy without carbon emissions. Nuclear power also emits no conventional air pollution. Carbon-free advanced nuclear technology can be used to generate electricity (and can follow net electric demand to be compatible with renewable generation), and can produce heat, which can be used for industrial applications, desalination, and to produce hydrogen or synthetic fuels, so the potential market for these technologies is substantial. Like its conventional counterpart, advanced nuclear energy is expected to be highly reliable, which may become an attribute receiving greater attention in light of recent reliability failures in Texas and California.

Electrification of a greater proportion of energy use is considered a key step towards decarbonization, so electricity generation is likely to grow more quickly in the future than it has in recent years, and access to a range of options for carbon-free electric generation is essential to reducing risks and maintaining progress in decarbonizing energy use. While significant attention has focused on renewable energy, there are several drivers of interest in electricity from nuclear power generation, including the ability to dispatch on demand ("dispatchable" or "firm" power as opposed to variable renewable energy), its suitability in regions with limited renewable resources, and its lower land requirements per unit of energy produced ("land use intensity") compared to renewable technologies such as wind and solar. Some advanced nuclear technologies may be suitable for locating at retiring coal plants, facilitating the transition from coal.[1] Analysis by some utilities has found that the cost of decarbonizing may be far less if

[1] https://nei.org/news/2021/terrapower-nuclear-plant-retired-coal-site

advanced nuclear technologies are part of the future asset mix.[2] In its 2021 report, *Net Zero by 2050,* the International Energy Agency concludes that nuclear power is essential for decarbonizing the energy system.[3]

Energy demand is expected to grow substantially in the developing world.[4] In many countries this demand growth will provide opportunities for nuclear power, especially advanced nuclear reactor designs that can be installed in smaller, modular increments compared to traditional, large-scale deployments. The think tank Third Way has identified 37 countries that are ready to implement advanced nuclear generation now and another 11 countries that will be ready by 2030; these countries represent 86 percent of the expected global electricity demand growth through 2050.[5]

Advances in materials science and changes in energy market conditions have stimulated renewed interest in nuclear power generation and innovative approaches to how it can be implemented. Advanced nuclear technologies will employ modular designs that can be built faster and more efficiently. They are expected to be operationally more flexible, including complementing intermittent renewable energy, simpler to operate, and inherently safer. These characteristics have led to increased interest from both current and prospective nuclear power plant operators. These advances have also substantially increased student interest in nuclear science and technology, leading to a growing pool of talent to support advanced nuclear projects.[6] The U.S. government has recognized the potential for advanced nuclear technologies and has supported development and early deployment efforts, for example through the Advanced Reactor Development Program (ARDP).[7] Programs like the ARDP and recent legislative actions like the Nuclear Energy Innovation and Modernization Act (NEIMA) and the Nuclear Energy Innovation Capabilities Act (NEICA) were made possible due to bipartisan support for advanced nuclear innovation .

Investors have become increasingly attuned to focusing their investments in activities that support environmental, social, and governance (ESG) objectives. These investment criteria may encourage greater interest in investments in advanced nuclear technologies.[8]

What Are Advanced Nuclear Technologies?

Advanced nuclear reactors are based on new and existing technologies that improve upon earlier generations of nuclear reactors in one or more of the following ways: cost, safety, waste management, and versatility.[9] Typically smaller in size, advanced nuclear reactors can be one-third or even one-thousandth the size of a conventional reactor. A smaller size, combined with innovations in design and manufacturing, enables factory manufacturing of key components and less on-site construction, leading to less steel and concrete, shorter construction times, and ultimately more predictable construction processes and more controllable costs. Modularity may also enable nuclear generation capacity to be built in smaller increments, better matching customer energy requirements and creating less strain on customers' financial

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[2] See, e.g., https://www.ethree.com/e3-examines-role-of-nuclear-power-in-a-deeply-decarbonized-pacific-northwest/

[3] https://www.iea.org/reports/net-zero-by-2050

[4] The 2020 BP Energy Outlook projects that energy demand in emerging economies *excluding* China will grow 50 to 77 percent by 2050. See https://www.bp.com/en/global/corporate/news-and-insights/press-releases/bp-energy-outlook-2020.html

[5] https://www.thirdway.org/memo/mapping-the-global-market-for-advanced-nuclear

[6] Between 2010 and 2019, B.S. degrees granted in nuclear engineering increased 40 percent and doctorates increased over 70 percent; see https://orise.orau.gov/stem/reports/ne-brief-82-2019-data.pdf

[7] https://www.energy.gov/ne/downloads/infographic-advanced-reactor-demonstration-program

[8] While not all institutions include nuclear investments within their ESG plans, many recognize nuclear energy's characteristics as an important, reliable zero-carbon energy option.

