INL/MIS-25-82903-Revision-0

GAIN Base Presentation Slide Deck 2/12/25

March 2025

Changing the World's Energy Future

Michelle Zietlow-Miller

Idaho National Laboratory

INL is a U.S. Department of Energy National Laboratory operated by Battelle Energy Alliance, LLC

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GAIN March 2025 Generic Presentation

Template

March 2025

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

GAIN Gateway for Accelerated Innovation in Nuclear

GAIN's Areas of Expertise

- Department of Energy Office of Nuclear Energy initiative
- Focus on initiating and completing projects that support commercial deployment of advanced reactors and technologies

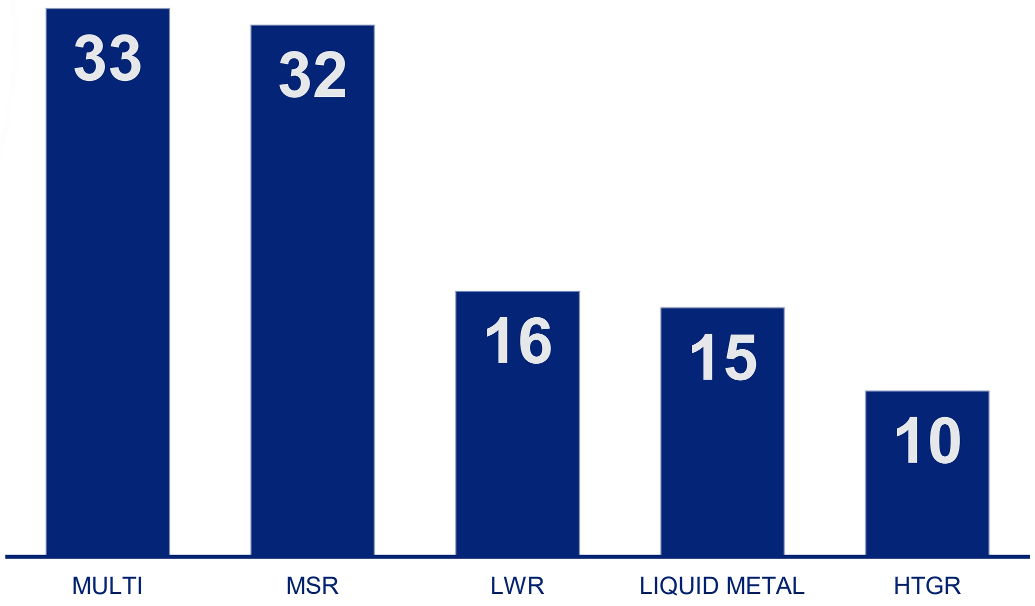
2024 HIGHLIGHTS

- Awarded 16 ***GAIN Nuclear Energy Vouchers*** at a value of nearly $5.4 million
- Published the ***advanced reactor cost study*** developed cost ranges for modeling and energy planning and provided the data for NREL's Annual Technology Baseline, which is used by utility planners and grid operators when planning their energy investments
- Worked with ***coal communities*** in Kentucky, Arizona and Montana to conduct feasibility studies to convert decommissioned coal stations into nuclear power stations
- Worked with ***states and communities*** across the U.S. to provide them with advanced nuclear information through conversation and testimony and connect them with Department of Energy financial and technical resources

