Nuclear Energy Today and into the Future

North Dakota Advanced Nuclear Energy Committee

September 2n4, 2025

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Gateway for Accelerated Innovation in Nuclear (GAIN)

GAIN
Gateway for Accelerated Innovation in Nuclear

INL/MIS-25-82903

Gateway for Accelerated Innovation in Nuclear

Small enough to be nimble, big enough to be relevant

GAIN Gateway for Accelerated Innovation in Nuclear

G GATEWAY

Gateway to national labs.

A ACCELERATED

Accelerated to match advanced nuclear developer pace and market window.

I INNOVATION

Innovation in all spaces with a bias toward taking risks.

N NUCLEAR

Nuclear to meet the nation's energy, environmental and economic needs

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What's driving load growth across the world and how does it impact the U.S.?

- AI, data centers and crypto are driving energy demand at the equivalent of the 6th largest country in 2026.
- Additional demand is estimated at 26,900 TWh by 2050, or the equivalent of adding the six times more than United States' power consumption.
- 84% of new electricity demand will occur in countries current projected to be ready for nuclear by 2030.
- Coal retirement, EV's, and other electrification will increase demand further.
- Around 71% of new demand will be outside of high-income countries.
- Potential to grow our U.S. supply chain for advanced reactors and export our technology to support increased demand.

AI Consumption (TWh) (2022)

Countries	Total Consumption
China	8,849
United States	4,277
India	1,852
Russia	1,119
Japan	1,036
Brazil	679
Canada	636
Korea, Rep.	607
Germany	561
France	470
AI/Data center/Crypto	460
Saudi Arabia	399
Mexico	348
Indonesia	332
United Kingdom	326

Source: International Energy Agency. Electricity 2024. Organisation for Economic Co-operation and Development (OECD). January 2024. https://www.iea.org/reports/electricity-2024. Accessed October 2024.

THIRD WAY

AI Consumption (TWh) (2026)

Countries	Total Consumption
China	9,231
United States	4,591
India	2,113
Japan	1,083
Russia	1,064
AI/Data center/Crypto	800
Brazil	706
Germany	640
Canada	628
Korea, Rep.	603
France	527
Indonesia	438
Saudi Arabia	415
United Kingdom	414
Mexico	397

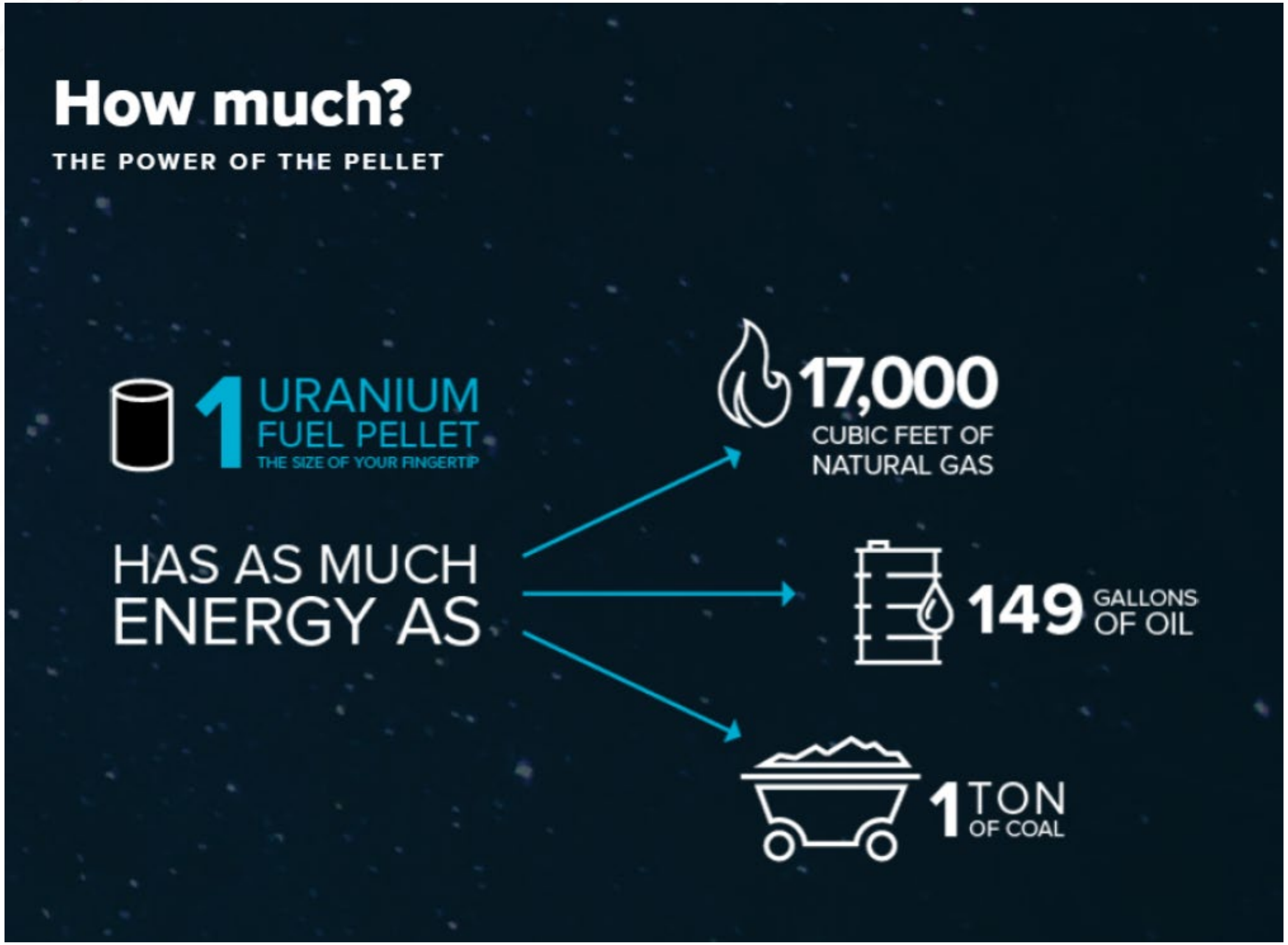
Source: International Energy Agency. Electricity 2024. Organisation for Economic Co-operation and Development (OECD). January 2024. https://www.iea.org/reports/electricity-2024. Accessed October 2024.

THIRD WAY

Google turns to nuclear to power AI data centres

Three Mile Island nuclear plant will reopen to power Microsoft data centers

Uranium Fuel Density



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Advanced Nuclear Versatility

SPECTRUM OF SIZES AND OPTIONS

Mini
(10s of MW)

Small
(100s of MW)

Large
(1,000+ MW)