[9] See https://crsreports.congress.gov/product/pdf/R/R45706

resources. With smaller sizes, nuclear power can reach and address the evolving needs of customers like municipal utilities, rural electric cooperatives, and industrial users for the first time. Factory fabricated modular design allows for relatively rapid iterations from first-of-a-kind (FOAK) units to n^{th}-of-a-kind (NOAK) units, facilitating technical, manufacturing, and construction learning that may quickly bring costs down during commercialization.[10]

To optimize energy output at a reduced cost and higher level of operational safety, advanced designs use fuels, coolants, and materials that may be similar to or different from those used in today's operating reactors. Many advanced reactors are designed for more flexible operation, allowing for electrical output that complements variable renewable generation on local power grids. Many advanced reactor designs will operate at higher temperatures, making it feasible for them to provide heat for secondary purposes like hydrogen production, desalination, and process heat. Advanced designs also use inherent and innovative safety measures to provide operational safety without active intervention including natural circulation and new fuel forms able to withstand extreme temperatures. These safety features reduce operational risk and minimize the need to rely on backup systems, ultimately simplifying construction as well.[11]

Background on Nuclear Technology

Existing Technology Model and Infrastructure

The United States has almost 100 nuclear reactors in operation, with each reactor averaging roughly 1,000 megawatts (MW) in size. They produce electricity by converting the heat of a nuclear reaction into steam, which is then transformed into electricity by using the steam to spin a turbine. This process is roughly 33% efficient at converting heat into electricity, so a nuclear reactor that produces 3,000 MW-thermal (MWt) of heat can be expected to convert that heat into 1,000 MW of electricity.

All existing U.S. commercial power reactors, and most worldwide, are "light-water" reactors (LWRs) that use "low enriched" uranium, or LEU. Uranium comes in many different isotopes; only the U-235 isotope is commonly used for nuclear fission reactors. Compared to naturally occurring uranium with a U-235 atom concentration of 0.7 percent, LEU fuel has a U-235 concentration greater than natural uranium and below 20 percent. Current commercial LWRs use fuel enriched to between 3 and 5 percent U-235. There is existing world-wide infrastructure for mining, chemical processing (conversion), enrichment, and fabrication of LWR fuels. The enrichment step is highly controlled by governments to enhance nuclear security and non-proliferation. Following enrichment, the fuel is typically chemically converted to uranium oxide and fabricated into its final form for eventual use in a reactor.[12] Fabricated nuclear fuel is stable and energy dense, so large quantities of energy can be stored on site for an extended period.

Advanced Reactor Technologies

Advanced Reactors currently under development come in a variety of sizes, technology options, and capabilities. Some advanced reactors are designed to use light-water as a coolant, similar to current commercial reactors, but with an emphasis on smaller sizes, modular deployment, significant factory fabrication, and inherent safety mechanisms. Reactors of this type are commonly referred to as Light-Water Small Modular Reactors (SMR).

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[10] https://www.nae.edu/239267/Chasing-Cheap-Nuclear-Economic-TradeOffs-for-Small-Modular-Reactors

[11] See https://nei.org/CorporateSite/media/filefolder/resources/fact-sheets/what-advanced-reactors-have-to-offer-2017.pdf

[12] For more information on the current nuclear fuel cycle see the Appendix and https://clearpath.org/tech-101/nuclear-fuel-101/

Some advanced reactor concepts use fuels and coolants that have been explored in various stages of research, development, and demonstration over the history of nuclear power development. These concepts are now being re-evaluated because of their potential advantages and are being further developed using advances in materials and computer-aided analysis and design. The following is an abbreviated summary of some of the options being developed; note that there are variants and hybrid designs that are not described in this list.[13]

Abbreviated List of non-LWR Advanced Reactor Technologies

- High-temperature gas-cooled reactors (HTGR): use a gas, typically helium, as a coolant and heat transfer mechanism,[14] operate at high-temperatures (500° C and up) for efficiency, and are able to provide industrial process heat. Some use "fast" neutrons that use fuel more efficiently. These reactors need to ensure the purity of the helium coolant system is maintained, based on decades of HTGR experience.
- Molten-salt reactors (MSR): use fuel typically embedded in a molten salt, which also serves as a coolant, providing efficient heat transfer. These reactors need to address the corrosivity of molten salt. In addition, if lithium is used, an appropriate tritium management program is needed. Decades of research experience at national laboratories have shown that there are opportunities to manage tritium appropriately through design and engineering controls.
- Liquid metal-cooled fast reactors (LMFR): typically use liquid sodium or lead as a coolant, providing efficient heat transfer; operate at high temperatures; and use fuel more efficiently. Coolant leakage needs to be carefully addressed to prevent lead corrosion and reactions of sodium with air and water, but most consider LMFR relatively mature technology.