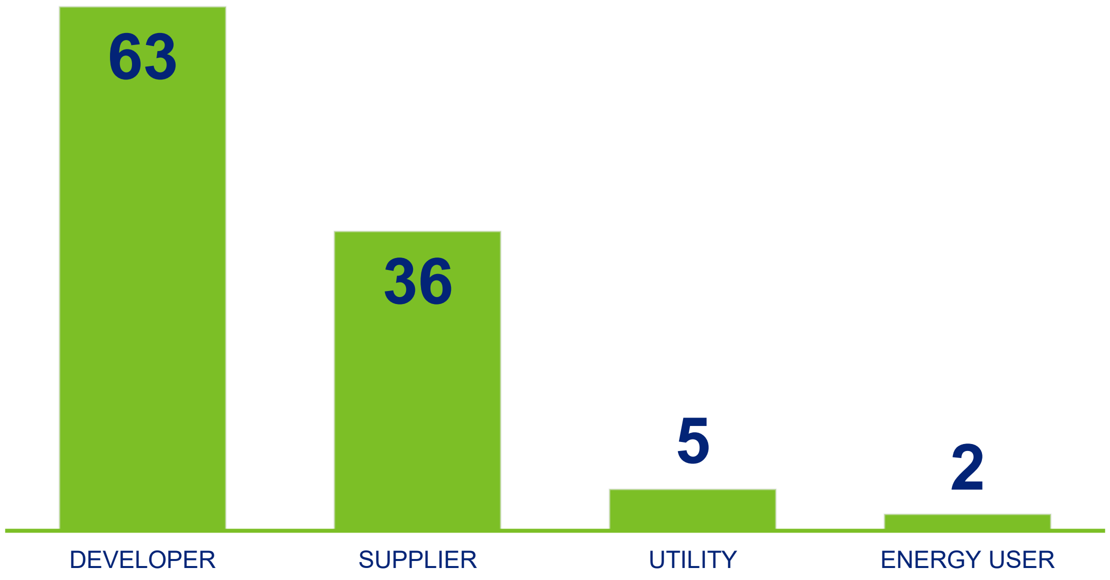
Voucher Statistics

- GAIN's Nuclear Energy Voucher Program provides funding and access to the expertise and resources at the U.S. Department of Energy's national laboratory complex in order to accelerate the commercialization of nuclear technologies

