Current Status of Advanced Nuclear Reactors

NC Energy Policy Council

Marc Nichol
Nuclear Energy Institute
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Agenda

- Technology
- Projects
- Cost/Value Proposition
- Regulatory
Current State

- Over 60 new technologies being actively developed by private sector
- DOE funding 12 different designs, >$5B over 7 years
  - 3 Demonstration Plants
  - 9 Technology Development
- U.S. utilities evaluating nuclear in IRPs
- Growing interest in conversion of coal power sites to nuclear
- Continued strong support in Congress
Types of Advanced Reactors

Range of sizes and features to meet diverse market needs

- **Micro Reactors (< 20MW)**
  - Oklo (shown)
  - Approximately a dozen in development

- **LWR SMRs <300MW**
  - NuScale (shown)
  - GEH X-300
  - Holtec SMR-160

- **High Temp Gas Reactors**
  - X-energy (shown)
  - Several in development

- **Liquid Metal Reactors**
  - TerraPower Natrium (shown)
  - Several in development

- **Molten Salt Reactors**
  - Terrestrial (shown)
  - Several in development

- **Non-Water Cooled**
  - Most <300MW, some as large as 1,000 MW
Advanced Nuclear Versatility

**Spectrum of Sizes/Options**
- **Micro** (Few MW)
- **Mini** (10s of MW)
- **Small** (100s of MW)
- **Large** (1,000+ MW)

**Variety of Outputs**
- **Electricity**
- **H₂** (Hydrogen)
- **Process Heat**

**Multitude of Uses**
- **Homes**
- **Businesses**
- **Vehicles**
- **Rail**
- **Shipping**
- **Factories**
- **Concrete**
- **Steel**
- **Water**
Projects
## Current State – DOE Demonstrations*

Planned to be online in late 2020s:

<table>
<thead>
<tr>
<th>Developer</th>
<th>Technology</th>
<th>Utility</th>
<th>Location</th>
<th>Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>NuScale</td>
<td>Integral PWR</td>
<td>UAMPS</td>
<td>Idaho</td>
<td>6 @ 77MW</td>
</tr>
<tr>
<td>TerraPower &amp; GE-Hitachi</td>
<td>Liquid Sodium</td>
<td>Pacific Corp.</td>
<td>Wyoming</td>
<td>345 - 500MW w/thermal storage</td>
</tr>
<tr>
<td>X-energy</td>
<td>High Temperature Gas</td>
<td>Energy Northwest</td>
<td>Washington</td>
<td>4 @ 80MW</td>
</tr>
</tbody>
</table>

* = does not include non-commercial demonstrations
## Current State – Other Demonstrations*

Planned to be online in late 2020s:

<table>
<thead>
<tr>
<th>Developer</th>
<th>Technology</th>
<th>Utility / Owner</th>
<th>Location</th>
<th>Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>TBD</td>
<td>SMR</td>
<td>OPG</td>
<td>Ontario, Canada</td>
<td>TBD</td>
</tr>
<tr>
<td>(GEH, X-energy, or Terrestrial)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Oklo</td>
<td>Micro Reactor</td>
<td>Oklo</td>
<td>Idaho</td>
<td>1.5 MW</td>
</tr>
<tr>
<td>Ultra Safe Nuclear Corp.</td>
<td>Micro Reactor</td>
<td>Global First (w/ OPG)</td>
<td>Chalk River, Canada</td>
<td>5 MW</td>
</tr>
<tr>
<td>TBD</td>
<td>Mobile Micro Reactor</td>
<td>Department of Defense</td>
<td>Idaho</td>
<td>TBD</td>
</tr>
<tr>
<td>(X-energy or BWXT)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TBD</td>
<td>Micro Reactor</td>
<td>Department of Defense</td>
<td>Alaska</td>
<td>TBD</td>
</tr>
</tbody>
</table>