Most non-LWR advanced reactor designs use fuel that has a higher enrichment of U-235 than current light-water reactors, with enrichment levels of up to 20 percent (high-assay low-enriched uranium, or HALEU).[15] There is no currently existing infrastructure to produce HALEU at commercial scale outside Russia.[16] Under the Energy Act of 2020, the U.S. DOE is required to support the availability of HALEU. DOE is currently implementing a three year, $170 million cost-shared program with Centrus Energy Corp. to build a pilot facility (with full-scale technology) capable of producing 600 kg of HALEU by June 2022.[17] DOE intends for the demonstration project to signal to vendors that there will be a proven domestic capability to produce HALEU when the market demands it.[18] HALEU production will not require extensive new technology, but will require capital investment in facility modifications and expansions, as well as improved transportation capabilities, that will be subject to NRC licensing and International Atomic Energy Agency (IAEA) safeguards.

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[13] For more information see https://www.nuclearinnovationalliance.org/advanced-nuclear-reactor-technology-primer as well as the Appendix and Advanced Reactor Technologies in Additional Resources

[14] See https://www.nrc.gov/reading-rm/basic-ref/glossary/coolant.html

[15] This is still well below the assay level needed for weapons or even for Navy ships, which is termed highly-enriched uranium or HEU.

[16] The Russian nuclear company Rosatom maintains that it can supply HALEU within 6-9 months of an order, see https://gain.inl.gov/HALEU_Webinar_Presentations/14-15-Newton-Kolosovskaya,TENEX-28Apr2020.pdf. There are restrictions on imports of uranium from Russia.

[17] See https://www.energy.gov/ne/articles/centrus-becomes-first-us-licensed-haleu-production-facility

[18] See https://www.energy.gov/ne/articles/what-high-assay-low-enriched-uranium-haleu

Similarly, some advanced reactors use fuel forms that are different from commercial LWRs, such as TRISO[19] or metallic fuels. Existing commercial fabrication capabilities for these fuels are limited, so new or modified facilities will be needed. Some advanced reactor developers may partner with existing fabricators to modify and expand existing facilities, they may work with national laboratories to establish fabrication capacity at lab facilities, or they may plan to build new fabrication facilities.

Diligence – Business Model

Technology, Product, and Company

Companies pursuing advanced nuclear technologies may be considering a range of products and target markets. The company should be prepared to describe the target uses for its technology, the markets in which it would be deployed, why it expects to be successful in those markets, and how it ultimately expects its technology to deliver profits.

- What problems are the company seeking to address through its technologies, i.e., what use cases are the company targeting? These may include:
    - Grid-connected electricity production, (many companies are particularly aiming for electricity production with load follow capabilities to accommodate variable output and pair better with renewables)
    - Industrial heat and power
    - Co-production of hydrogen (and potentially other zero-carbon fuels)
    - Desalination
    - Microgrids
    - Remote or emergency power (e.g., replacement for diesel generation in remote locations)
    - Thermal propulsion (space, marine)
- What reactor technology is the company developing, and why has the company chosen that technology? Aspects to highlight may include:
    - Size of the reactor (physical footprint and thermal power output per reactor)
    - Projected cost of the power plant, and comparison to competing technologies
    - Maturity of the associated technologies and associated technical and regulatory risk
    - Experience of the developer (as a designer and manufacturer of nuclear systems)
    - Ease of manufacture and transport to the destination
    - Time to complete construction
    - Output characteristics for target uses, e.g.:
        - thermal output temperature
        - electric generation efficiency
        - ability to ramp up/down to follow load requirements (load following) and integrated storage, which may be important for integration with renewable generation
    - Inherent safety features – a key objective of advanced nuclear reactors is to ensure the avoidance of offsite impacts without requiring operator actions, AC or DC power, or the addition of coolant for an unlimited duration[20]

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[19] Tri-structural isotropic (TRISO) particle fuel is composed of small particles of uranium coated with graphite and other materials that contain the fission products of uranium and are very resilient even in high temperatures.
[20] https://www.nae.edu/19579/19582/21020/239120/239255/Why-the-Unique-Safety-Features-of-Advanced-Reactors-Matter

- Flexibility regarding site characteristics, including land use and safety perimeter (see the regulatory discussion)
- Approach to fuel management, including fuel handling and used fuel disposal
- Previous RD&D experience with similar technologies
- NRC licensing approach and status

What is the business model and why?

Energy markets are complex, and the company should be prepared to provide details regarding the markets it anticipates entering. If the company is principally targeting grid-connected generation, that can be a competitive market requiring in-depth understanding of the revenue potential from power generation; how revenue may vary by location, season, and hour; and how that revenue may change in the future as other new technologies are introduced to the power grid. It also requires an understanding of the differences between markets controlled by independent system operators (frequently described as competitive, organized or restructured markets) compared to those controlled by integrated utilities and their regulators (vertically integrated markets). If the company expects that international deployment will be an important aspect of its initial business plan, export rules applicable to nuclear technologies will need to be considered early in development (see the regulatory discussion).

The company should have credible cost estimates for the deployment of its technology at different stages in its development, recognizing that greater uncertainty will exist for less mature technologies. The company should also have estimates of staffing and operating costs once the technology is in operation.