Voucher Awards by Reactor Type

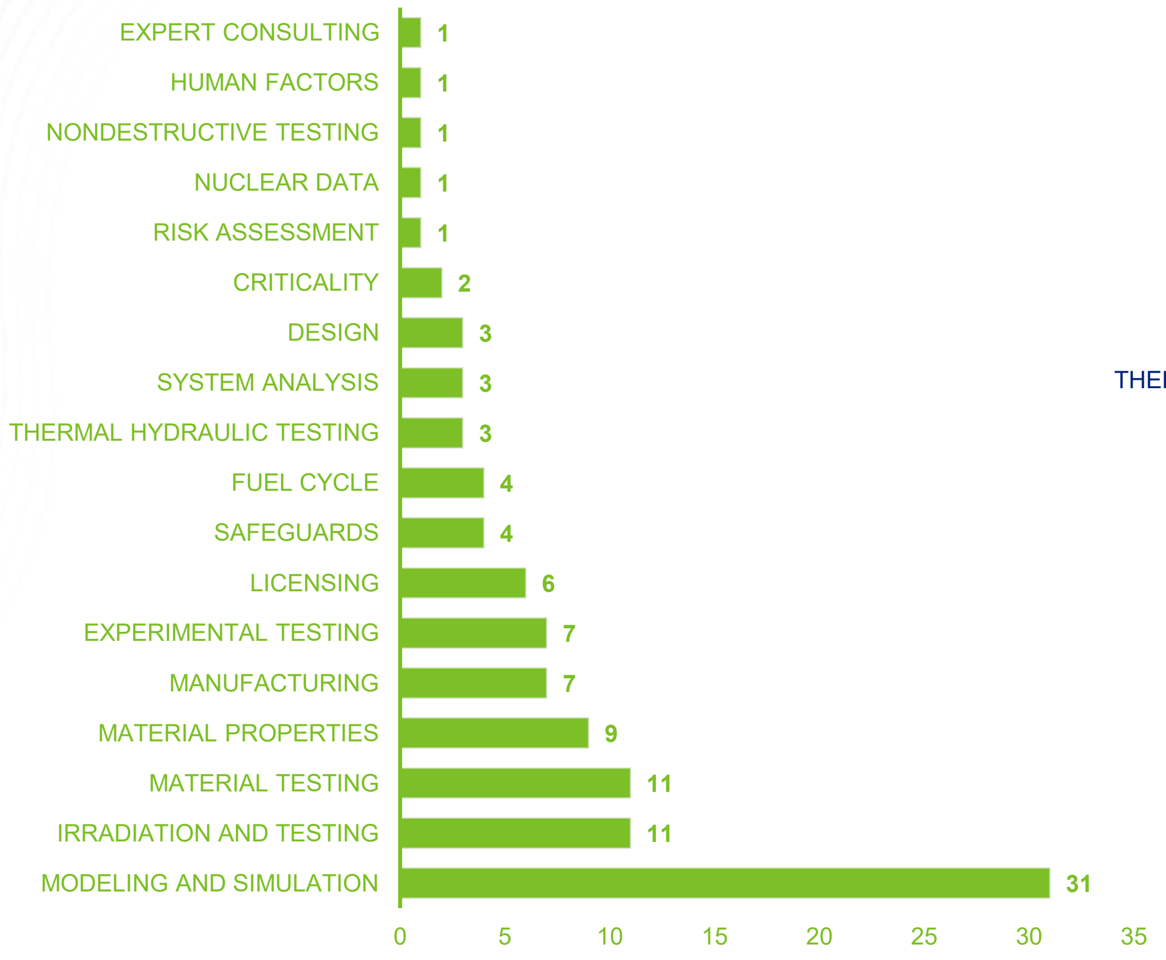


Voucher Awards by Company Type

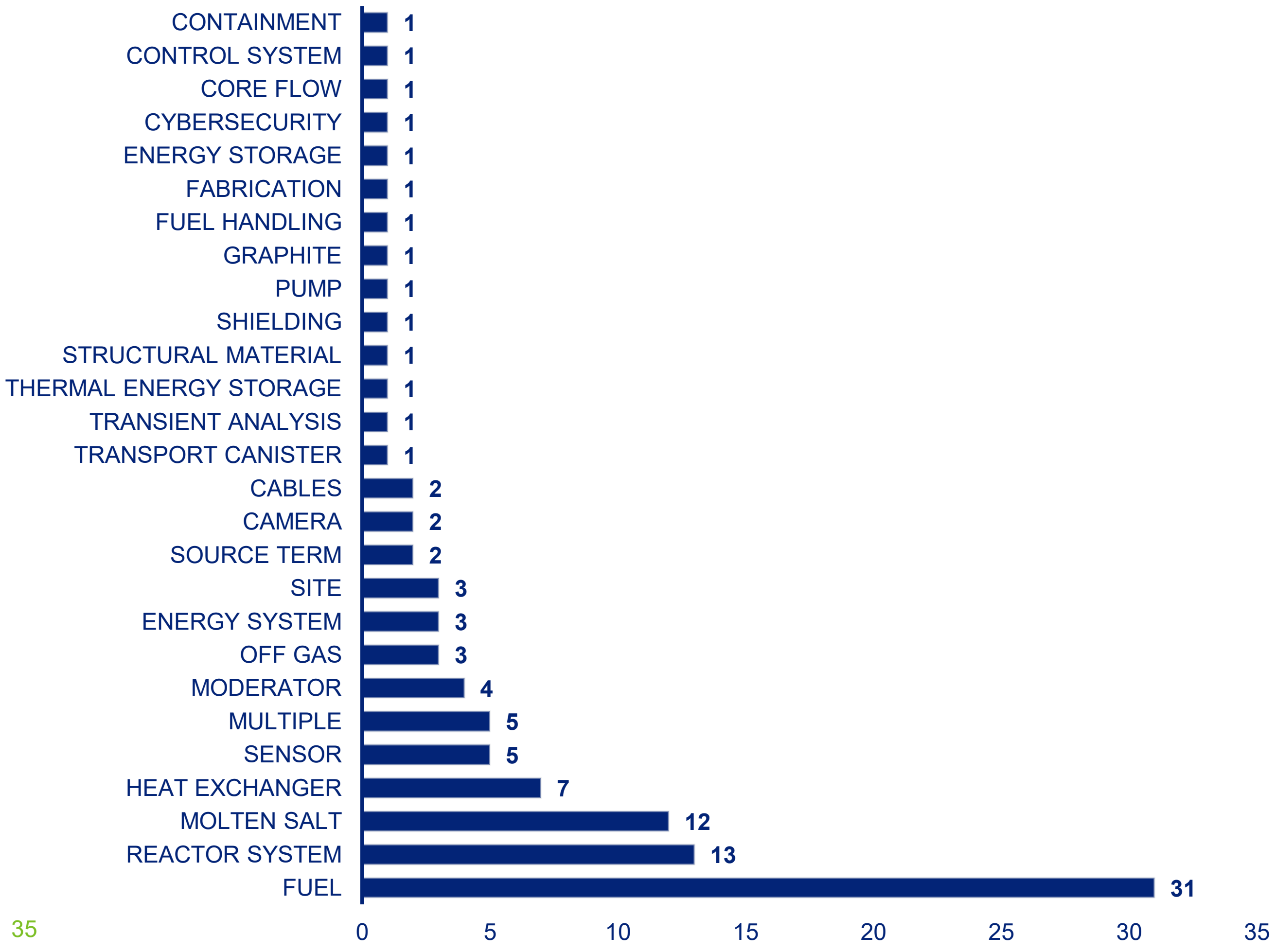


Voucher Statistics – Work Areas

Voucher Awards by Work Type



Voucher Awards by Component Type



Nuclear Energy Voucher Program

- Vouchers competitively award access to DOE national laboratory facilities and staff
- ***NOT*** a financial award to businesses