Small Town: 1 Megawatt
Mid-size City: 1 Gigawatt
The U.S.: 1,000 Gigawatts

VARIETY OF OUTPUTS

Electricity

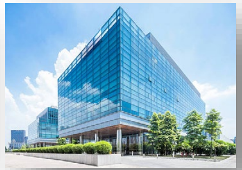
Hydrogen

Process Heat

MULTITUDE OF END USES

Homes

Vehicles



Businesses

Aviation

Rail

Shipping

Concrete

Steel

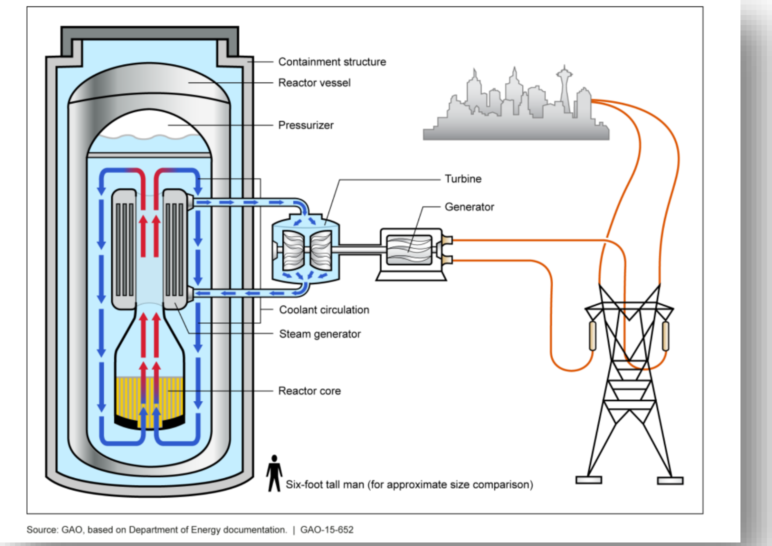
Factories

Desalinization

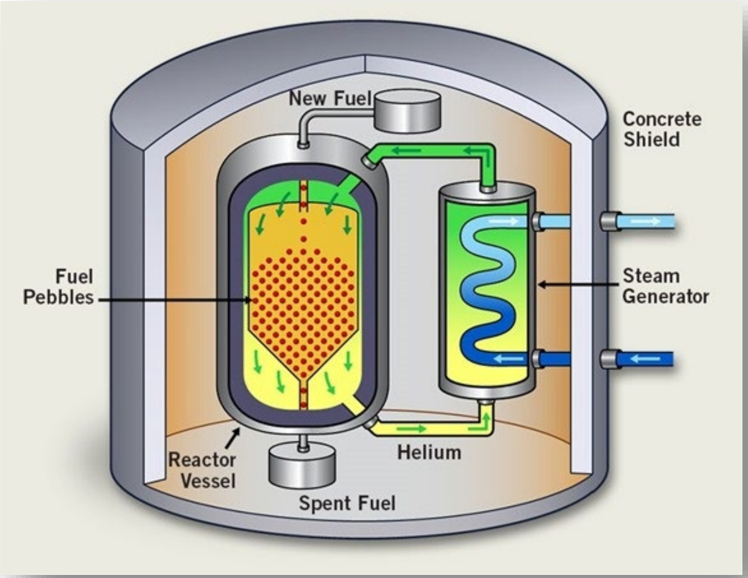
Space

Advanced Reactor Types

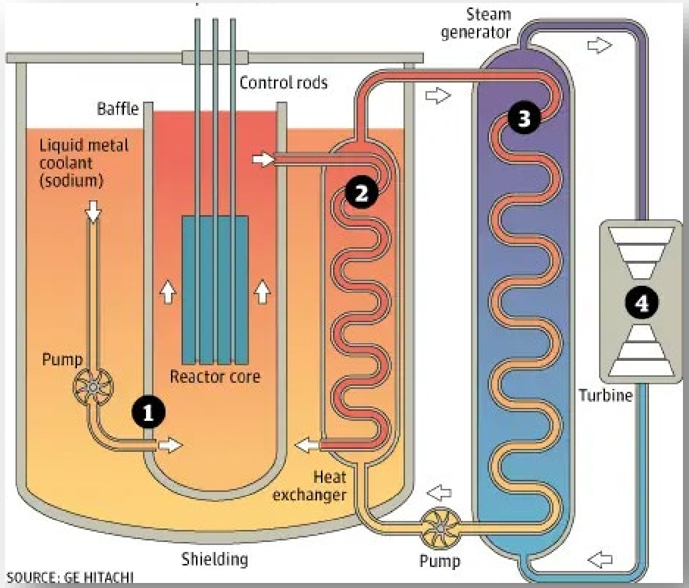
LIGHT WATER REACTORS IN SMALL MODULAR REACTOR FORM



HIGH-TEMPERATURE GAS REACTORS

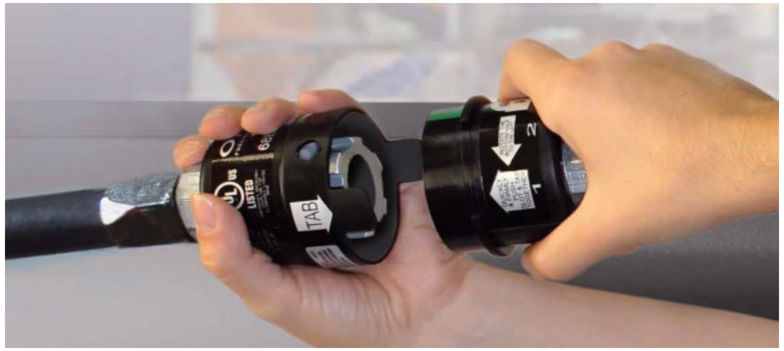


LIQUID METAL FAST REACTORS / MOLTEN SALT

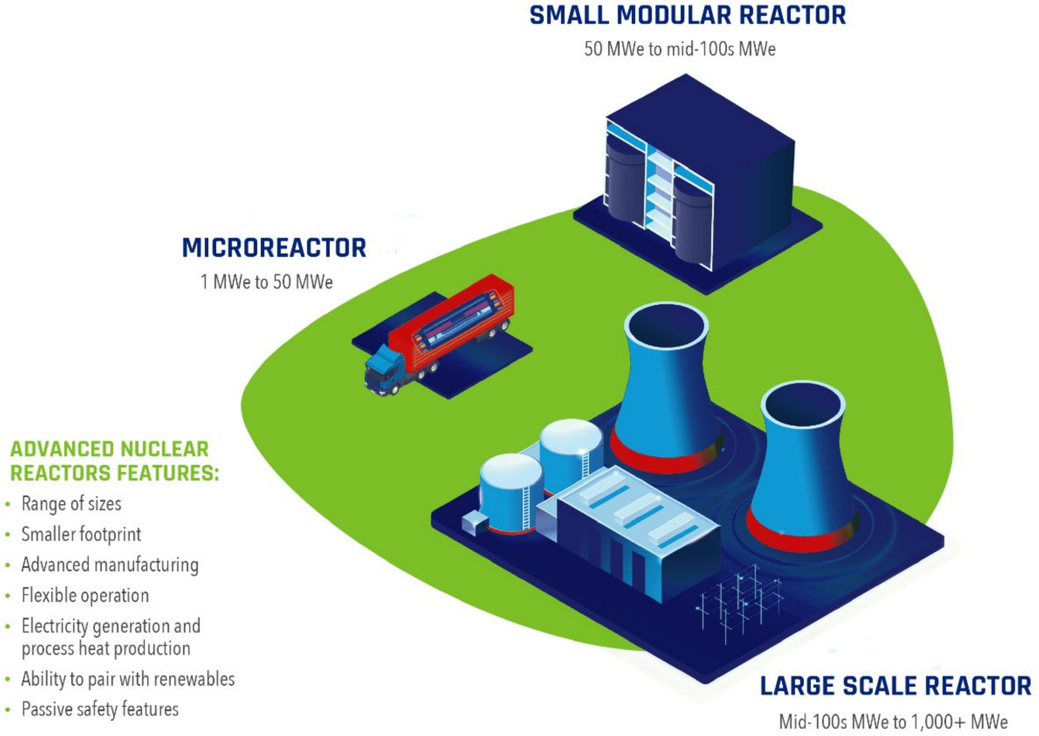


Active vs. Passive vs. Inherent Safety

ACTIVE	PASSIVE	INHERENT
Requires an external input to function	Relies on natural forces, property of materials, or internally stored energy	Relies on fundamental properties or design choices
A valve needs an electrical current to operate or a pump needs electricity to operate	Long term decay heat removal to heat sink using density changes and gravity heads	Design achieves reactor shutdown by negative power reactivity feedback (self limiting reaction)
Current plants	Advanced reactors (light water and non-light water)	Advanced reactors (light water and non-light water)
Example: Air Bag	Example: Self-Retracting lifeline	Example: Quick Disconnect Shutoff Valve

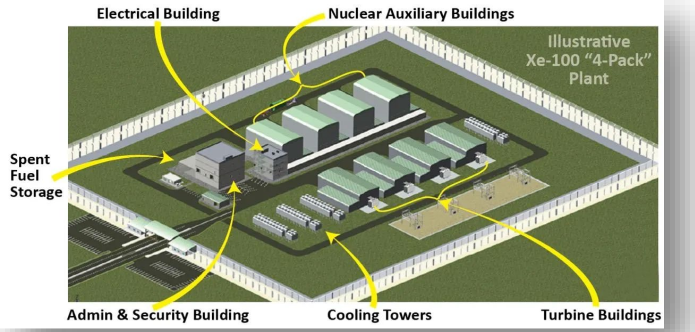


Nuclear Reactor Output and Footprint



VOGTLE PWR

- Output: 2,430 MWe
- Plant footprint: ~600 acres
- EPZ boundary: 10 miles



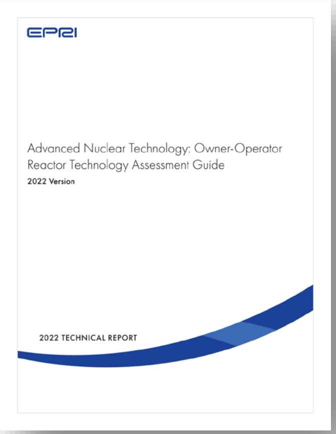
X-ENERGY

- Output: 320 Mwe (4 x 80 MWe)
- Plant footprint: 10 acres
- EPZ boundary: < 1 mile

GAIN Gateway for Accelerated Innovation in Nuclear

Reactor Technology Assessment Guide

- Developed by EPRI
- Provides an owner-operator, or potential owner-operator, with a straightforward decision-making framework including an uncomplicated and repeatable process
- Intended to cover all sizes and types of reactors, be regulatory neutral, and of value to all EPRI's global stakeholders
- GAIN used this methodology with several non-nuclear utilities


EPRI

Advanced Nuclear Technology: Owner-Operator Reactor Technology Assessment Guide

2022 Version

2022 TECHNICAL REPORT

DEFINE AND UNDERSTAND
their business objectives

EVALUATE
general technologies and specific designs

DEVELOP
a defendable justification for a primary selection and alternatives

UNDERSTAND
the inherent risk of technology and design selection and provide tools to help manage that risk