Competition in the grid-connected energy market will come from renewable generation, possibly combined with storage technologies to manage variability over hourly or daily time periods. As the technologies mature, competition could also come from long-term (seasonal) energy storage technologies and gas-fired technologies with carbon capture or using carbon-free fuels such as hydrogen. Competition in other markets may come from a variety of technologies including those using fossil fuels, with or without carbon capture depending on the future regulatory environment, or with zero-carbon fuels such as hydrogen as they are developed and deployed.

The company should be prepared to demonstrate how its technology will be competitive and generate revenues and adequate returns on capital based on deployment in its target markets.

How does the company intend to deploy?

Historically, nuclear plants typically have been designed by technology companies; built under contract by engineering, procurement, and construction companies; owned by one or a consortium of electric utilities or electric generating companies; and operated by an affiliate of one of the owners. Advanced nuclear generation could use a similar model, or could pursue alternative deployment models such as integrating the design, construction (using contractors as desired), ownership, and operating roles.

- Does the company intend to license its technology to other companies that will manufacture and construct the units?
- Will it manufacture units or key components? If not, who are the key manufacturing and supply chain partners for these units or key components?
- Will it construct (engaging engineering, procurement, and construction contractors) and deliver units to customers?
- Will it operate units, and sell power and/or heat as a product?

- If the company expects to be engaged in manufacturing, construction, or operations, how does the management plan to acquire the additional capabilities that will be required?
- Who are the company's partners and how experienced are they? What supply-chain agreements are in place? How do the partnerships and agreements support both US and international projects, if the company contemplates those?
- Does the company plan to sell other products such as hydrogen?
- Where does the company expect that the technology will be initially deployed, and what level of control is there regarding that site?
- What is the expected pace of deployment?

Finance and Operations

Diligence regarding the company's finance and operations during technology development is for the most part consistent with that for other investments in a similar stage of development. Advanced nuclear technologies vary in their scale and degree of development, and different paths and approaches can be taken to reduce risks and position the technologies for commercial deployment. In some cases multiple rounds of risk-reduction on scale prototypes will be feasible, whereas in others incremental testing of components, pilot-scale testing or other approaches may be necessary.

Demonstrating and deploying nuclear facilities can be capital-intensive. Management should be able to describe a view of how these steps can be financed. Additionally, key milestones that may be needed before demonstration and deployment can be achieved include finding a site, regulatory and environmental approval by both the Nuclear Regulatory Commission (NRC) and relevant state agencies (or federal agencies if on federal land), a fuel plan or fuel agreement, a long-lead procurement plan, and operating plans or agreements.

Regarding the company's near-term situation, management should be able to describe the current risk-reduction focus, the employees, contractors, and other financial commitments in place, the burn rate associated with those commitments, a view of the progress that can be achieved with the funding on hand, and the prospects for achieving a measurable degree of risk reduction prior to requiring additional funding.

Business Development

Depending on the stage, development of advanced nuclear technologies may involve collaborations and partnerships with several external parties. The company should be prepared to describe engagements with external parties including letters of intent, memoranda of understanding, and agreements or contracts with key partners. Key aspects of the engagements should be described including the scope, future commitments, rights, or options, exit rights and processes, and experience to date under the relationship. Commitments to some parties, including potential suppliers or customers, may provide opportunities to secure development financing. Key areas in which external relationships or commitments may have been developed include:

- Entities who control sites for prototype or commercial facilities
- Suppliers of key components or materials and associated experience supplying nuclear power projects
- Engineering, procurement, and construction firms for pilot or commercial deployment
- Customers such as electric utilities or industrial customers
- Communities seeking investment or looking to repurpose a legacy fossil asset

In addition, as the company proceeds through development, there may be opportunities for revenue generation based on technical capabilities or components created in the course of developing the ultimate product. The company should describe any actual or potential interim revenue generation.

Technology Development and Validation

Diligence on the technology should include the company's technical expertise, computer simulations, and experimental validation, as well as any work on prototypes.

The company should have technical expertise to support its design spanning the following areas:

- Thermal hydraulics (hydraulic flow in thermal fluids)
- Reactor physics
- Nuclear fuel, including its lifecycle transportation, storage and treatment requirements
- Materials science, specifically with an understanding of heat and radiation effects on materials
- Balance-of-plant (how the reactor is integrated into other elements of the plant)
- Systems engineering
- Radiation protection and shielding
- Security and safeguards[21]
- Safety analysis (deterministic and probabilistic)
- Regulatory affairs, domestically and internationally
- Risk assessment
- Cost analysis

The company should describe the following aspects of technology development:

- Has the type of technology been used before, or is there information from prior experience that can inform expectations regarding performance?
- What software is being used for simulations and analyses, and why? What areas of analysis is the software supporting? What is the experienced application and validation basis of the software?
    - Neutronics[22]
    - Heat and mass transfer
    - Fuel performance
    - Mechanical and structural design
    - Materials performance
- What is the company's relevant experience and expertise with these tools?
- How has the software been validated, e.g., by experimental data?
- Has the company worked with external parties on the analyses? Are there IP implications or agreements associated with that work?
- How have the results of analysis been reviewed or confirmed?
- Are there prior demonstrations of the technology? How representative and complete is the data from prior demonstrations with respect to the company's designs and expected operating conditions?