VOUCHER VALUE ~$50K – $500K
Voucher recipient is responsible for 20% cost share

4
FOUR CYCLES PER YEAR

AVAILABLE TO MAJORITY (>51%) U.S. OWNED COMPANIES

STANDARD CRADA

1
LIMIT TO ONE APPLICATION PER CYCLE

ONE-YEAR PERIOD OF PERFORMANCE

GAIN state engagement

- GAIN works with nuclear curious states and communities around the nation as they consider advanced nuclear in their energy portfolios.

2024 STATE ENGAGMENTS

- Attended public meetings with local partners in ***Arizona***, ***Montana***, ***Pennsylvania***, and ***Colorado***
- Testified to state-level energy committees in ***Minnesota***, ***Montana***, ***Illinois***, ***Alaska***, and ***Colorado***
- Briefed staffers for several legislative delegates in many states
- Customized webinars and workshops for ***Kentucky***, ***Virginia***, and ***California***
- Worked with local economic development teams in ***West Virginia***, ***Pennsylvania***, ***Tennessee***, ***Montana***, and ***Utah***
- Supported the DOE engagement with the National Association of State Energy Officials, National Association of Regulatory Utility Commissioners, Governor's Association and National Conference of State Legislatures

GAIN Gateway for Accelerated Innovation in Nuclear

GAIN legacy document projects

- GAIN built a process that allows U.S. companies to request and obtain access to export-controlled information without a contract, provided they meet the process criteria.
- Legacy documents include nuclear program documents from the last 70 years.
- The most requested documents are Applied Technology documents, created by the Department of Energy's Office of Nuclear Energy in the 1970s to preserve the foreign-trade value of certain NE-funded work

Criteria #1

The requester must be a U.S. citizen.

Criteria #2

Restricted Party Screening is performed on the requestor and their company. If there are any issues, no documents are released.

Criteria #3

The company must have a working relationship with GAIN and/or DOE.

Criteria #4

The request must be in line with the known technology the company is pursuing.

Criteria #5

The request must be reasonable in terms of volume. If not, GAIN works with the industry requestor to focus the request. If the request is still too large, GAIN asks the requestor to break the request into phases.

Legacy Documents Program

- Legacy document release process
- Legacy document research packages
- Acquisition and Preservation
  - Digitization
  - Database creation

GAIN LEGACY CONTACTS

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Jon Grams, Jonathan.grams@inl.gov

What are legacy documents?

HISTORICAL DOCUMENTS

All nuclear legacy work from the last 70 years

APPLIED TECHNOLOGY DOCUMENTS

These are the documents most requested by industry. This marking was created by the DOE Office of Nuclear Energy in the 1970s to preserve the foreign-trade value of certain NE-funded work.

DATASETS

There is an increasing interest in having access to legacy datasets.

The GAIN Legacy Document Release Process

is a process that allows U.S. companies to request and obtain access to export controlled information without a contract

provided they meet the process criteria.

Process Criteria

Criteria #1

The requester must be a U.S. citizen.