* = does not include non-commercial demonstrations
<table>
<thead>
<tr>
<th>State</th>
<th>Legislative Action</th>
<th>Utility Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alaska</td>
<td>Bills introduced to repeal voter approval to site</td>
<td>Interest in micros for mining/DoD</td>
</tr>
<tr>
<td>Arizona</td>
<td></td>
<td>Utility interest in 25 MWe of UAMPS/NuScale</td>
</tr>
<tr>
<td>Idaho</td>
<td>Tax incentives passed</td>
<td>Host of UAMPS/NuScale SMR</td>
</tr>
<tr>
<td>Montana</td>
<td>Passed bill to study coal to SMR</td>
<td>Northwest Energy interested in coal to nuclear</td>
</tr>
<tr>
<td>Montana</td>
<td>Repealed voter approval to site</td>
<td></td>
</tr>
<tr>
<td>Nebraska</td>
<td>Passed bill on SMR tax incentives</td>
<td></td>
</tr>
<tr>
<td>North Carolina</td>
<td>Passed bill paying for ESP</td>
<td>Duke Energy includes SMRs in IRP</td>
</tr>
<tr>
<td>Virginia</td>
<td>Nuclear Energy Strategic Plan</td>
<td>Dominion includes SMRs in IRP</td>
</tr>
<tr>
<td>Washington</td>
<td>Clean energy standard including nuclear</td>
<td>Energy Northwest with X-energy demo</td>
</tr>
<tr>
<td>Washington</td>
<td></td>
<td>Grant County PUD MOU with X-energy and NuScale</td>
</tr>
<tr>
<td>Wyoming</td>
<td></td>
<td>Rocky Mt. Power siting for Terrapower demo</td>
</tr>
</tbody>
</table>
Coal to Nuclear Transition

- Coal power plant shutdowns can be devastating to local communities
- Transition to a small modular reactor (SMR) can provide carbon-free replacement power while:
  - Capitalizing on existing infrastructure,
  - Saving jobs, and
  - Supporting communities
- Pursuing policy actions to encourage coal to nuclear
Cost/Value Proposition
Current State – Affordability

$\text{SMALL} + \text{INHERENTLY SAFE} = \text{COST-COMPETITIVE}$

**Simpler**
- Inherent Safety
- Less Equipment
- Smaller Facility
- Regulatory Efficiency

**Readily Available Equipment**
- Off-the-shelf Equipment
- Proven Performance

**Factory-Built**
- 60-80% of Equipment
- U.S. Supply Chain Growth

**Faster Construction**
- Smaller Structures
- Assembly vs. Construction
- Modern Construction Methods

**Improved Performance**
- Higher Thermal Efficiency
- Design and Construction Best Practices
- Operational Excellence
Figure 4: GHG abatement costs. The y-axis represents the incremental cost of each scenario compared to a Reference case that does not apply an emissions constraint.

$ Advanced Reactor Cost Competitiveness in Electric Markets

Considering system reliability needs makes nuclear even more affordable.
Government Deployment Support

- Valuing all carbon-free sources of energy
- State Programs
  - Tax incentives (e.g., property)
  - Advanced cost recovery
  - Infrastructure
- Federal Programs
  - Cost-share
  - Tax Credits (e.g., Production)
  - Loan Guarantees
  - Federal Power Purchase Agreements

http://smrstart.org/policy-statement/
Regulatory
NRC Applications and Pre-Application

- NuScale – Light-water SMR
- Oklo Aurora – micro-reactor
- GEH BWRX-300 – Light-water SMR
- General Atomics EM2 – gas cooled fast reactor
- Holtec SMR-160 – Light-water SMR
- Kairos Power – salt cooled with TRISO fuel
- Terrestrial Energy – molten salt reactor
- TerraPower – Natrium
- TerraPower – molten chloride fast reactor
- Westinghouse – micro-reactor
- X-energy XE-100 – high-temperature gas reactor

Information above from NRC as of Aug 16, 2021
Advanced Reactor Safety

Building upon a strong safety record

- Operating fleet: one of the safest industrial working environments
  - Strong-Independent Regulator, Built tough, Operational Performance
- Enhancing safety for advanced reactors*

**Inherent Safety Features**
- Rely on physics
  - Natural circulation
  - Gravity
  - Below grade
  - Higher melting points
  - Atmospheric pressure

**Reduce Risks**
- Smaller source terms
- Minimize potential for accidents
- Mitigate consequences

**Emergency Response**
- Maintain safety without the need for
  - Power
  - Additional coolant
  - Human actions
  - Emergency planning

*Features vary by design
Regulatory Priorities

- Streamlining the regulatory process
  - Timely and efficient NRC safety reviews
  - Environmental reviews
- Resolving key technical and policy issues
  - Emergency planning zones
  - Physical security
  - Population criteria for siting
- Modern and efficient regulatory framework
  - Risk-informed licensing approaches
  - Technology-inclusive rulemaking
Top-Line Summary

- Tangible movement to multiple initial demonstrations in 2020s
- Federal and state policies evolving in right direction
- Regulatory and licensing activities are progressing
- Increasing customer interest in deployments around 2030

Spectrum of technologies available for deployment in 2030s
DISCUSSION
Key technologies and policy areas

Power
- Nuclear
- Storage
- Natural Gas
- Carbon Capture
- Hydro
- Geothermal

Industrial
- Concrete
- Metals
- Hydrogen

Federal R&D (basic and applied)

Demonstration Programs

Deployment Incentives

“Ecosystem” e.g. Regulatory Reform
From gas to solar, cheap clean technology has received public policy support to move it up the global “S curve.”