[21] "Safeguards" refers to physical protection of special nuclear material through material control and accounting programs.
[22] "Neutronics" is the study of the motions and interactions of neutrons with materials

- Computer simulation is greatly advanced today; however, experimental testing may be needed if there isn't sufficient data from prior experiments and demonstrations, or if there are gaps in the data or how it applies to the company's technologies.
    - How has the company balanced what it has accomplished or intends to accomplish with computer simulation vs. experimental testing?
    - What testing has the company done, what are the results, and what are the implications?
    - What further testing does the company plan to conduct, and how will that testing fill in remaining gaps in the technology development?
    - What arrangements has the company made or does it plan to make for testing facilities?

The company should describe any review of its analysis or results by outside experts, including the experts' qualifications and conclusions. To the extent potential investors rely on the conclusions of any outside advisors, they should confirm the advisors have had access to key data on the technology and any tests and results.

Regulatory and Licensing

Companies intending to sell their technology in the United States will need regulatory approval from the U.S. Nuclear Regulatory Commission (NRC).[23] NRC approval is highly valued outside the United States as well due to the Commission's recognized commitment to ensure the nuclear industry meets the highest safety standards. The NRC is a model for independent nuclear regulators in many countries.

The two existing pathways to obtain an NRC license for a commercial reactor are based on the NRC's experience with the current fleet of large light-water reactors.[24] The NRC is developing a pathway intended to be better suited to advanced reactors, aiming to have it in place in late 2024.[25] In the meantime, advanced reactor developers are beginning to navigate the existing pathways.

The company should describe the process it is pursuing to obtain licenses within the United States and in any other countries where it expects to demonstrate or sell its technology in its initial deployments. The company should describe its current level of engagement with the NRC and whether it has a regulatory engagement plan or licensing project plan. The company and potential foreign investors should be aware that foreign ownership interests can complicate licensing.[26] For potential deployment in any other countries, the company should describe its understanding of the regulatory requirements and its engagement with regulators. Recognizing that the regulatory process for advanced reactor technologies may change as companies proceed, the company should describe the resources involved in near-term regulatory efforts and the costs expected to be incurred.

Siting

A recognized advantage of nuclear power generation is its low land use intensity, that is, the small land area it requires compared to the amount of power it produces. In particular, SMRs and microreactors may be able to use sites much smaller than traditional reactors, enabling co-location with industrial facilities or

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[23] Companies based in the United States but not planning sales or operations in the United States may instead need to engage with DOE, which regulates reactor technology designed in the United States but wholly produced and constructed in other countries; see the discussion on export requirements below.
[24] See https://www.nrc.gov/reading-rm/doc-collections/fact-sheets/licensing-process-fs.html
[25] https://clearpath.org/our-take/a-simpler-dedicated-pathway-for-advanced-nuclear-reactor-licensing/
[26] See, e.g., https://www.morganlewis.com/-/media/files/publication/outside-publication/article/usnuclearreactors_15aug09.ashx

district heating. Ongoing regulatory processes are focused on modernizing and right-sizing the emergency planning zone for advanced reactors, which would simplify the licensing process, decrease planning and operating costs, and considerably expand the number of locations that nuclear plants could be sited.[27] The company should describe its expectations regarding siting and emergency planning zones.[28]

Local community engagement and buy-in is crucial for all energy projects, including nuclear projects. The company should be able to describe its plans for engaging with host communities to understand their objectives and concerns with respect to economic development, environmental protection, and equity, consistent with the principles of environmental justice. The company should describe potential community benefits and concerns, and how it plans to realize those benefits and address those concerns.

Under the National Environmental Policy Act (NEPA) and NRC's implementing regulations, NRC must complete an environmental impact statement for any license for a commercial power reactor constructed in the United States. NEPA analysis is required for any "major federal actions significantly affecting the quality of the human environment" and NRC licensing is considered a major federal action. NEPA review requires a broad look at the environmental aspects of a project, including site-specific impacts such as land use, water consumption, and wildlife disruption. It also requires consideration of alternatives, including a no-action alternative. NEPA is a process statute, not substantive, meaning that as long as NRC completes the process it does not have to pursue any alternative identified in the analysis. Some regulatory reforms could make NEPA requirements more straightforward, but these have yet to be implemented. Site selection and analysis is the responsibility of the operator of the reactor, not the reactor developer. (Some developers may pursue a business model in which they are also the owner and operator). However, the company should be able to describe the overall plan for addressing NEPA analyses and how responsibility for that plan is being managed.