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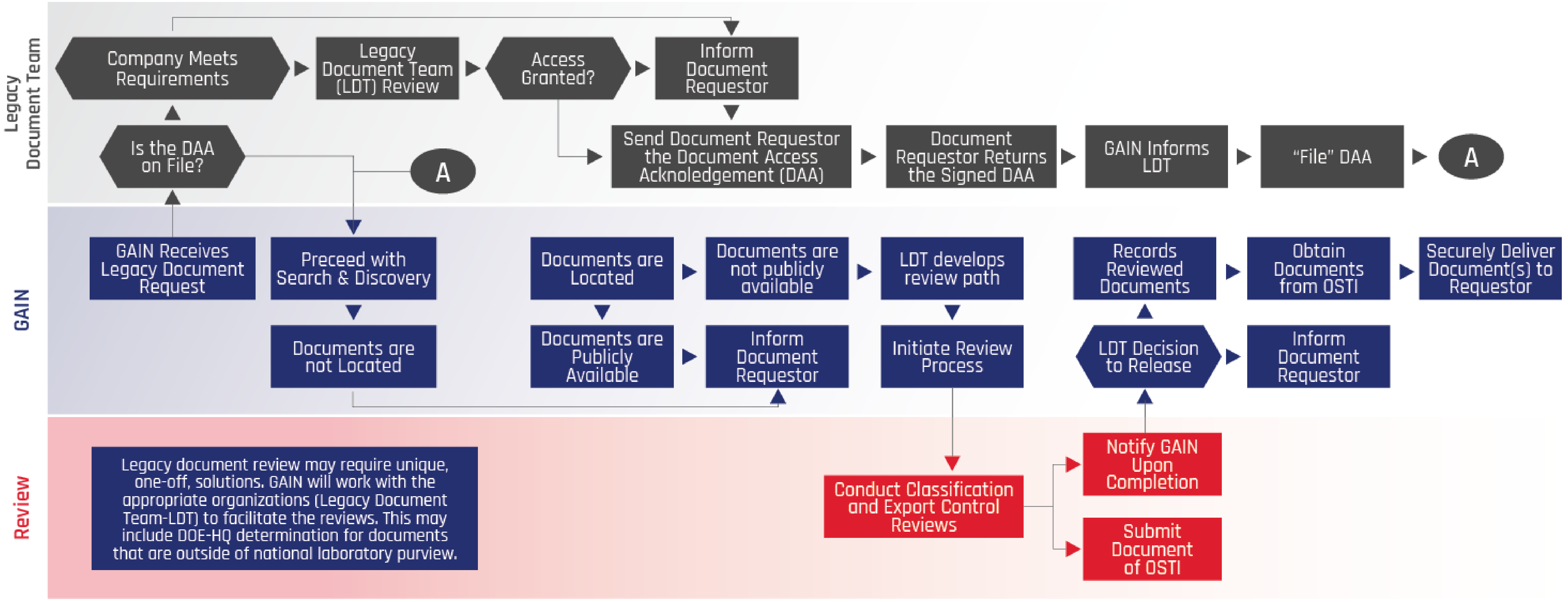
GAIN Legacy Document Release Process