Nuclear Ecosystem

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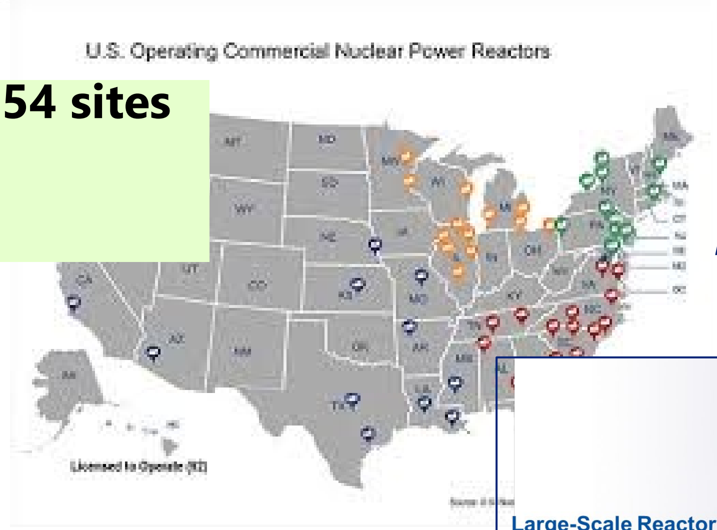
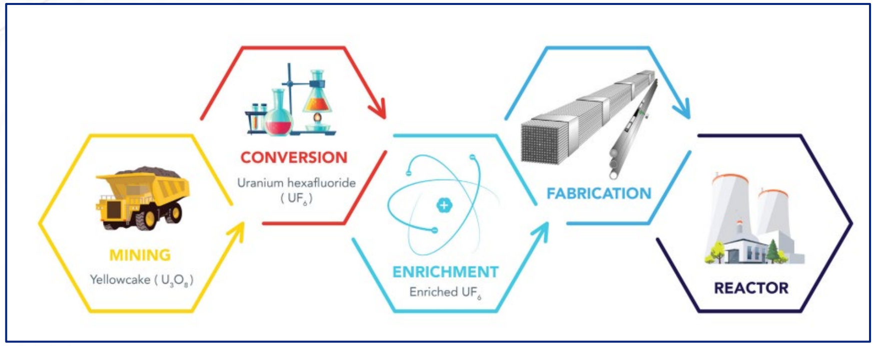
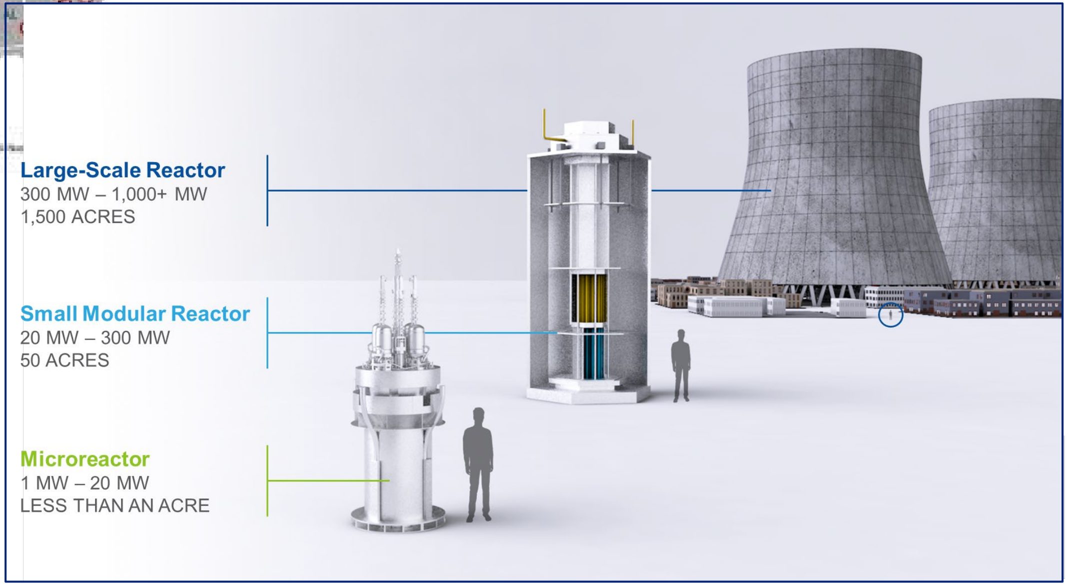
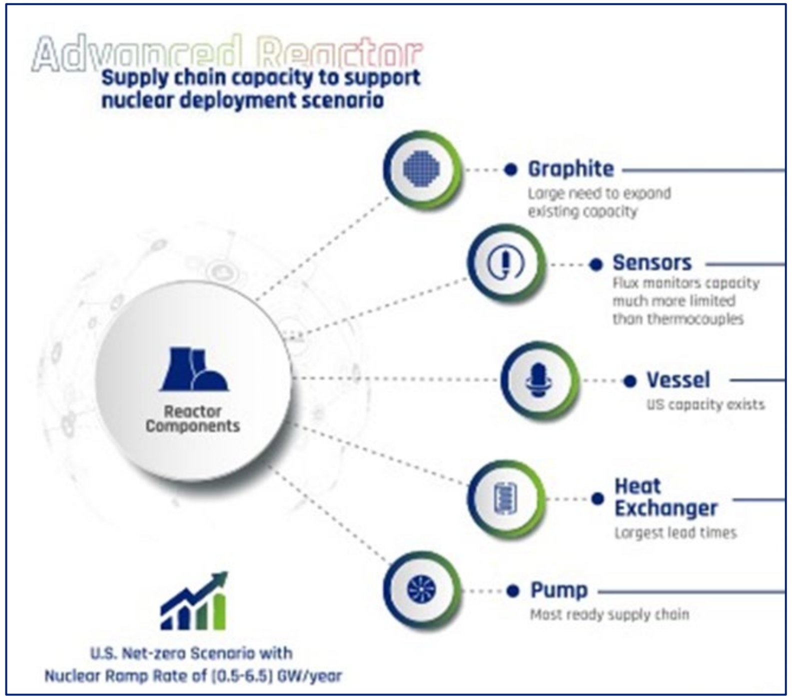
US has 94 operating nuclear reactors @ 54 sites

- 86 units w/licenses that expire by 2050;
- 33 units w/licenses that expire by 2035.









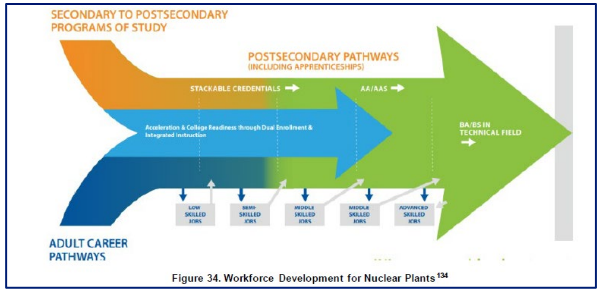
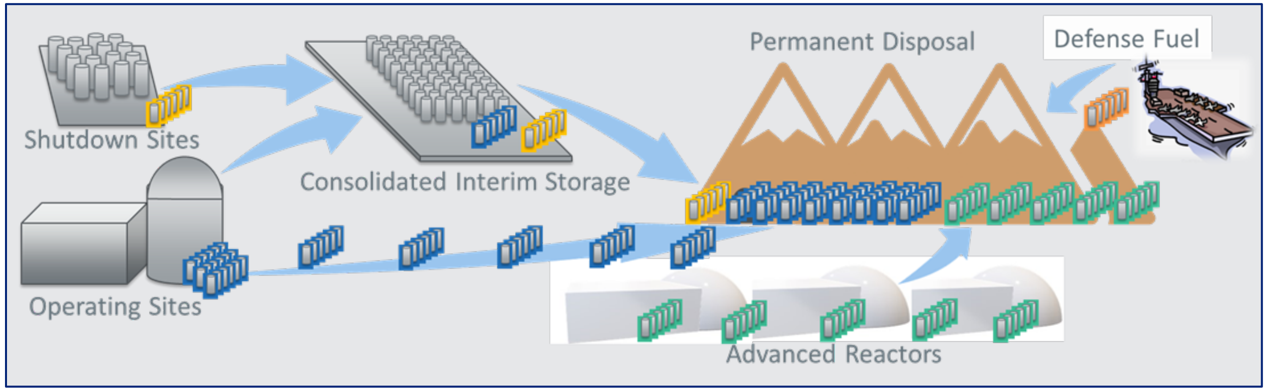


Figure 34. Workforce Development for Nuclear Plants[134]



Uranium

- Current fleet of reactors utilize uranium fuel enriched up to 5% U-235
- Nearly all Gen IV reactors will require HALEU (High Assay Low Enriched Uranium) to operate, which is enriched between 5% and 20% U-235

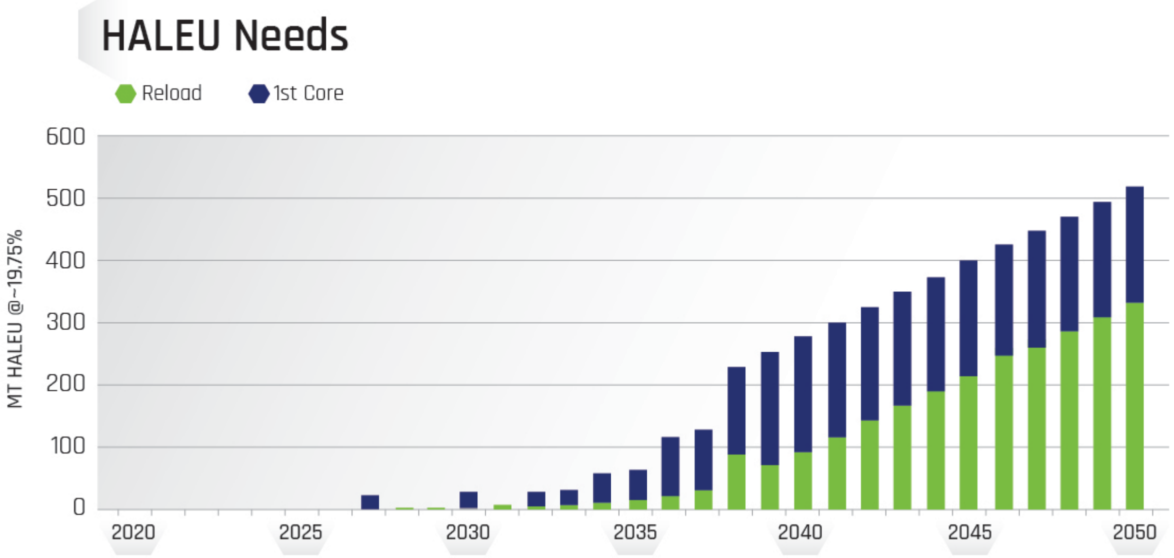
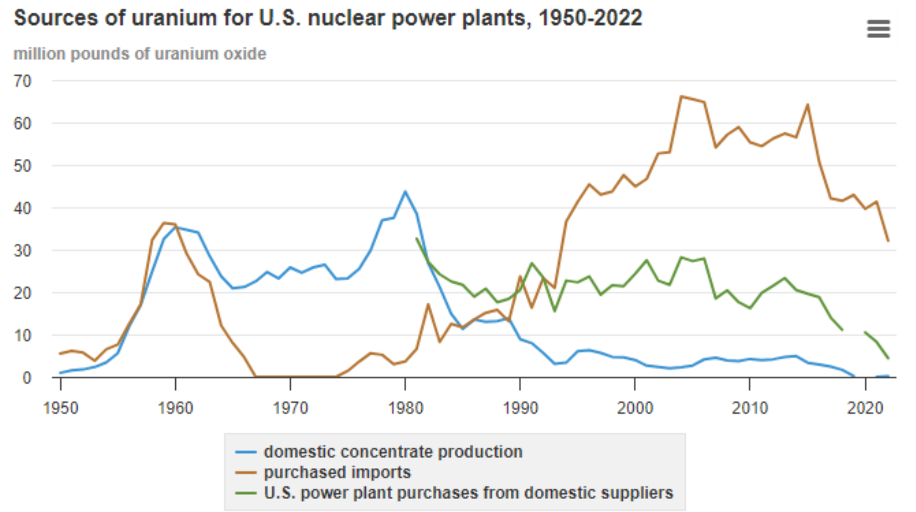


