Laying the Foundation for New and Advanced Nuclear Reactors in the United States

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What will it take for new and advanced nuclear reactors to play a role in a net-zero emissions future?
Nuclear power plants are the largest source of low-carbon electricity in the United States. They supply 18.2% of total U.S. electricity and half of total low-carbon electricity.

There are 92 nuclear power plants in the United States (442 across the globe).

The initial license lifetime of a nuclear power plant in the United States.
U.S. Demand for Electricity Projected to Grow

Annual Energy Outlook

NREL 100% by 2035 Study

White House Long-term Strategy

Electricity Consumption [TWh]

Source: NREL
About the Study

Origin: Congressional interest, interest within the National Academy of Engineering, discussions between the Board on Energy and Environmental Systems and the Nuclear and Radiation Studies Board

Sponsors:
• A philanthropic donation to the National Academy of Engineering by Dr. James J. Truchard
• DOE’s Office of Nuclear Energy

Framing Questions: What would it take for new nuclear technologies to be an option in an increasingly decarbonized and continually decarbonizing energy system? What are the opportunities and barriers?

Outputs: A workshop proceedings (2022), a consensus report (2023), a follow-on workshop (TBD)

This briefing shares the results of the committee’s report.
About the Study – Scope

**What IS in scope**

Identifying opportunities and barriers to advanced nuclear reactor commercialization in the United States over the next 30 years as part of a decarbonization strategy. Topics include:

- Research, development, and demonstration
- Manufacturing, construction, and operational characteristics
- Economic, regulatory, societal, and business challenges
- Applications outside the electricity sector
- Role of the U.S. government
- National security and nonproliferation
- Future workforce and educational needs

**What is NOT in scope**

Read the companion report:
https://nap.nationalacademies.org/26500
About the Study – Committee

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About the Study – Information Gathering Highlights

DOE Office of Nuclear Energy

Idaho National Laboratory

U.S. Nuclear Regulatory Commission


Industry: Eastman Chemical, Dow Chemical


Security and Safeguards: Department of State, Argonne National Laboratory, Sandia National Laboratories, National Nuclear Security Administration, Nuclear Threat Initiative, Nuclear Energy Institute

Understanding the Societal Challenges Facing Nuclear Power – A Workshop

https://nap.nationalacademies.org/resource/26606/interactive/
Many variables affect whether advanced nuclear can be viable in tomorrow’s energy market – how could we get there?
The Evolving Electricity System: Different Opportunities and Challenges Every Decade

The race against climate change is both a marathon and a sprint.
Core Variables Crucial for Commercial Success

- Reactor Technology Research
- Safety Regulations
- Project Management and Construction
- Workforce
- Alternative Applications
- Federal Funding from Design to Deployment
- Community Engagement and Acceptance
- Financing
- Security and Safeguards
- International Marketing
## What Are New and Advanced Nuclear Reactors?

<table>
<thead>
<tr>
<th>Reactor Technology</th>
<th>Technology Experience</th>
<th>Technology Gaps</th>
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<tr>
<td>Small Modular LWR</td>
<td>Evolution from currently operating LWRs</td>
<td>Develop and qualify unique plant components</td>
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<tr>
<td>Liquid Metal Fast Reactor</td>
<td>Several small SFRs operating worldwide</td>
<td>Qualify annular metal fuel and advanced steel alloys, Perform source term experiments to reduce conservatisms</td>
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<tr>
<td>High-Temperature Gas Reactor</td>
<td>Several small HGTRs operating worldwide</td>
<td>Qualify fuel and graphite (&lt;1100 K outlet temp designs), Qualify materials used in heat exchanger and other components (&gt;1100 K outlet temp designs)</td>
</tr>
<tr>
<td>Fluoride Salt-Cooled Reactor</td>
<td>FHR designed, reduced-scale prototype planned for demonstration</td>
<td>Demonstrate corrosion/control for Flibe-based salt in presence of neutron field, Demonstrate materials for strength, corrosion resistance, and irradiation stability in operation, Demonstrate tritium migration and radioactivity control, Demonstrate passive safety systems</td>
</tr>
<tr>
<td>Heat-Pipe-Cooled Reactor</td>
<td>LANL space reactor demonstrated concept at reduced power scale</td>
<td>Develop compact PCU operation and integration with heat-pipe core cooling, Develop autonomous control and instrumentation, Demonstrate passive safety systems</td>
</tr>
<tr>
<td>Molten Salt-Fueled-Cooled Reactor</td>
<td>ORNL experiments operated without power conversion systems</td>
<td>Demonstrate corrosion control for salts, tritium migration and control, materials for long-term operation, Demonstrate passive safety systems</td>
</tr>
<tr>
<td>Gas Fast Reactor</td>
<td>No reactor ever built</td>
<td>Qualify fuel, clad, and structural materials for safety and radiation damage, Demonstrate passive safety systems</td>
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RECOMMENDATION 2.2: The Department of Energy (DOE) should initiate a research program that sets aggressive goals for improving fuels and materials performance. This could take the form of a strategic partnership for research and development involving DOE’s Office of Nuclear Energy and Office of Science, the U.S. Nuclear Regulatory Commission, the Electric Power Research Institute, the nuclear industry, national laboratories, and universities. The program should incentivize the use of modern materials science, including access to modern test reactors, to decrease the time to deployment of materials with improved performance and to accelerate the qualification (ASME Section III, Division 5 or equivalent) and understanding of life-limiting degradation processes of a limited number of high-performance structural materials, e.g., reactor core materials and cladding.
**RECOMMENDATION 4.3:** Congress and the DOE should maintain the Advanced Reactor Demonstration Program concept. The DOE should develop a coordinated plan among owner/operators, industry vendors, and the DOE laboratories that supports needed development efforts. The ARDP plan needs to include long-range funding linked to staged milestones; on-going design, cost, and schedule reviews; and siting and community acceptance reviews. This plan will help DOE downselect among concepts for continued support toward demonstration. A modification in the demonstration schedule that takes a phased (vs. concurrent) approach to reactor demonstration may be required. For example, funding would be continued for the first two demonstrations under the ARDP. A second round of demonstrations of designs expected to mature from the current ARDP Risk Reduction for Future Demonstrations award recipients could be funded for demonstration under an “ARDP 2.0” starting thereafter and going into the future.
Financial Incentives