Targeted innovation policy supports global scale-up

Low cost enables global deployment

ECA and multi-lateral support for deployment in developing nations

Innovation-targeted incentives pull tech into markets

Early PPPs for demo

Basic / Applied R&D

Clean Tech Market Share

Time
U.S. Nuclear Landscape

Current Projects
- What was in the Energy Act of 2020
- Ongoing nuclear projects and timelines
- The Advanced Reactor Demonstration Program (ARDP)
- Civil Nuclear Credit Program

Role of Existing Nuclear to Reduce Emissions
- Why the NRC needs to modernize its regulatory requirements
- The development of 10 CFR Part 53
- Other ongoing regulatory efforts

Future Projects and Momentum
- Hydrogen demonstrations
- Nuclear legislative initiatives
- What more is needed
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1. Current Advanced Nuclear Projects
2. Role of Existing Nuclear
3. Future Projects and Legislation
Biggest Climate Policy Success in Over a Decade

20+ Large-Scale Clean Energy Demonstrations
- Advanced Nuclear
- Carbon Capture, Utilization, Storage
- Enhanced Geothermal Systems
- Grid-scale Energy Storage
- Industrial Decarbonization Technologies

Early to Mid-2020s

Advanced Nuclear Fuel Availability Program

Integrated Energy Systems and Hydrogen Demos

Enhancements to Loan Guarantee program
- No fees until financial closing
- Ability to reduce fees, provide a credit subsidy
- Project eligibility expansion, more transparency

Research, development, demonstration, and technical assistance for industrial energy
- Plan to develop and deploy smart manufacturing technologies

Elevate the DOE Office of Technology Transitions
- Empowers office to better support American entrepreneurship
Historical development

- Senators Lamar Alexander (R-TN) and Lisa Murkowski (R-AK), working with ClearPath and the National Labs, came up with the idea in 2016
- Concept was included in multiple bipartisan bills
- Kicked off in FY20 appropriations and authorized in the Energy Act of 2020

Clear goals and timelines

- Build 2 commercial reactors in 7 years: TerraPower in WY + X-energy in WA
- Also supports 5 longer-term designs, e.g., Kairos research reactor Hermes
- This moonshot goal mobilized the entire industry

Requirements for application

- Goal required robust teams of reactor developers, utilities, private capital, and manufacturers to meet these timelines and cost share requirements
- Need to actually submit an NRC license application for review and approval
- Need a plan to procure fuel
The Benefits of Setting a Goal

**Align Industry**
Concrete goal aligned private industry resources in order to meet the aggressive timeline

**Bipartisan Support**
Congressional support - from authorization to appropriations - will keep program on track and provide oversight

**Regulatory**
Funding for NRC modernization has enabled them to review advanced reactors

**DOE Resources**
Companies leveraging historical DOE and National Lab research, e.g., X-energy and Kairos using TRISO fuel tested at ORNL
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ClearPath to a Clean Energy Future 2021: The Role of Utility Commitments on the Path to 2050
Power Sector Emissions Could Flatline After 2025

Major Changes in Generation between 2020 and 2050

34% load increase

Source: Clear Path to a Clean Energy Future
Electric Utility Targets Cover Over 70% of Electric Customers

Utility Decarbonization Targets

Source: Smart Electric Power Alliance Utility Decarbonization Tracker
Utility Commitments Narrow the Gap to Net-Zero

Source: Clear Path to a Clean Energy Future
Nuclear is an affordable way to reach commitments

- Maintaining existing nuclear reactors is one of the cheapest ways to help meet utility commitments and reduce carbon emissions

- Utility commitments scenario:
  - Preserved 22 GW of nuclear that closed in reference scenario
  - Leads to 228% more electricity generated from nuclear reactors in 2050 than in reference scenario
  - Still included significant nuclear retirements