Figure 31. Projected HALEU Needs for Advanced Non-LWRs to 2050[126]



eia

Data source: U.S. Energy Information Administration, *Monthly Energy Review*, Table 8.2, June 2023
Note: Data withheld for U.S. power plant purchases from domestic suppliers in 2019 and for domestic production in 2020 to avoid disclosure of individual company data.

Click to enlarge

Owners and operators of U.S. civilian nuclear power reactors purchased 40.5 million pounds of U_3O_8e (equivalent) from U.S. and foreign suppliers during 2022.

Sources and percentage shares of total U.S. purchases of uranium in 2022 were:

27% Canada

25% Kazakhstan

12% Russia

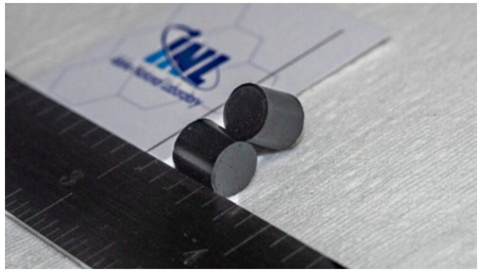
11% Uzbekistan

9% Australia

16% Six other countries combined

HALEU

- DOE selected first recipients of HALEU Availability Program



  - Kairos Power
  - Radiant Industries
  - TerraPower
  - Triso-X
  - Westinghouse

- Honeywell's Metropolis Works Plant has been Restarted – 15000 tU/Year

- DOE awarded 6 contracts to spur America's Domestic HALEU Supply
  - BWXT
  - Centrus
  - Framatome
  - GE Vernova
  - Orano
  - Westinghouse

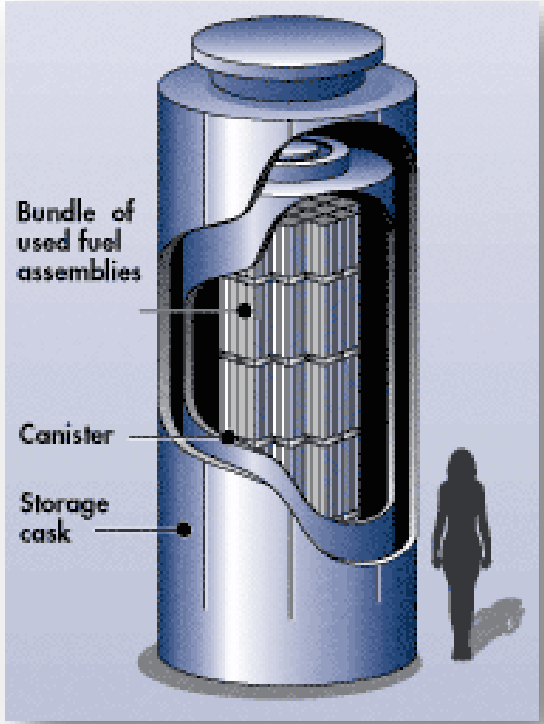
Supply Chain

Figure 46: High level overview of nuclear component supply chain

Step	Supply chain segments to meet the demand of the final product	Significant domestic suppliers	Cost competitive among US suppliers	Cost competitive between US suppliers vs. global suppliers	Is foreign supply source significant secure?	Likely best course of action
Mining and milling	Indium, Niobium, Yttrium, Hafnium	No	N/A	N/A	May be	Leverage intl. markets
	Chromium, Nickel	No	?	?	Yes	Leverage intl. markets
	Cadmium, Cobalt, Copper, Lead, Silver, Tin, Titanium, Tungsten, Vanadium, Zirconium	Yes	Yes	Yes	Yes	Expand existing US capability and leverage intl. markets
Processing	Steel	Yes	Yes	Yes	N/A	Expand existing US capability
	Concrete	Yes	Yes	Yes	N/A	Expand existing US capability
	Other	Yes	Yes	Yes	N/A	N/A
Component	Large component forging and manufacturing	No	?	?	Yes	Expand existing US capability and leverage intl. markets
	Other component forging and manufacturing	Yes	Yes	Yes	Yes	Expand existing US capability
Assembly	Module assembly	Limited	N/A	N/A	May be	Build US capability

Some of the materials used to construct nuclear reactors have been identified as critical minerals on the US Geological Survey Critical Minerals list;[143] of particular concern are Hafnium, Niobium, Yttrium, Chromium, and Nickel.[144] The Advanced Manufacturing Production Credit under Section 48X of the IRA supports domestic production of these critical minerals.

On-site storage of used commercial fuel



The 57 used fuel casks hold all the fuel from 49 years of the DC Cook Plant in Michigan operations. Both units at DC Cook are still operating.

Beyond Oppenheimer: How Nuclear Weapons and Nuclear Reactors are Different | Department of Energy

What's the Market for Nuclear Energy?

- Over the next decade natural gas and nuclear reactors will be the firm resources that ensure reliable power
- Gas prices and the cost of advanced nuclear are sensitive to eachother
- Nuclear energy has the potential to be deployed at a large scale provided the costs of new nuclear declines over time and supply chains are scaled up to support development

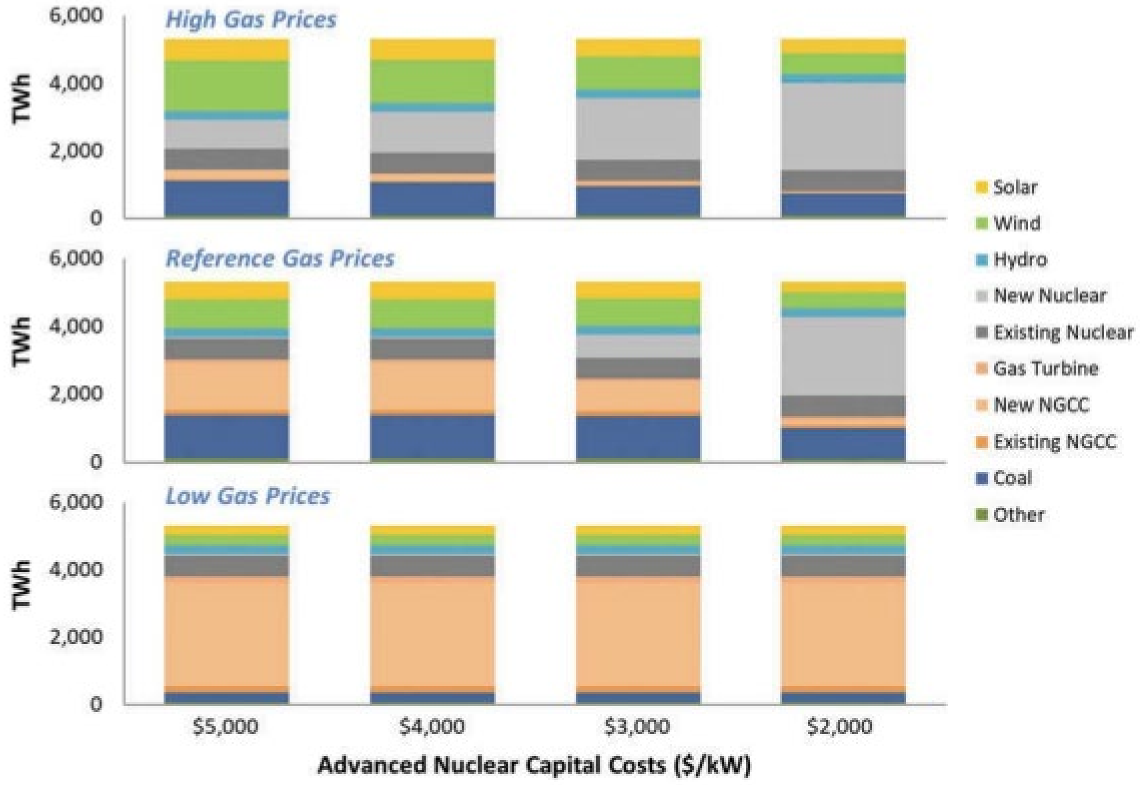


Figure 7. Generation mix in 2050 for four advanced nuclear capital cost cases (per kW electric) and three natural gas fuel price cases[31]

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What's the cost of new nuclear?

