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

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CONSENSUS REPORT BRIEFING

What will it take for new and advanced nuclear reactors to play a role in a net-zero emissions future?

About the Study – Committee

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[1] Until April 2022
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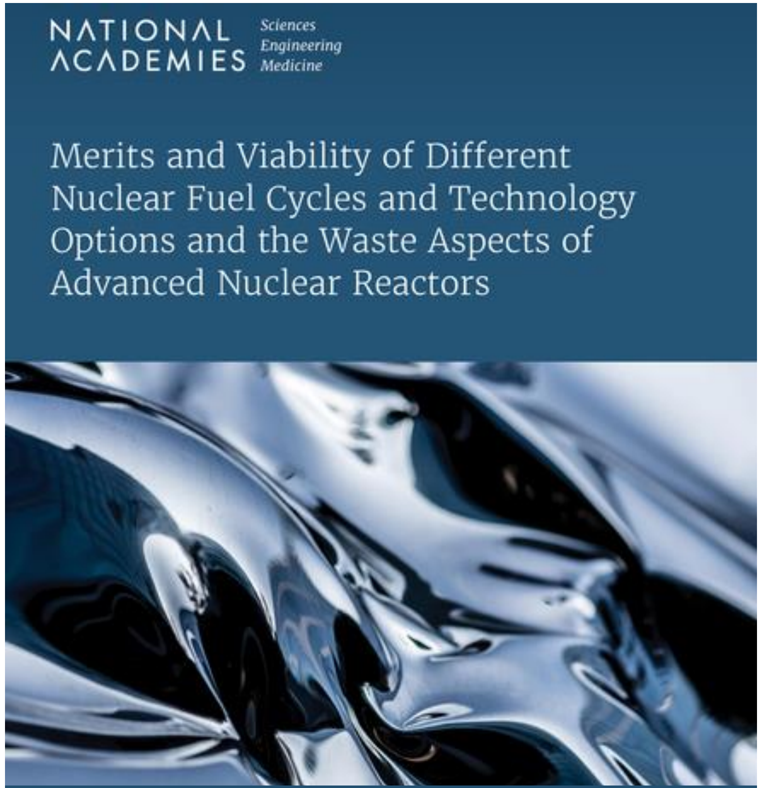
About the Study – Scope

