Advanced Nuclear Energy - Nuclear Innovation Alliance

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Energy and Utilities Finance and Policy Committee
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Patrick White, Project Manager, NIA
Advanced nuclear energy can play a key role in achieving environment, climate, and energy goals

- NIA is a “think-and-do” tank working to ensure the conditions for success for advanced nuclear energy to be a key part of the climate solution

- Advanced nuclear energy can ensure and accelerate progress towards achieving deep decarbonization goals
Why do we need advanced nuclear energy for deep decarbonization?

• We need to pursue a portfolio of promising technological options to provide the best chance of success
• The electricity system needs a variety of energy resources in order to be reliable, affordable and zero-carbon
• In particular, the electricity system needs clean firm resources like advanced nuclear energy to balance variable clean resources
• Deep decarbonization studies show that firm energy sources like nuclear energy make it more likely to achieve deep decarbonization and reduce decarbonization costs
Commercial advanced reactor deployment is underway for several technology developers in the United States.

Technology development is being supported by both federal and private investments.
Development and deployment of advanced nuclear energy has climate, domestic, and international benefits

**American leadership**
- Re-establish American global leadership in nuclear technology and decarbonize emerging economies.

**Decarbonizing power & non-electric sectors**
- Complement renewables to reach 100% carbon-free electricity.
- Provide district heating, power industrial facilities, and produce hydrogen.
- Replace existing fossil fuel infrastructure.

**Economic advantages**
- Create a new industry and support economic growth with high-paying construction and operations jobs.
- Reduce costs and increase flexibility.

**Safety improvements**
- Innovative designs enable inherently safe reactors that don’t require electricity or operator action to shutdown safely.

**Replacing retiring power plants**
- Coal power plants provide 25% of total electricity in Minnesota in 2020.
- Nuclear plants provide 26% of MN electricity and half of its clean electricity.
- These plants will need to be replaced with clean energy as plants retire.
What is advanced nuclear energy?
Advanced nuclear energy adds flexibility and versatility in comparison to conventional nuclear through innovative design.

<table>
<thead>
<tr>
<th>Conventional Nuclear Energy</th>
<th>Advanced Nuclear Energy</th>
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<tbody>
<tr>
<td>Predominantly Large: More than 500 MW&lt;sub&gt;e&lt;/sub&gt;</td>
<td>Versatile: 1.5 MW&lt;sub&gt;e&lt;/sub&gt; to 300+ MW&lt;sub&gt;e&lt;/sub&gt;</td>
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<tr>
<td>Predominantly Light-Water Reactors</td>
<td>Wide Variety of Reactor Technologies</td>
</tr>
<tr>
<td>Primarily Baseload Generation</td>
<td>Flexible and Dispatchable Generation</td>
</tr>
<tr>
<td>Designed with Active Safety Systems</td>
<td>Designed with Inherent Safety Systems</td>
</tr>
<tr>
<td>Exclusively Low Enriched Uranium Fuel Rods</td>
<td>Variety of Proposed Fuels</td>
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</table>

- Reactor Size
- Reactor Technology
- Generation Type
- Safety Approach
- Fuel & Efficiency
Definition of advanced nuclear energy includes a variety of nuclear technologies with different advantages.

- **Advanced Light-Water Reactors**
  Evolutionary design from existing reactors with inherent safety features.

- **High-temperature reactors (HTRs)**
  High temperatures drive high efficiency, well-suited for process heat or hydrogen production. Uses TRISO fuel.

- **Molten Salt-Fueled Reactors (MSRs)**
  Using molten salt for coolant and a fuel form, MSRs can bring significant safety benefits.

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**Fast Fission**

- **Gas-cooled fast reactor (GFR)**
  An evolution of HTRs, GFRs operate at very high temperatures while using a more sustainable fuel cycle.

- **Sodium-cooled fast reactor (SFR)**
  With many existing experimental reactors, SFRs offer increased fuel efficiency, reduced waste, and passive safety features.

- **Lead-cooled Fast Reactor (LFR)**
  Similar in design to SFRs, LFRs are advantageous as lead is operationally safer than sodium.
Variety of reactor sizes and low-carbon products enable integration of advanced nuclear into future energy systems.
Licensing Advanced Nuclear Energy
Nuclear Regulatory Commission (NRC) licenses all commercial nuclear facilities in the United States.
Existing regulatory frameworks for nuclear energy are optimized for today’s operating nuclear reactors

Monticello Nuclear Generating Plant, Monticello, Minnesota

- Predominantly Large: More than 500 MW$_e$
- Predominantly Light-Water Reactors
- Primarily Baseload Electricity Generation
- Designed with Active Safety Systems
- Low Enriched Uranium Fuel Rods

Image source: North Wright County Today
Regulatory modernization activities are underway to effectively and efficiently license novel advanced reactors.