Export Requirements

Companies intending to sell reactors outside the United States need to be aware of the export-control restrictions that ensure the safe and secure deployment of civil nuclear technology. In accordance with the Atomic Energy Act of 1954, export of nuclear technologies may be subject to licensing or authorization requirements from one or more agencies including the Department of Energy (DOE), Department of State, Department of Commerce, Department of Defense, and the NRC.[29]

Generally, the DOE National Nuclear Security Administration (NNSA), the NRC, and the Bureau of Industry and Security of the Department of Commerce are responsible for authorizing the export of civil nuclear technologies and services. Under 10 CFR Part 810, the NNSA is responsible for authorizing the transfer of unclassified nuclear technology and assistance to foreign atomic energy activities within the United States or abroad.[30] This first step is necessary in order to engage in international civil nuclear trade. In addition, NRC approval under 10 CFR Part 110 is also necessary for any entity seeking to export

[27] See https://www.govinfo.gov/content/pkg/FR-2020-05-12/pdf/2020-09666.pdf

[28] Further information on siting and environmental review may be found in "Advanced Nuclear Reactor Plant Parameter Envelope and Guidance," National Reactor Innovation Center (NRIC) https://nric.inl.gov/wp-content/uploads/2021/02/NRIC-PPE-Guidance-Feb-2021-Final.pdf

[29] https://www.export.gov/industries/civil-nuclear/exporting-guide

[30] See: https://www.energy.gov/nnsa/10-cfr-part-810

(or import) NRC-controlled nuclear equipment or material.[31] If one or more of these processes are applicable, the transfer of civil nuclear technologies and services may also require that the destination country have in place an agreement for peaceful nuclear cooperation with the United States as established under section 123 of the Atomic Energy Act, commonly known as a "123 agreement."[32] These agreements can take years to establish, and may sometimes be difficult to negotiate. Other factors that may be considered in export determinations include the destination country's nonproliferation credentials and the significance and scope of its nuclear trade relationship with the United States. Finally, nuclear-related multi-use items like simulators, detectors, and many types of valves, pipes, and other parts may be subject to approval from the Bureau of Industry and Security. Companies anticipating exports should explain their strategies for complying with the export rules.

Intellectual Property

The company's intellectual property, or IP, is one of their most valuable assets, and management should be expected to describe the company's IP and how it is secured, including, if relevant, in international markets. The company should describe what patents they have applied for, which have been granted, and in what jurisdictions.

The company should describe its strategy for continuing to develop IP and to maintain its rights despite the potentially long timeframe to reach commercialization. The company must also describe the IP provisions of any collaboration agreements with DOE, national labs or universities, and any risks those terms create for protection of the company's IP.

Supply Chain and Fuel Cycle

Advanced nuclear technologies may require special materials, and some components may need to follow NRC-approved quality controls. The company's supply chain arrangements are critical from technology development through production, and the company should be prepared to describe how it is addressing them.

For prototypes used in testing, the company may require special materials. The company should describe its current or contemplated sources for these materials and how it will maintain adequate supply as it scales up to production.

For production, the company should describe its plans to address supply chain requirements, and any agreements in place or discussions regarding its supply chain. These should include discussion of components that may require adherence to NRC-approved quality controls. If the company has received any government funding, it should describe any associated requirements, especially regarding supply-chain commitments.

For the fuel cycle, the company may require thorium, enriched lithium, enriched chlorine, HALEU, recycled nuclear fuel, and/or advanced fuel fabrication capabilities. As described earlier in this guide, sources for some of these materials and services are not yet commercially available, though DOE and commercial parties are engaged in developing supply. The company should describe its plans for sourcing fuel, including any discussions or agreements in place, and any regulatory approvals that it must obtain.

[31] 10 CFR Part 110 - Export and Import of Nuclear Equipment and Material
[32] See "Nuclear Cooperation with Other Countries: A Primer," Congressional Research Service, https://fas.org/sgp/crs/nuke/RS22937.pdf

The company should describe its fuel cycle, including whether, how often, and how additional fuel must be supplied to its reactors.

The company must also describe the requirements for removing used fuel from its reactors and the potential approaches to managing the used fuel (the responsibility for used fuel will rest with a project's operator, unless agreements specify otherwise, which may or may not be the technology developer, depending on the business plan). Currently, there are no permanent disposal sites for used nuclear fuel. Existing commercial nuclear reactors in the United States typically store their used fuel on-site and may eventually store them in consolidated interim and permanent storage facilities.

Information Technology

As with any business involving valuable information, attention must be paid to data security. Furthermore, because of the statutory controls on export of nuclear design information, the company should describe its approach to managing this information and how it ensures compliance with the relevant laws, including those restricting how and where information on nuclear designs may be stored.

Legislative

Laws regarding nuclear technology development, the development of prototypes or demonstration projects, and export of nuclear technology are evolving.[33] The company should describe how they are remaining current with statutory changes, pending legislation, and administrative or regulatory actions.

Companies involved in cutting-edge technologies such as advanced nuclear development may engage with legislators to support research and development, funds for demonstrations, policies enabling or supporting nuclear energy deployment, or similar objectives. The company should describe its legislative objectives, its engagement with legislators, and its process to ensure compliance with lobbying rules. The company should also describe its engagement with advocacy groups.