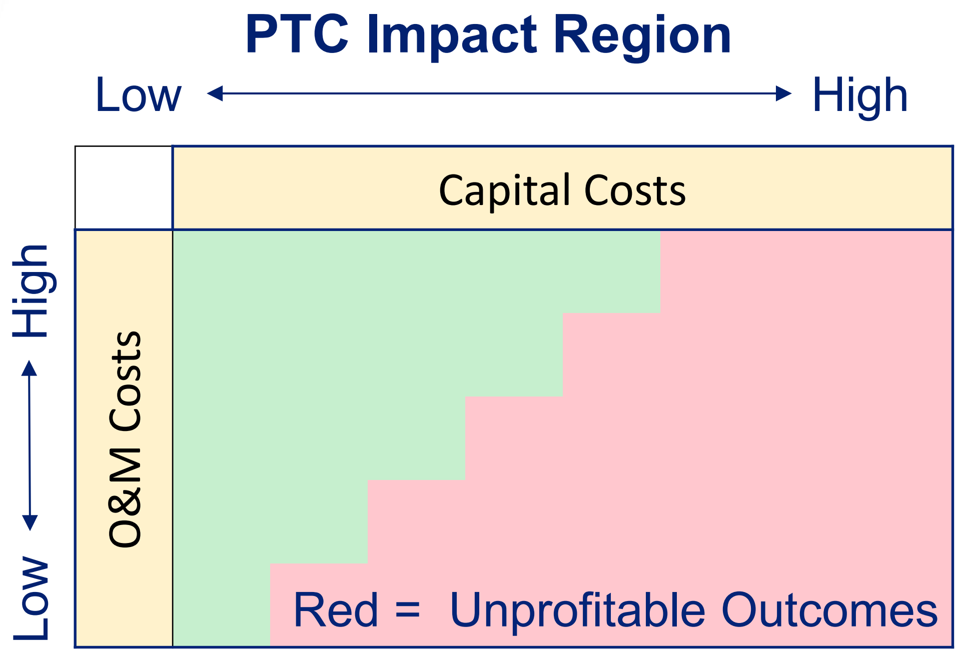
- OPG and GE Announced Green Light to proceed on Darlington Project
- 4 GE BWRX-300 Units, 1200 MW total
- First Reactor estimated at $4.4B with additional 1.2B for common Infrastructure
- Total $15.0B
- First Unit expected by 2030, project will continue into the 2030's
- Estimated to create 18,000 jobs

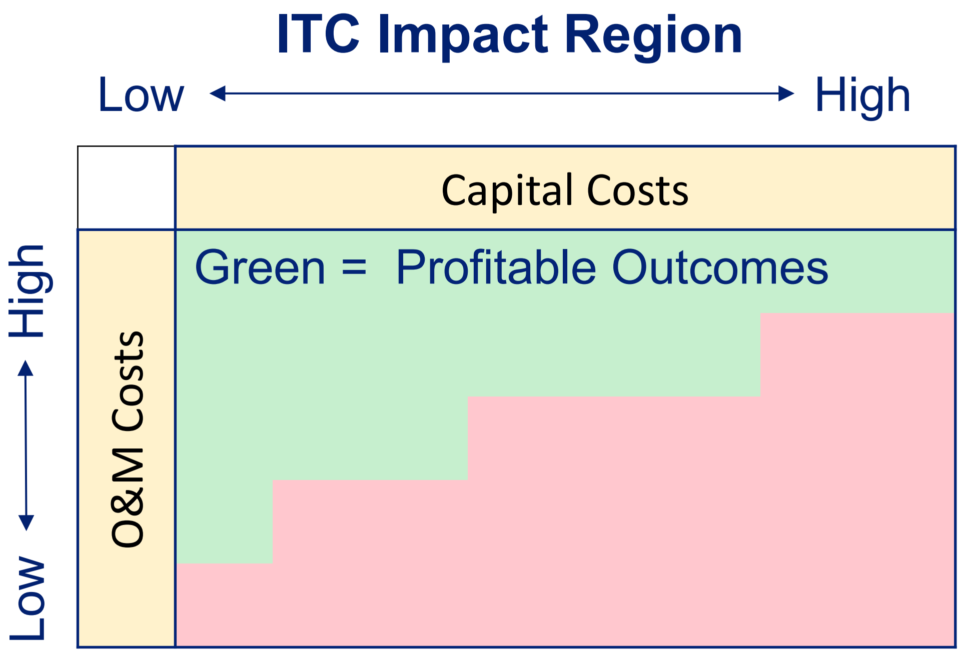
	Unit 1	Unit 2	Unit 3	Unit 4	Common	Total
Overall Cost	4.4B	3.7 B	3.1B	2.6 B	1.2B	15.0B
Owner Capital Cost ($/KWe)	$14,640	$12,444	$10,248	$8,784		
% Reduction		85%	70%	60%		

Learning Curves will result in better cost performance, do impact cost performance

Derisking Projects: Tax Credits

- The Inflation Reduction Act (IRA) of 2022 supports advanced nuclear technologies through Section 45Y PTC and Section 48E ITC.
  - These credits offer distinctly different financial incentives and include bonuses for domestic content and location





When more concerned about **capital cost risks: Pick ITC**

When more concerned about **O&M cost risk: Pick PTC**

What does nuclear power addition offer a community?

- Nuclear can bring lasting jobs to a plant for 40-80 years
- There are both direct jobs created as well as indirect and induced jobs
- Many other technologies such as wind, solar, and gas only bring construction jobs
- For every $100 of electricity produced, $50 of economic activity occurs in suppliers and support industries

Figure 14: Nuclear provides high paying jobs and the most jobs on site per GW[49,50]

Generation type	Permanent jobs on site, jobs/GW	Industry wage median, $/hour	Benefits concentrated in local community?
Nuclear	237 / ~500	$56	✓
Coal	107	$49	✓
Natural gas	~30	$49	✓
Wind	80	$37	✗
Solar	~36	$34	✗

Note 237 jobs is an estimate for SMRs; ~500 represents the current operating fleet of large reactors; coal and natural gas are both the value of "Fossil Fuel Electric Power Generation;" when they were measured separately in the 2020 USEER Wage Report, they were within ~5% of each other; hydropower onsite jobs per GW not available, but industry median wage was $51/hour

Deployment Scenario Comparison - Overview

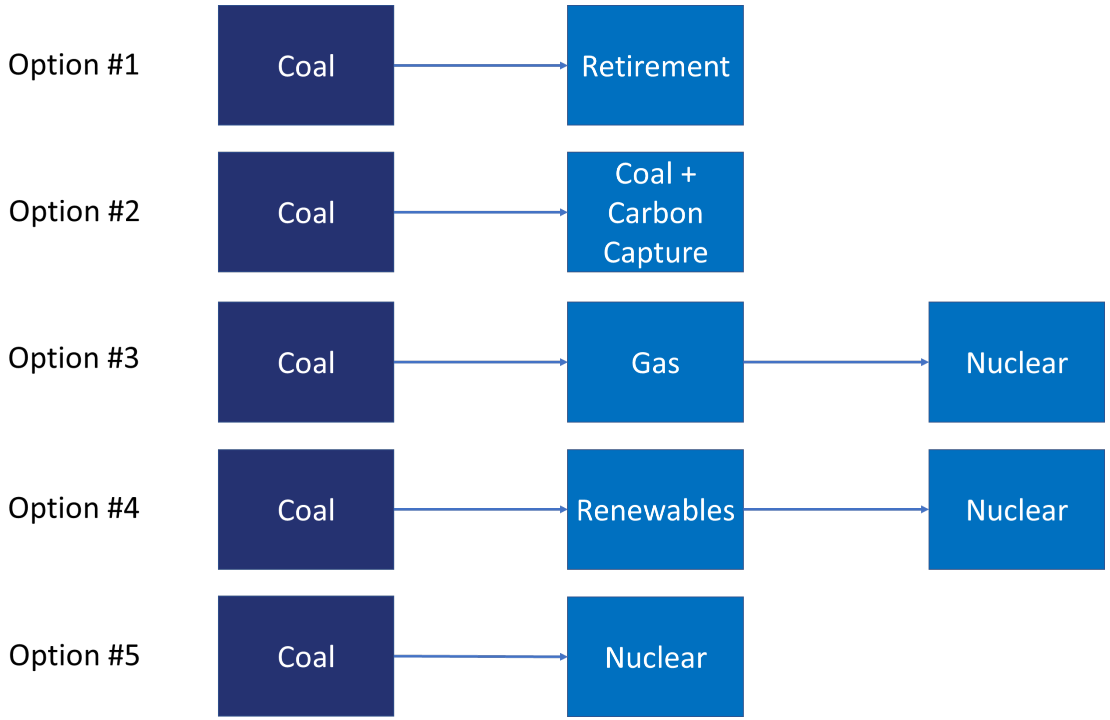
Scope: Assess the feasibility of different technologies at Colstrip Power Plant (CPP). Baseline case is continued coal plant operations.