RECOMMENDATION 4.4: To enable a cost-competitive market environment for nuclear energy, federal and state governments should provide appropriately tailored financial incentives (extending and perhaps enhancing those provided recently in the Inflation Reduction Act) that industry can use as part of a commercialization plan, consistent with the successful incentives provided to renewables. These tools may vary by state, locality, and market type. Continued evaluation of the recently passed incentives will need assessment to determine their adequacy. The scale of these incentives needs to be sufficient not only to encourage nuclear projects, but also the vendors and the supporting supply chains.
Electricity will be the Main Mission for Nuclear, but...

RECOMMENDATION 5.1: Industrial applications using thermal energy present an important new mission for advanced reactors. A key R&D need is to assess system integration, operations, safety, community acceptance, market size as a function of varying levels of implicit or explicit carbon price, and regulatory risks, with hydrogen production as a top priority. DOE, with the support of industry groups like EPRI and the nuclear vendors, should conduct a systematic analysis of system integration, operation, and safety risks to provide investors with realistic models of deployment to inform business cases, and work with potential host communities.
Historical overnight capital cost components (based on LWRs)

- **5-10%**
  - Owner Cost

- **10%**
  - Turbine Generator

- **10-20%**
  - Nuclear Island

- **10-20%**
  - EPC Costs

- **40-50%**
  - Civil Work

SOURCE: Buongiorno et al., 2018.
To streamline timelines and reduce costs, site preparation and construction R&D must be a priority

RECOMMENDATION 6.8: While it is vital to demonstrate that advanced reactors are viable from a technical perspective, it is perhaps even more vital to ensure that the overall plant, including the on-site civil work, can be built within cost and schedule constraints. Since it is likely that costs for onsite development will still be a significant contributor to capital cost, and the ~$35M in DOE funding for advanced construction technologies R&D is small in comparison to the hundreds of millions spent on nuclear island technology research, more should be done over an extended period to research technologies that may streamline and reduce costs for this work. The Department of Energy should expand its current efforts in advanced construction technology R&D and make these advanced technologies broadly available, including to vendors participating in the ARDP Risk Reduction and ARC20 programs.
Ensuring Successful Project Management

To make subsequent deployments possible, building and maintaining skilled labor from project to project is key.