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

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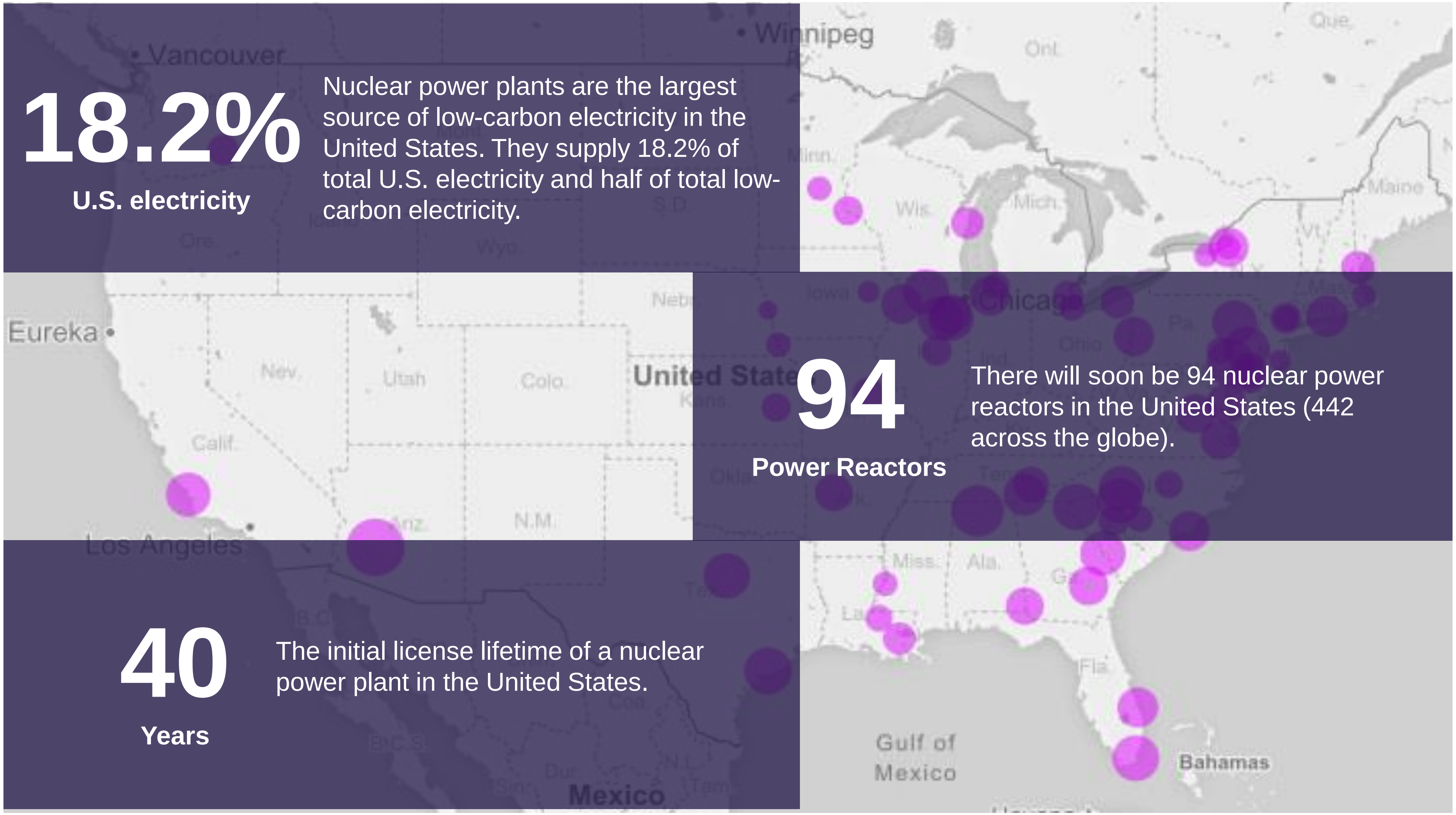
The Current State of Nuclear Power in the U.S.



18.2%

U.S. electricity

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.