Risk-Informed
“Focus on probability and consequence”

Performance-Based
“Focus on outcomes, not design features”

Technology-Inclusive
“Focus on rules applicable to any reactor technology”
Advanced reactors developers are making progress in licensing, with developers starting NRC pre-application and application activities for specific facilities, sites, and designs:

<table>
<thead>
<tr>
<th>NRC Applications (Site or design)</th>
<th>NRC Pre-applications (Site identified)</th>
<th>NRC Pre-applications (Site independent)</th>
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<tbody>
<tr>
<td>NuScale (UAMPS)</td>
<td>X-Energy (Xe-100)</td>
<td>General Atomics (EM²)</td>
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<tr>
<td>Kairos Power (Hermes)</td>
<td>TerraPower (MCFR)</td>
<td>Westinghouse (eVinci)</td>
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<td></td>
<td>TerraPower/GE (Natrium)</td>
<td>Kairos Power (KP-FHR)</td>
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<td>USNC/UIUC (MMR)</td>
<td>Holtec (SMR-160)</td>
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<td>Oklo (Aurora)</td>
<td>Terrestrial Energy (IMSR)</td>
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<td>GEH (BWRX-300)</td>
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State of Play on Advanced Nuclear Energy State Actions
States are exploring and taking action to encourage deployment of advanced nuclear energy
Advanced Nuclear Energy: The Takeaways

- Nuclear energy is an important tool for climate change mitigation
- Advanced nuclear energy can help play a unique role in decarbonization
- Development of advanced nuclear energy is already underway in the US
- NRC regulatory modernization and federal investment in technology innovation are enabling advanced reactor development
- State legislative policy changes can catalyze technology deployment
For More Information and Follow-up:

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Additional/Back-up Slides
Utilizing advanced nuclear energy increases the likelihood of achieving deep decarbonization and reduces costs.

Local case study of Pacific Northwest show that baseload low carbon energy resources (like nuclear) can help offset the cost of deep or full decarbonization. Source: Energy+Environmental Economics
Innovative technology and design strategies help ensure the safety of advanced reactors

<table>
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<tr>
<th>Inherent Safety Methods</th>
<th>Reduced Advanced Reactor Hazards</th>
<th>New and Robust Forms of Fuel</th>
<th>New Reactor Siting Paradigms</th>
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<tbody>
<tr>
<td>Advanced reactor are designed with new inherent safety features:</td>
<td>Advanced reactor designs reduce inherent hazards:</td>
<td>Advanced reactor designs utilize a variety of special fuel forms that:</td>
<td>Advanced reactor designs can utilize new approaches to siting:</td>
</tr>
<tr>
<td>• Replacing active safety systems with inherent safety systems</td>
<td>• Lower reactor power reduces post-shutdown cooling demands</td>
<td>• Survive high temperatures (TRISO fuel forms)</td>
<td>• Placing reactors underground to reduce natural or man-made risks</td>
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<tr>
<td>• Minimal reliance on emergency electric power and operators to ensure safe shutdown</td>
<td>• Smaller reactors have smaller radiological inventories that reduce accident consequences</td>
<td>• Maintain operation stability in a liquid form (molten salt reactors)</td>
<td>• Eliminating off-site accidents and reducing community emergency planning requirements</td>
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<td>• Quickly dissipate excess heat (metal fuel forms)</td>
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New, competitive advanced reactor industry is growing nationwide
Reimagining the advanced nuclear fuel cycle can improve the long-term sustainability of nuclear technology
Advanced reactor developers are working with NRC to both use existing rules and help inform future licensing rules.

Near-term licensing reform: 10 CFR Part 50 and Part 52
- Effectively use existing licensing processes for first-of-a-kind advanced reactor projects

Longer-term licensing development: 10 CFR Part 53
- Inform NRC rulemaking on new licensing process for future advanced reactors

Use and help inform NRC rulemaking on environment, siting, and decommissioning

On-going regulatory reform:
- Risk-informed, performance-based regulations
# NIA’s U.S. Advanced Nuclear Energy Strategy

## State Level Recommendations:

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<th>Recognize the Opportunity of Advanced Reactors</th>
<th>Early Movers Support Demo Projects</th>
<th>Innovation Hubs Support Economies</th>
<th>Decarbonization of Power Sector at Scale</th>
<th>Decarbonization At Other Sectors</th>
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<tbody>
<tr>
<td>Advanced reactor will bring high paying jobs and economic development to areas. Restrictions must be eased for reactors to be sited.</td>
<td>Early adopters of advanced nuclear demonstrations projects can support rapid commercialization of advanced reactor.</td>
<td>Advanced reactors can serve has hubs that will develop supply chain and systems that bring broad and other economic benefit to areas.</td>
<td>Advanced nuclear energy can complement renewable energy and serve as a strong, baseload energy source to achieve a 100% carbon free electric sector.</td>
<td>Advanced reactors will be able to produce hydrogen, power desalination plants, and decarbonize other industries like steel making and cement.</td>
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