Identify advantages and challenges associated with different technologies at CPP

- Consider potential deployment windows

Build out high-level scenarios to ensure they will be useful in the future

- Coal with Carbon Capture
- Natural Gas with/without Carbon Capture
- Wind with Battery Storage
- Solar with Battery Storage
- Nuclear



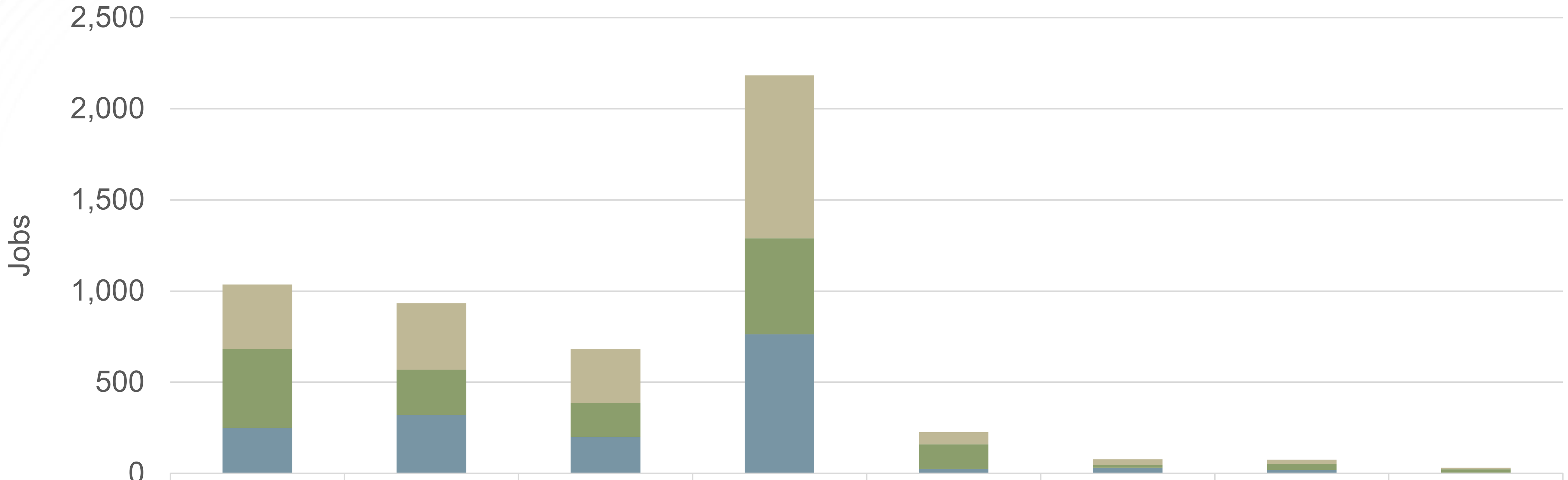
Colstrip Deployment Options

Deployment Scenario Comparison

<table>
<tr><th>Technology Type</th><th>Key Risks</th><th>Key Opportunities</th></tr>
<tr><td>Coal with Carbon Capture (CC)</td><td rowspan="2">• Maturing Technology, New Supply Chain with High Demand
• Licensing/Permitting Timelines
• CO2 Pipeline and Geological Storage</td><td rowspan="2">• Interconnection Agreement Modification
• Leverage Existing CPP Infrastructure</td></tr>
<tr><td>Natural Gas with CC</td></tr>
<tr><td>Natural Gas without CC</td><td>• Licensing/Permitting Timelines
• Natural Gas Transmission Line</td><td>• Mature Technology, Developed Supply Chain
• Interconnection Agreement Modification
• Leverage Existing CPP Infrastructure</td></tr>
<tr><td>Wind with Battery Storage</td><td rowspan="2">• Interconnection Agreement Studies
• Land Availability
• Additional Substations/Switchyards and Network Upgrades</td><td rowspan="2">• Mature Technology, Developed Supply Chain
• Licensing/Permitting
• Leverage Existing CPP Infrastructure</td></tr>
<tr><td>Solar with Battery Storage</td></tr>
<tr><td>Nuclear</td><td>• Advanced Nuclear Technology and Supply Chain in Development
• Interconnection Agreement
• Licensing/Permitting Timelines
• Infrastructure Upgrades</td><td>• Regulatory Opportunities</td></tr>
</table>

Several different technology futures are viable for Colstrip.

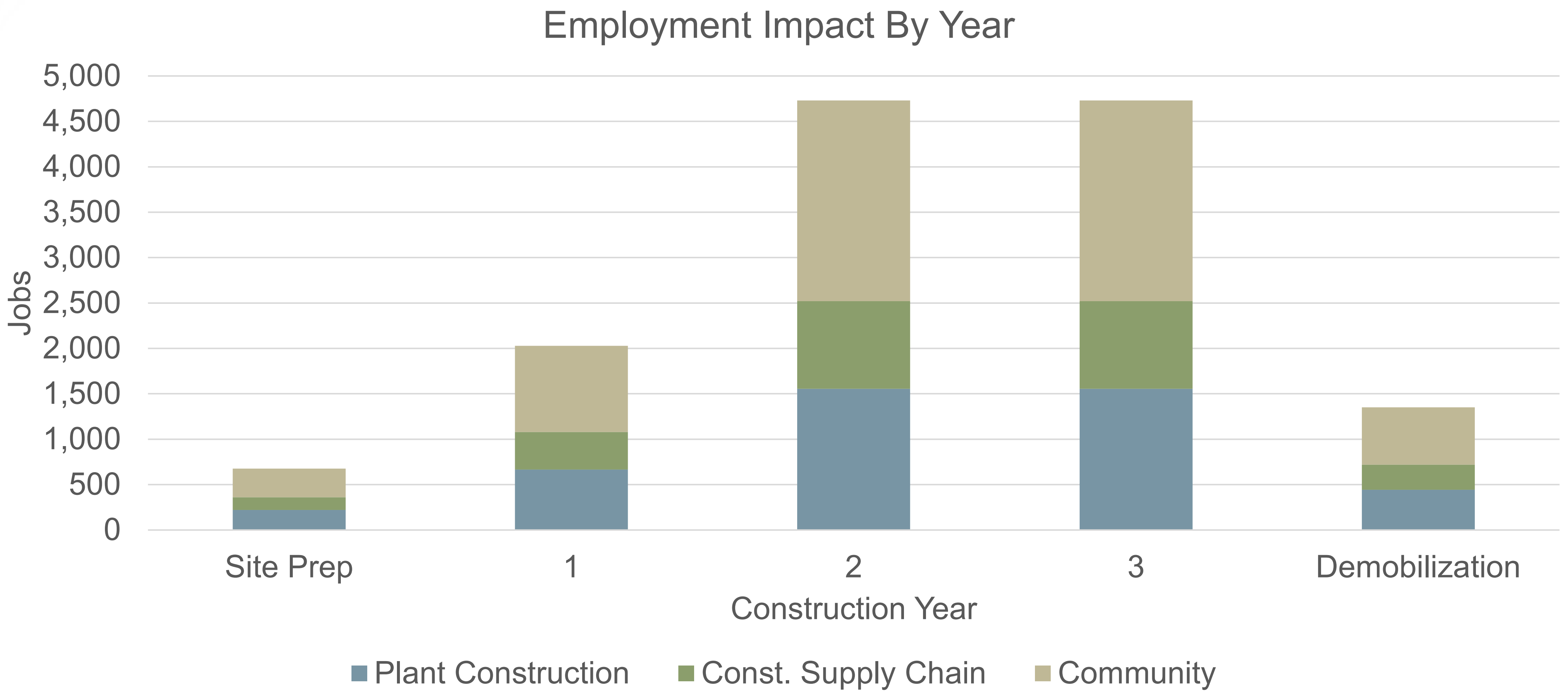
Employment Impact Comparison



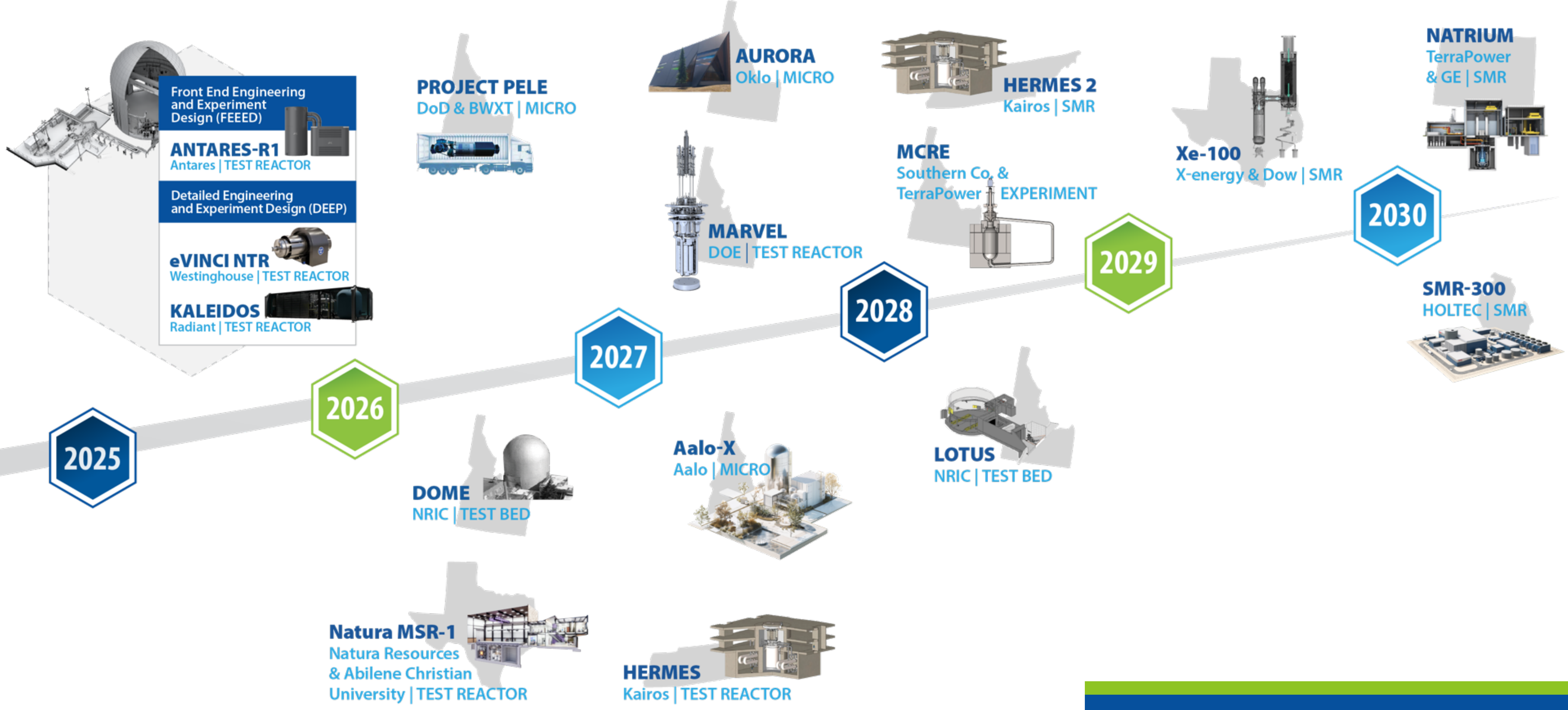
	Colstrip Power Plant (1480 MWe)	Rosebud Mine	Nuclear (500 MWe)	Nuclear (1400 MWe)	Natural Gas (500 MWe)	Rosebud Power Plant (41 MWe)	Wind (200 MWe)	Solar (150 MWe)
Community	353	364	294	894	66	31	24	8
Supply Chain	433	248	188	527	134	15	33	18
Facility Ops	250	321	199	762	25	31	18	4