94

Power Reactors

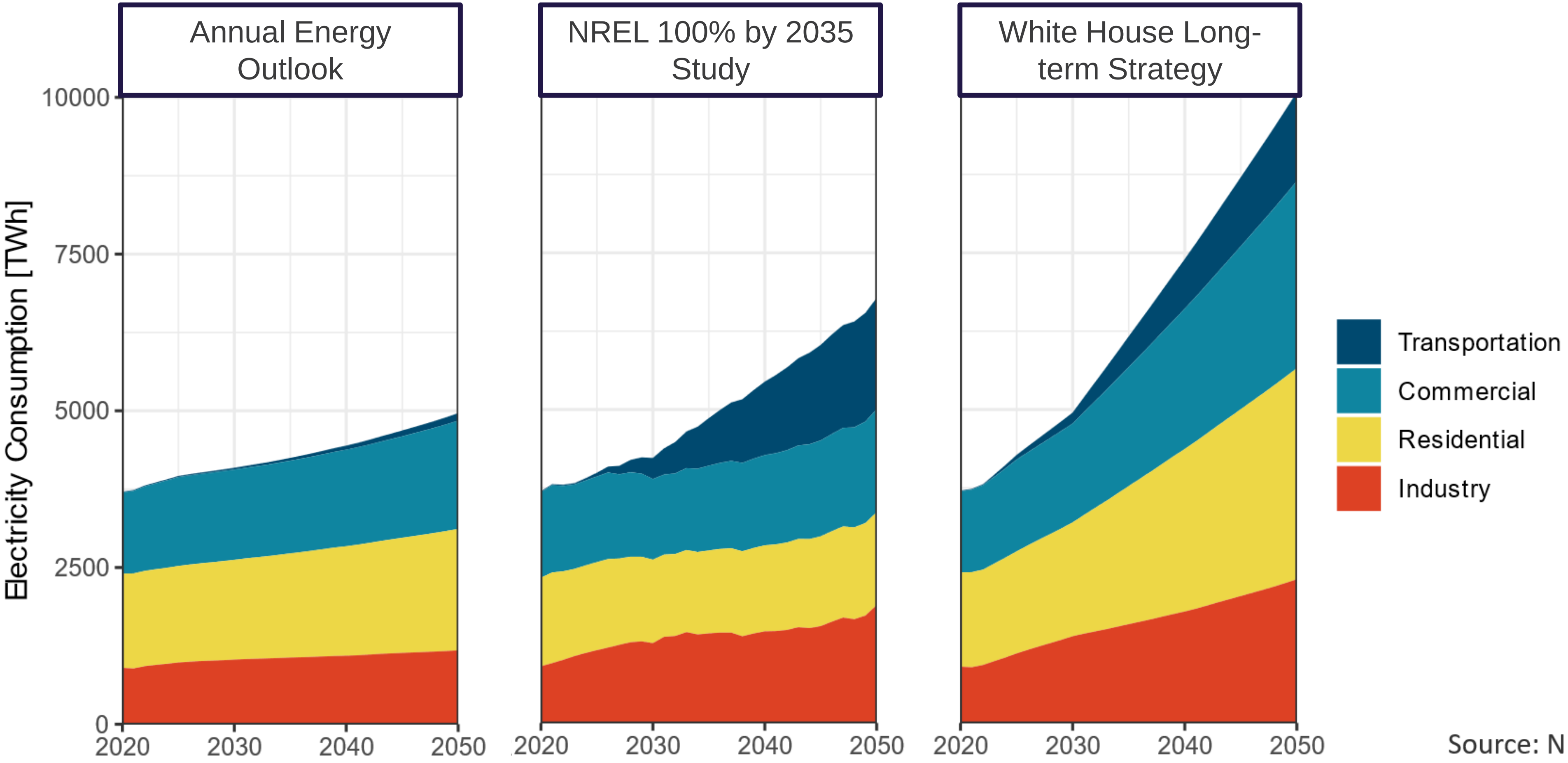
There will soon be 94 nuclear power reactors in the United States (442 across the globe).

40

Years

The initial license lifetime of a nuclear power plant in the United States.

U.S. Demand for Electricity Projected to Grow



Source: NREL

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Why consider nuclear power to meet growing energy demand?

- Nuclear provides a low carbon energy source
- High capacity factor – complementary to renewables
- Economic – **if cost targets are met**
- Small land footprint
- Long lifetime

What Are Advanced Nuclear Reactors?

Technological maturity (↑)

Reactor Technology	Technology Experience	Technology Gaps
Small Modular LWR	Evolution from currently operating LWRs	Develop and qualify unique plant components
Liquid Metal Fast Reactor	Several small SFRs operating worldwide	Qualify annular metal fuel and advanced steel alloys Perform source term experiments to reduce conservatisms
High-Temperature Gas Reactor	Several small HGTRs operating worldwide	Qualify fuel and graphite (<1100 K outlet temp designs) Qualify materials used in heat exchanger and other components (>1100 K outlet temp designs)
Fluoride Salt-Cooled Reactor	FHR designed, reduced-scale prototype planned for demonstration	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
Heat-Pipe-Cooled Reactor	LANL space reactor demonstrated concept at reduced power scale	Develop compact PCU operation and integration with heat-pipe core cooling Develop autonomous control and instrumentation Demonstrate passive safety systems
Molten Salt-Fueled-Cooled Reactor	ORNL experiments operated without power conversion systems	Demonstrate corrosion control for salts, tritium migration and control, materials for long-term operation Demonstrate passive safety systems
Gas Fast Reactor	No reactor ever built	Qualify fuel, clad, and structural materials for safety and radiation damage Demonstrate passive safety systems