Resolution of Risk over Time

The previous sections of this guide have identified diligence questions in a variety of subject areas. However, the relevance of these questions may change depending on the maturity of the potential investment candidate. Optimally, incremental funding will correspond to the reduction of specific identified risks. Development of advanced nuclear technology can be capital-intensive, especially in its later stages, so management needs to anticipate sourcing additional capital and to identify the risk-reduction targets associated with each stage of funding.

Below is a summary of the information that investors might expect to see as a potential advanced nuclear investment matures. Of course, elements will vary for each potential investment depending on its circumstances and path to maturity, so the descriptions below should be considered broadly and not as specific expectations.

- **Start-up stage.** Company management is likely to be focused on one or a small number of reactor technologies and be able to describe the characteristics of the technologies that support that focus, such as efficiency, safety, simplicity (and therefore expectation of reduced

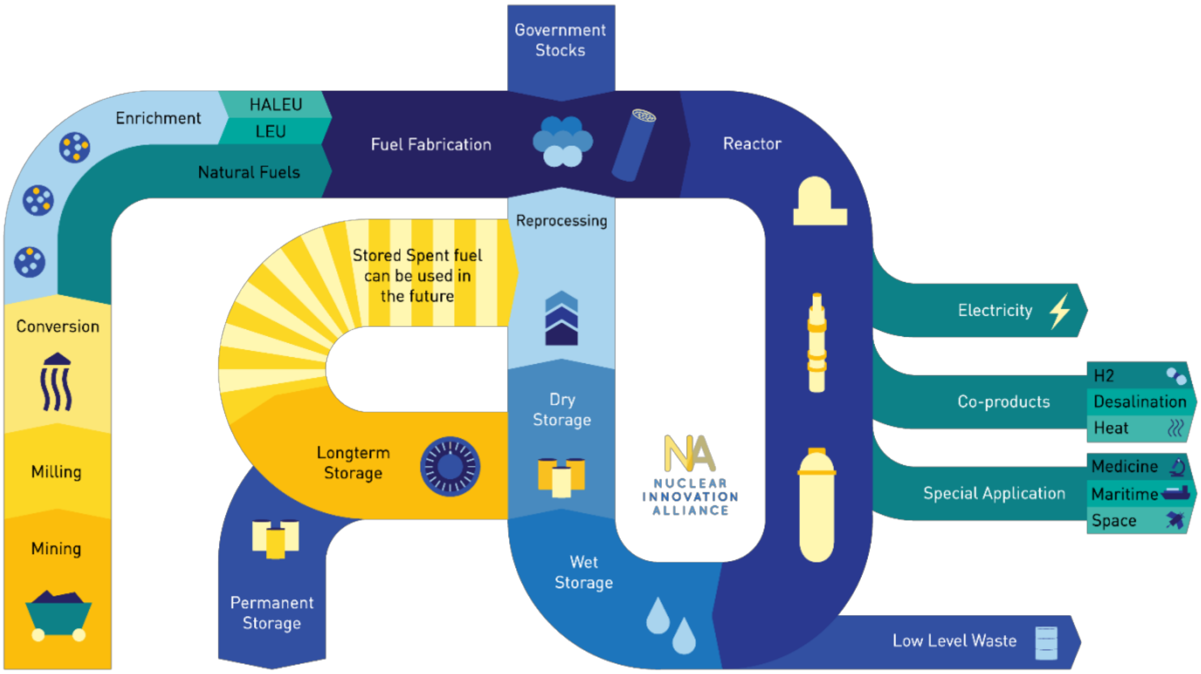
[33] For example, since 2018 the Nuclear Energy Innovation Capabilities Act (NEICA) and the Nuclear Energy Innovation and Modernization Act (NEIMA) were passed with bipartisan support, the Energy Act of 2020 was passed incorporating several provisions on nuclear technology, and in 2020 DOE issued the report "Restoring America's Competitive Nuclear Advantage" incorporating several recommendations that could result in future legislation. https://www.atlanticcouncil.org/event/restoring-us-nuclear-competitiveness/

construction complexity), etc. They should be able to describe the types of markets where the technology could be most attractive (e.g., grid-based power, industrial heat, or remote power). The company may have initial analysis and lab tests supporting feasibility. However, substantial investment risks may remain regarding design, materials, performance, economics, and markets.