Facility Ops Supply Chain Community

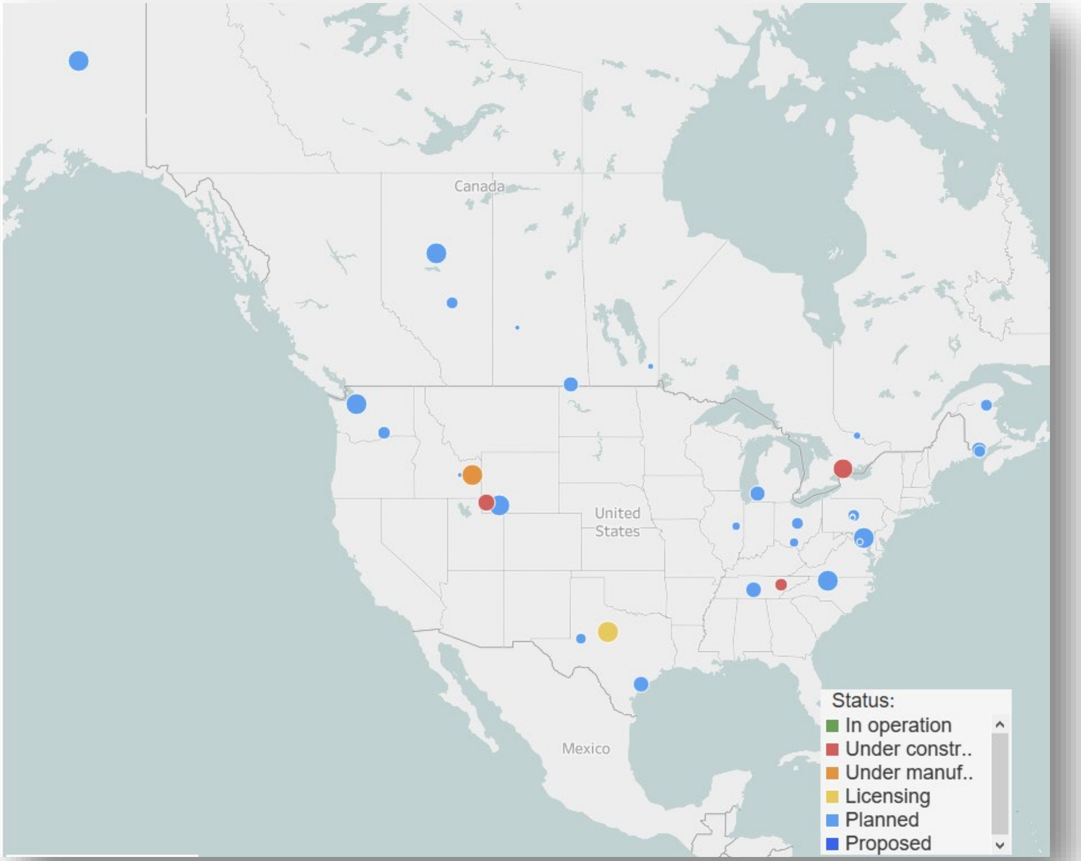
Nuclear Construction Employment Impact by Year
500 MWe Installed Capacity



Accelerating advanced reactor demonstration and deployment



Advanced Nuclear in North America



- 32 active projects that includes a mix of reactor demonstrations, commercial demonstrations, and commercial reactors
- 12 deployment dates prior to 2030
- Variety of agreements, 7 are firm contracts

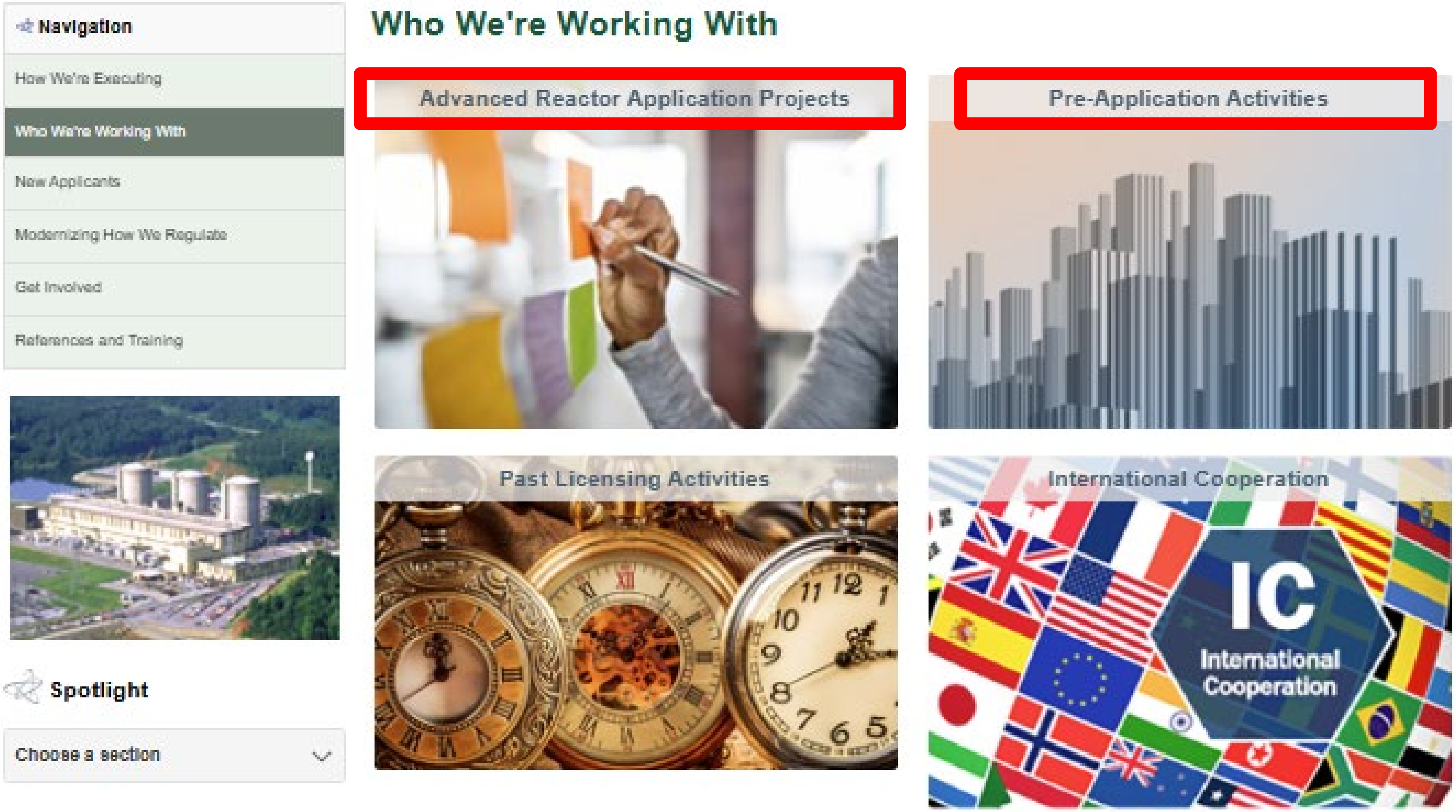
14
MICROREACTORS

4 HIGH TEMPERATURE GAS REACTOR
3 SODIUM FAST REACTOR
2 MOLTEN SALT REACTOR
3 SOLID CORE HEAT PIPE
2 TBD

18
SMALL MODULAR REACTORS

4 HIGH TEMPERATURE GAS REACTOR
3 SODIUM FAST REACTOR
3 MOLTEN SALT FAST REACTOR
7 LIGHT WATER REACTOR
1 FLUORIDE SALT-COOLED HIGH-TEMPERATURE REACTOR