Postulated Advantages of Advanced Reactors Over Existing Reactors

- Improved safety
- Lower costs
- Shorter Construction Times
- Higher thermal efficiency
- Higher temperature output
- Reduced regulatory restraints on deployment
- Increased operational flexibility

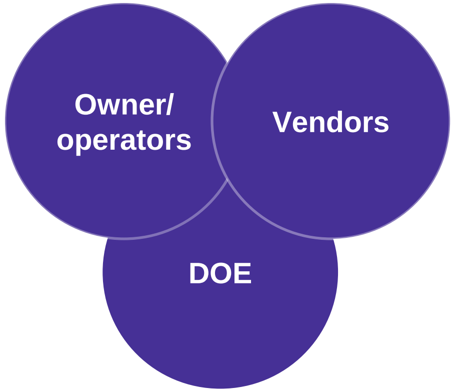
Many variables affect whether advanced nuclear can be viable in tomorrow's energy market – how could we get there?

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
- Fuel Cycle
- Waste Disposal
- Financing
- Security and Safeguards
- International Marketing

Federal Funding From Design to Deployment

Coordination among owner/operators, vendors, and DOE labs is needed to meet demonstration milestones



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.

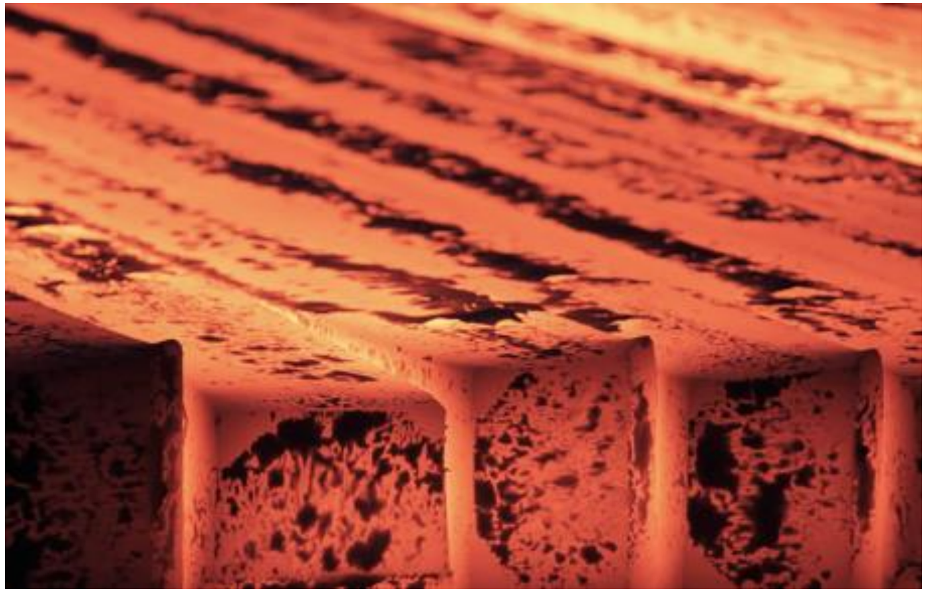
Financial Incentives

Incentives at various levels of government will be required

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…

Realistic models for non-electric deployment scenarios are needed for investors and industrial partners



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.

Project Management and Construction

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Investment in Advanced Construction Techniques

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 management and workforce capacity 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.

Preparing for an Expanded Workforce

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.

Timely Updates to Regulatory Requirements

Adequate staffing and funding is needed to expedite rulemaking

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.

Community Engagement and Societal Acceptance

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.

Designing Reactors With Security Requirements in Mind

Clear regulatory guidance is needed to complete reactor designs

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.**

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
- Fuel Cycle
- Waste Disposal
- 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.

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Thank you!

Questions?

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