RECOMMENDATION 6.2: Nuclear owner/operators pursuing new nuclear construction should consider establishing a consortium or joint venture to pursue the construction on behalf of the group, thereby enabling the creation and maintenance of the necessary skilled personnel to pursue projects successfully. Alternatively, advanced reactor developers operating within the traditional project delivery model should implement a long-term business relationship, preferably an equity partnership such as a joint venture or a consortium, with a qualified engineering, procurement, and construction (EPC) firm experienced in the nuclear industry.
To prepare for an expanded workforce, identifying critical skills gaps and funding training programs is key

RECOMMENDATION 6.1: In anticipation of the necessary expansion in workforce to support more widespread deployment of nuclear technologies, the Department of Energy should form a cross-department (whole of government) partnership to address workforce needs (spanning the workforce from technician through PhD) that is comparable to initiatives like the multi-agency National Network for Manufacturing Innovation. The program would include the Departments of Labor, Education, Commerce, and State, and would team with labor organizations, existing construction craft training programs, industry, regulatory agencies, and other support organizations to identify gaps in critical skills and then fund training and development solutions that will close these gaps in time to support more rapid deployment. In carrying out these efforts, it will be important to take full advantage of existing efforts at universities, commercial nuclear facilities and national labs that already have well established training and workforce development infrastructure in place.
RECOMMENDATION 7.1: Advanced reactors will not be commercialized if the regulatory requirements are not adjusted to accommodate their many differences from existing light water reactors. A clear definition of the regulatory requirements for a new technology must be established promptly if timely deployment is to be achieved. The NRC needs to enhance its capability to resolve the many issues with which it is and will be confronted. In recognition of the urgency for the NRC to prepare now, Congress should provide increased resources on the order of 10s of millions of dollars per year to the NRC that are not drawn from fees paid by existing licensees and applicants.

RECOMMENDATION 7.4: The NRC should expedite the requirements and guidance governing siting and emergency planning zones (EPZs) in order to enable vendors to determine the restrictions that will govern the deployment of their reactors.
Best practices for community engagement must be adopted. These include:

- An overriding commitment to **honesty, transparency**, and **consistency** of communication.
- A **consent-based**, participatory, and long-term process of site selection.
- The right for communities to **veto** or **opt out** until an agreed-upon milestone.
- Some form of socially acceptable **compensation** granted for affected communities.
- Partial funding for communities and public interest groups to conduct **independent analyses**.
- Retention of **some control** over a facility, perhaps through partnerships.
- There are **no guarantees** in siting: owners should be prepared to walk away.
RECOMMENDATION 8.5: The developers and future owners that represent the advanced nuclear industry must adopt a consent-based approach to designing, siting, and operating new facilities. The siting approach will have to be adjusted for a particular place, time, and culture. Following best practices will require additional time and financial resources to be allotted to successfully site and construct new nuclear power facilities, and the industry must account for these costs in their plans. The industry should be willing to fully engage with a community, hear their concerns and needs and be ready to address them, including adjusting plans. While this would raise the likelihood of successful deployment, it is not a guarantee of success. Additionally, the industry, guided by experts in consent-based processes, should capture best siting practices in guidance documents or standards.
RECOMMENDATION 9.1: The modification of the security requirements proposed by the NRC staff could have significant implications for the design, staffing and operations of advanced reactors, thereby impacting business plans. Delays in providing clear regulatory guidance may impact capital availability and increases the potential for costly re-design if guidelines do not align with expected modifications to existing protocols. Congress should provide additional funding for NRC evaluation of security guidelines and the Commission should expedite its consideration of the staff proposal and seek to complete the rulemaking promptly if significant changes are deemed appropriate. In that case, the prompt completion of the associated guidance should also be a high priority.
Government Support in International Markets

State and private support is crucial for safeguards, international deployment, and competitiveness

RECOMMENDATION 9.5: The United States should develop a plan for increased and sustained long-term financial and technical support for capacity building in partner countries, including cost requirements for using U.S. national labs and universities as training platforms. This plan should include partnering with U.S. reactor vendors to develop a safety, safeguards and security “package,” where the United States and the vendor could offer customized support to a host country for developing and implementing new safety, security and safeguards arrangements.

RECOMMENDATION 10.2: International nuclear projects by US exporters are likely to require a financing package that reflects a blending of federal grants, loans, and loan guarantees along with various forms of private equity and debt financing. The Executive Branch should work with the private sector to build an effective and competitive financing package for US exporters.
Sustained Effort, Robust Financial Support, and Prompt Regulatory Updates are Key

...but every variable matters!

- Reactor Technology Research
- Safety Regulations
- Project Management and Construction
- Workforce
- Alternative Applications
- Federal Funding from Design to Deployment
- Community Engagement and Acceptance
- Financing
- Security and Safeguards
- International Marketing
Given the urgent need to respond to climate change, it is important to advance the commercialization of all low-carbon technologies. In order for advanced reactors to contribute significantly to a decarbonized energy system, there are many challenges that must be overcome.

This will require sustained effort and robust financial support by the Congress, federal agencies, the nuclear industry, and the financial community.
Thank you!

Questions?

Download the report here: https://nap.nationalacademies.org/catalog/26630.

Stay tuned for other related events in Summer and Fall 2023, including a follow-on workshop!