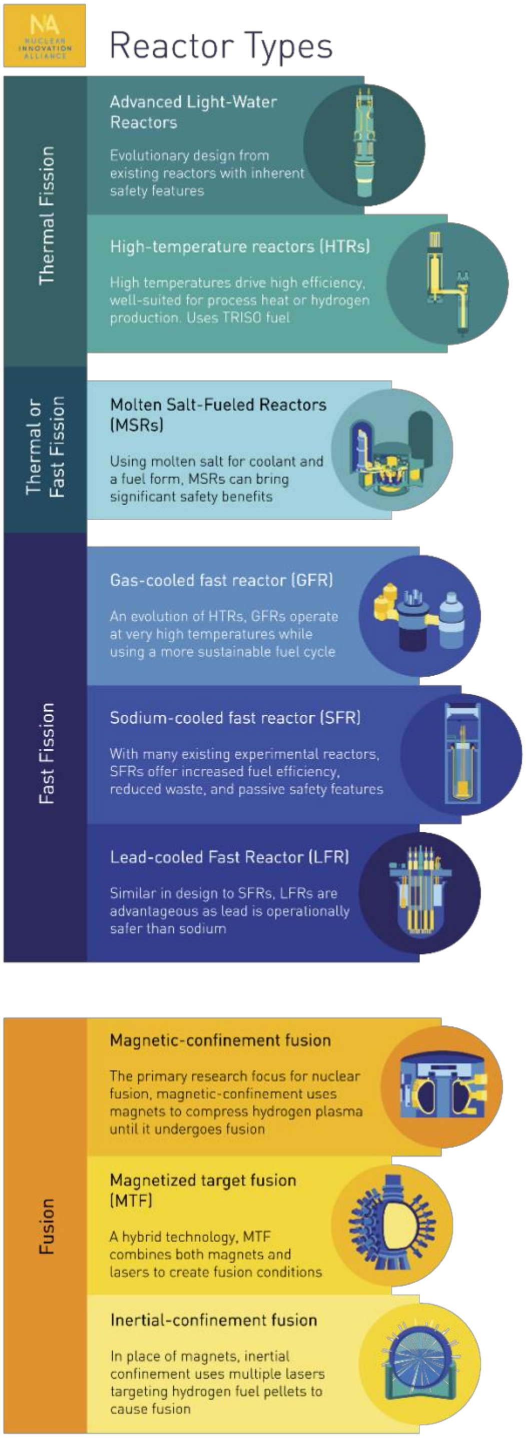
- **Early development.** Company management may have a clearer view of its target technology or technologies, a refined view of use cases, and an initial view of the economics to support that view. The company should have data to support key design elements and should be considering how to support the licensing process. Substantial investment risks may remain regarding integrated systems, construction and operating costs, overall economics, licensing, and supply chain.
- **Later development.** Company management should be developing a view of facility costs and economics, and how to market their technology to potential customers. They should have or be well along on a licensing plan and have a funding plan for that work. They may be developing plans for one or more demonstration or initial deployment projects, including host locations and sources of financing. They should be in discussions with future customers and suppliers. However, substantial investment risk may remain regarding the implementation of the licensing plan, the cost and timing of demonstrations, the performance of demonstrations, ultimate economics, and the degree of market interest.

Appendices

Nuclear Fuel Cycle



Advanced Reactor Technologies



Additional Resources

Advanced Reactor Technologies

Advanced Nuclear Reactor Technology: A Primer
https://www.nuclearinnovationalliance.org/advanced-nuclear-reactor-technology-primer

International Atomic Energy Agency https://www.iaea.org/topics/nuclear-power-reactors

International Atomic Energy Agency, Advanced Reactors Information System (ARIS)
https://aris.iaea.org/

World Nuclear Association https://world-nuclear.org/information-library/nuclear-fuel-cycle/nuclear-power-reactors/generation-iv-nuclear-reactors.aspx

Generation IV International Forum https://www.gen-4.org/gif/jcms/c_59461/generation-iv-systems

Third Way

Advanced Nuclear Map https://www.thirdway.org/graphic/2020-advanced-nuclear-map-progress-amidst-a-tumultuous-year

Database of Advanced Nuclear Projects
https://docs.google.com/spreadsheets/d/16FGmWhZmp0m7ev1dN51U2E7uwOWdjI5iul7JDn9fdAY/edit#gid=0

DOE Programs

DOE Office of Nuclear Energy https://www.energy.gov/ne/office-nuclear-energy

Advanced Reactor Demonstration Program https://www.energy.gov/ne/nuclear-reactor-technologies/advanced-reactor-demonstration-program

Gateway for Accelerated Innovation in Nuclear (GAIN) https://www.energy.gov/ne/initiatives/gateway-accelerated-innovation-nuclear-gain

National Reactor Innovation Center (NRIC) https://nric.inl.gov/

Versatile Test Reactor https://www.energy.gov/ne/nuclear-reactor-technologies/versatile-test-reactor

Transformational Challenge Reactor https://www.energy.gov/ne/transformational-challenge-reactor-tcr

Nuclear Innovation: Clean Energy Future (NICE) https://www.energy.gov/ne/initiatives/nuclear-innovation-clean-energy-future

DOE National Laboratories https://www.energy.gov/national-laboratories

Argonne National Laboratory, Nuclear Energy Division https://www.ne.anl.gov/

Idaho National Laboratory https://inl.gov/research-programs/nuclear-energy/

Oak Ridge National Laboratory, Fusion and Fission Energy and Science Directorate
https://www.ornl.gov/directorate/ffesd