Source: Clear Path to a Clean Energy Future
1. Current Advanced Nuclear Projects
2. Role of Existing Nuclear
3. Future Projects and Legislation
Hydrogen (H2) and Nuclear

**Positives**
- H2 is a potential revenue stream
- High electrical capacity factor means a lower cost
- Potential for higher efficiency HTSE

**Negatives**
- Demand market is not big enough yet for dedicated production

### Exelon - Location TBA, Midwest
- **Fully contracted**
  - 2019 H2@Scale award funded by EERE+NE
  - 1-3 MW PEM LT electrolysis
  - Used on site and sold to nearby users
  - Operations in Q1 '22

### Energy Harbor - Davis Besse, OH
- **In negotiations**
  - NE FOA with EERE
  - Needs an award increase for switchyard upgrades
  - 1-3 MW LT electrolysis
  - Not official, sold to Columbus bus system and Cleveland Cliffs DRI steel plant
  - Operations in ‘22

### Xcel Energy - Location TBA, MN
- **Not yet awarded**
  - NE FOA with EERE
  - 250 kWe HTSE
  - No offtaker yet
  - Testing HTSE skid at INL in Q1 '22
  - Operations in ‘22

### Arizona Public Service - Palo Verde, AZ
- **Not yet awarded**
  - NE FOA with EERE
  - Raising funds with offtakers and private investment
  - 20 MW LT electrolysis
  - APS will purchase H2 for 30H2:70NG co-firing in CCPP
  - Production at CCPP with PPA from Palo Verde
  - Online goal in ‘25

**Positives**
- H2 is a potential revenue stream
- High electrical capacity factor means a lower cost
- Potential for higher efficiency HTSE

**Negatives**
- Demand market is not big enough yet for dedicated production
## Nuclear Legislative Initiatives

<table>
<thead>
<tr>
<th>Policy Initiatives</th>
<th>Overview</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bipartisan Infrastructure Bill</td>
<td>Authorizes and appropriates funding for the ARDP; authorizes feasibility studies for siting advanced reactors; and creates existing nuclear credit program.</td>
</tr>
<tr>
<td>American Nuclear Infrastructure Act (ANIA) (S.2373)</td>
<td>A broad bill that establishes multiple programs supporting both currently operating nuclear reactors as well as the next generation of reactor technologies.</td>
</tr>
<tr>
<td>Energy Sector Innovation Credit (S.2475/H.R.4720)</td>
<td>Creates a new “technology neutral” tax incentive that facilitates investment in innovative new dispatchable clean energy technologies.</td>
</tr>
<tr>
<td>Nuclear Power Purchase Agreements Act (H.R. 4834)</td>
<td>Allow the Secretary of Energy to enter into long-term power purchase agreements (PPAs) with new nuclear power plants with federal facilities, and must enter one long-term PPA by December 31, 2026.</td>
</tr>
<tr>
<td>Hydrogen Production Tax Credit (multiple bills)</td>
<td>Creates a production tax credit for hydrogen that is based on the emissions intensity of production.</td>
</tr>
<tr>
<td>Multiple other bills to incentivize nuclear energy deployments</td>
<td>Nuclear Licensing Efficiency Act (H.R.1578); Modernize Nuclear Reactor Environmental Reviews Act (H.R. 1559); Advanced Nuclear Deployment Act (H.R.1746); Strengthening American Nuclear Competitiveness Act (H.R.7405)</td>
</tr>
</tbody>
</table>
Funding for Advanced Reactor Demonstration Program
Includes advance funding $2.48 billion for the two large demos, the TerraPower Natrium reactor and the X-Energy high temperature gas reactor. This fulfills most of the federal share of these projects.

Funding for Civil Nuclear Credit Program
Establishes a program to support economically struggling nuclear reactors with clean energy credits through a reverse auction system. Appropriates $1.2 billion per year for five years to initiate the program.

Other Clean Energy Demonstrations
Includes $500 million for demonstrations of clean energy on former mine land, including nuclear. Also establishes a ~$2 billion hydrogen “hub” to be primarily supported by nuclear energy.
Path Forward

Federal
- Effective policies can spur innovation and deployment
- Many projects require additional support
- Still need to address gaps like HALEU supply

State
- Projects are built at the state level
- Advanced nuclear reactors can be sited at different locations
- Ensure that nuclear is incorporated into resource planning

Projects
- Must execute on ARDP and other commercial projects
- New ideas, like integrated energy systems and replacing decommissioning coal plants with nuclear, further increase nuclear’s potential impact