Advanced Nuclear Project Status with NRC



https://www.nrc.gov/reactors/new-reactors/advanced/who-were-working-with.html

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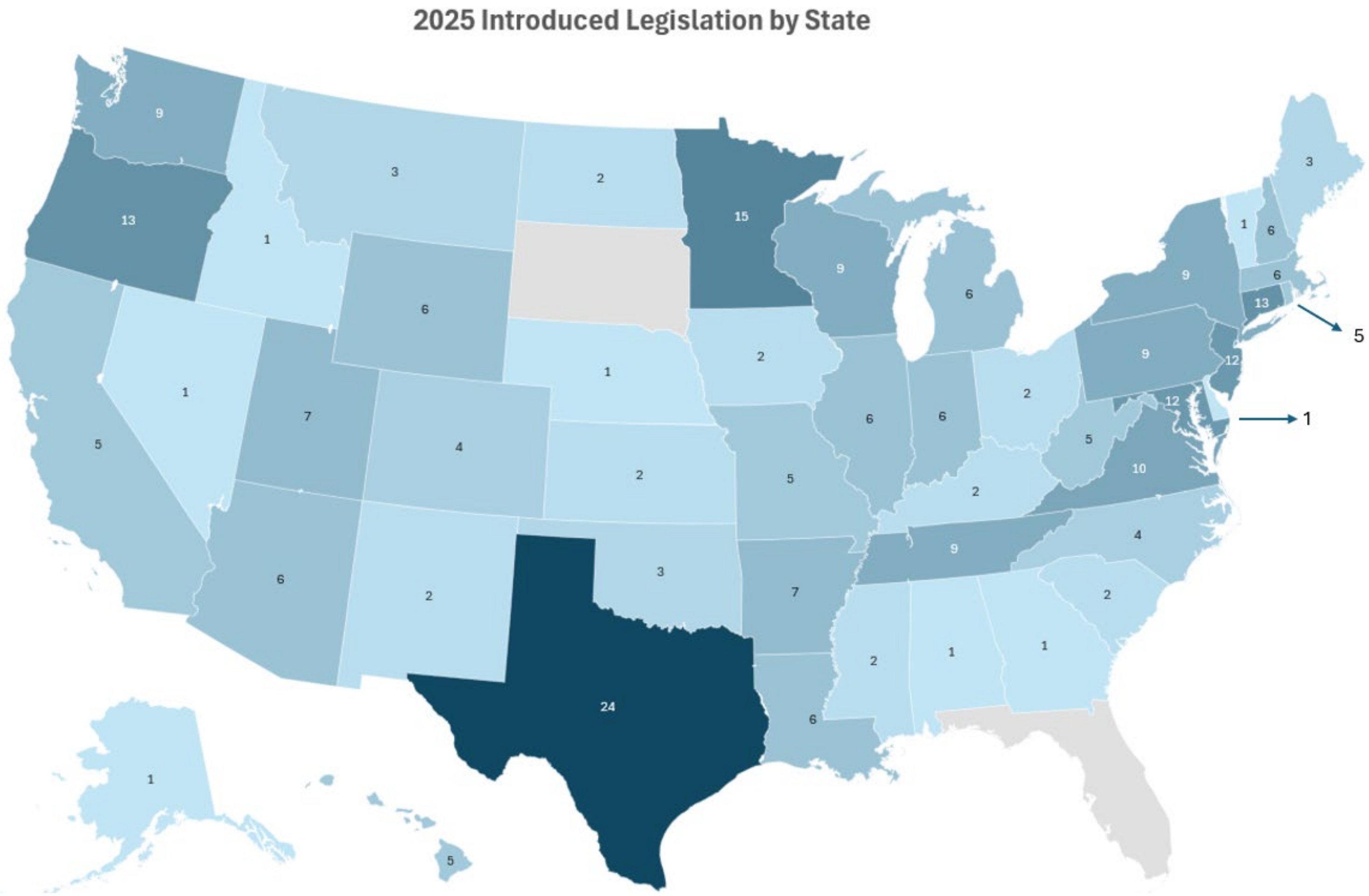
Feasibility Study Categories Covered by State

Current Fleet License Extension	Moratorium Repeals/ Exemptions	Classifying Nuclear	Feasibility Study/Working Groups	Establishment of Authorities	Promoting Development	Fossil Fuel Transition	Workforce Development	Supply Chain	Financial Incentives
Pennsylvania Washington	Connecticut	New Hampshire	Indiana New York North Dakota	Kentucky Texas	Indiana Louisiana Texas Virginia	Kentucky Maryland	Indiana Kentucky Maryland New Hampshire New York Tennessee Texas Virginia	Indiana Kentucky Maryland New Hampshire New York Tennessee Texas Virginia	Indiana Louisiana Michigan New Hampshire New York Tennessee Texas

Federal Resources	System-Wide (Framework) Cost	Advanced Rate Recovery	Design Suitability/ Standardization	Siting	Regulatory	Permitting Pathways	Consortia	Community Engagement/ Education
Connecticut Louisiana Virginia	Louisiana Washington	Texas	Indiana New York	Louisiana Nebraska New York Virginia	Connecticut Indiana Louisiana	Colorado Indiana Louisiana Michigan Texas	Louisiana Michigan	Indiana Louisiana Michigan Nebraska New Hampshire New York Texas

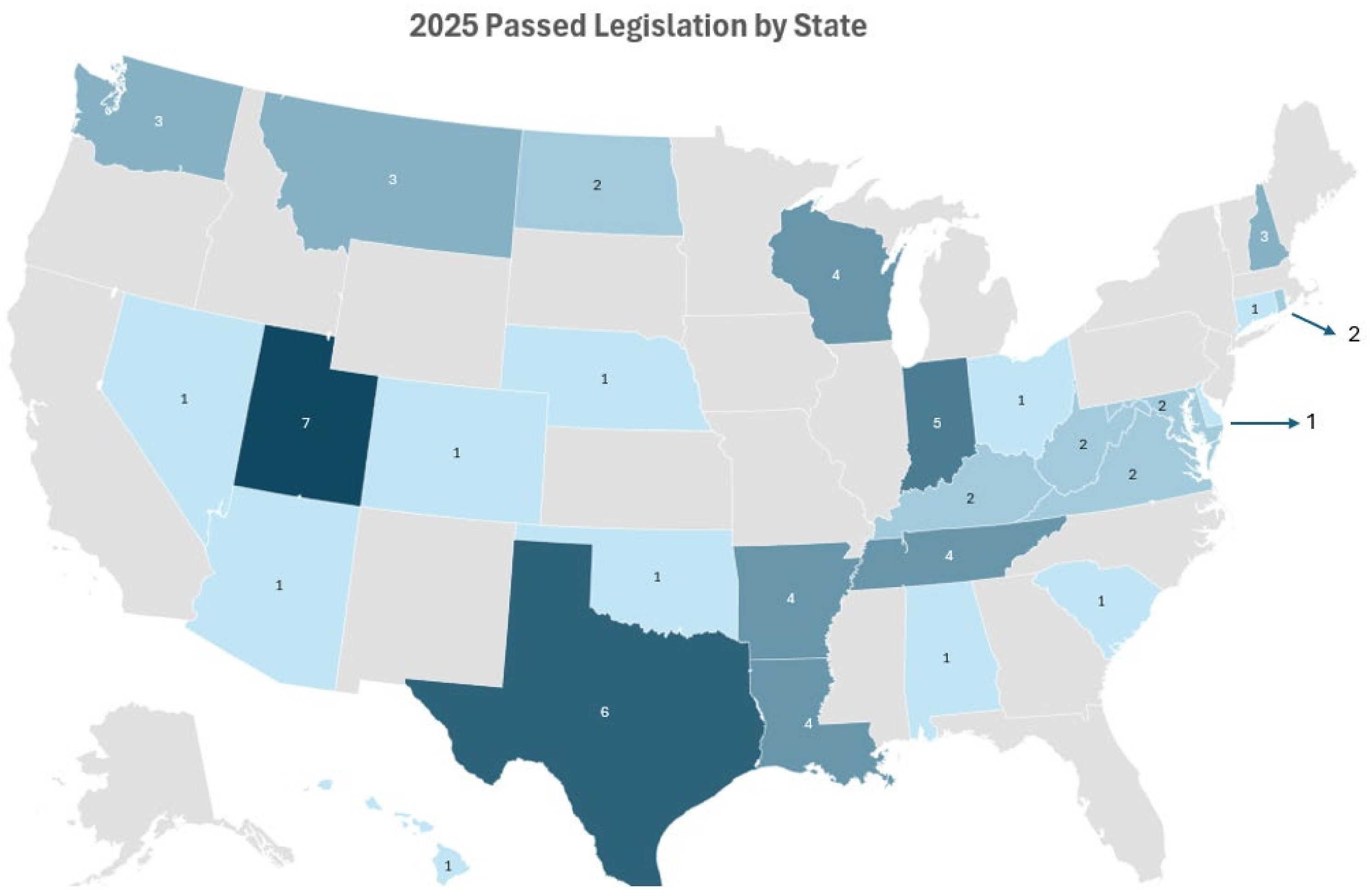
Note: 22 Categories identified – 19 have had actions take

2025 State Nuclear Legislation



48 states with at least one bill introduced.

2025 State Nuclear Legislation



68 bills passed and enrolled into law.

Regional Interest in Nuclear

- The **Minnesota** PUC approved Xcel Energy's 20-year license extension for Prairie Island NPP. Xcel will file an extension with the NRC in 2026.

- NextEra Energy has filed with the NRC to restart the Duane Arnold NPP in **Iowa.**

- **Nebraska** PPD has begun Phase II of its AR siting study, including community engagement in all proposed sites.

- The **South Dakota** PUC approved rate increases for NWE to explore the potential of ARs in the state.

- **Colorado** enrolled legislation classifying nuclear energy as clean, allowing for inclusion in the state's CES.

- **Montana** enrolled legislation authorizing the temporary storage of SNF on-site of generators, as well as uranium conversion and enrichment facilities.

- TerraPower has begun non-nuclear construction at its Natrium project in Kemmerer, **Wyoming.** A construction permit from the NRC is expected by end of 2025.

- SaskPower is contemplating building an AR near the City of Estevan, **Saskatchewan**, just miles from the North Dakota border. Final investment decision in 2029.

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Revision Log

- INL/MIS-25-82903slides 1-77 approved 3/27/25
  - 4/7/25 updated INL Demonstration and Deployment Map from Comms