GAIN Gateway for Accelerated Innovation in Nuclear

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

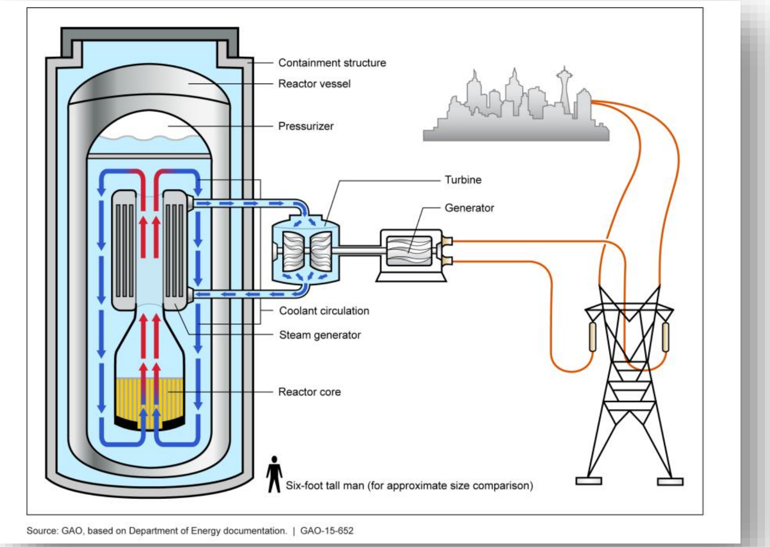
Factories

Desalinization

Space

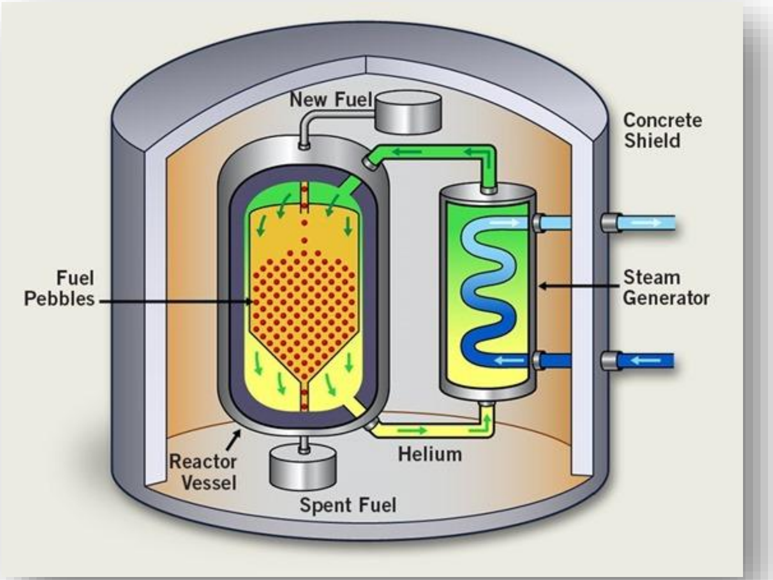
Advanced Reactor Types

LIGHT WATER REACTORS IN SMALL MODULAR REACTOR FORM

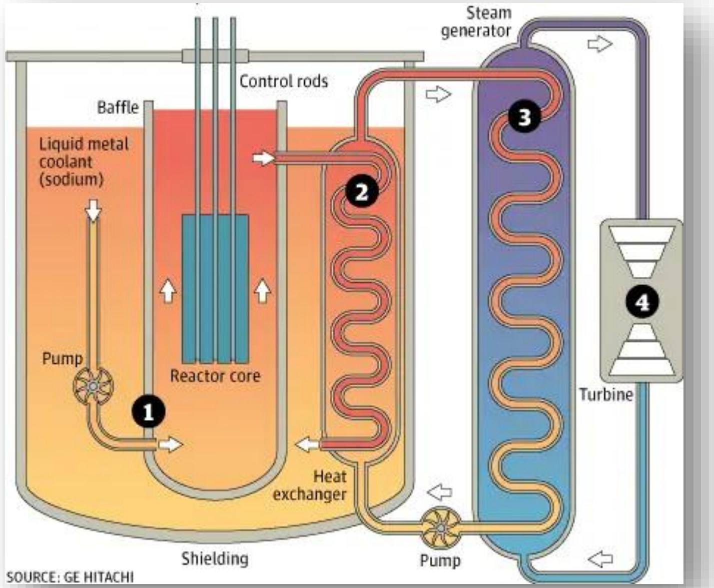


Source: GAO, based on Department of Energy documentation. | GAO-15-652

HIGH-TEMPERATURE GAS REACTORS



LIQUID METAL FAST REACTORS / MOLTEN SALT



SOURCE: GE HITACHI

Advanced Reactors

- Advanced reactors are nuclear fission reactors with significant improvements, including additional inherent safety features, compared to reactors operating today in the U.S

Walk-Away Safety

Requires no or minimal operator intervention to remain safe in the event of an accident.

Versatility

Can provide heat energy for industrial processes, water desalination, and load-following to support intermittent power sources.

Waste Re-use and Disposal

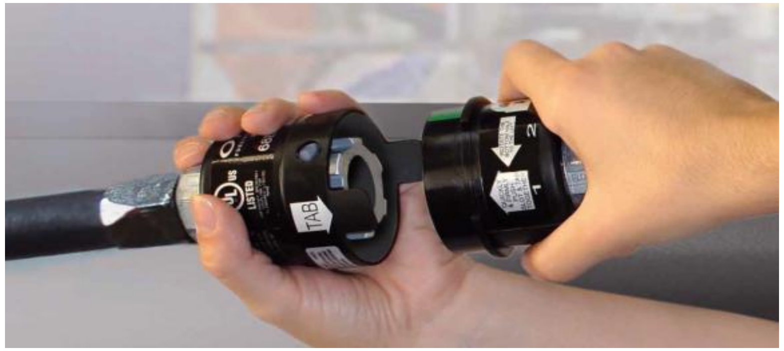
Can greatly reduce the amount of spent fuel requiring disposal, and some technologies can re-use spent fuel.

Financeability

Can employ factory manufacturing and be made with less capital cost.

Active vs. Passive vs. Inherent Safety

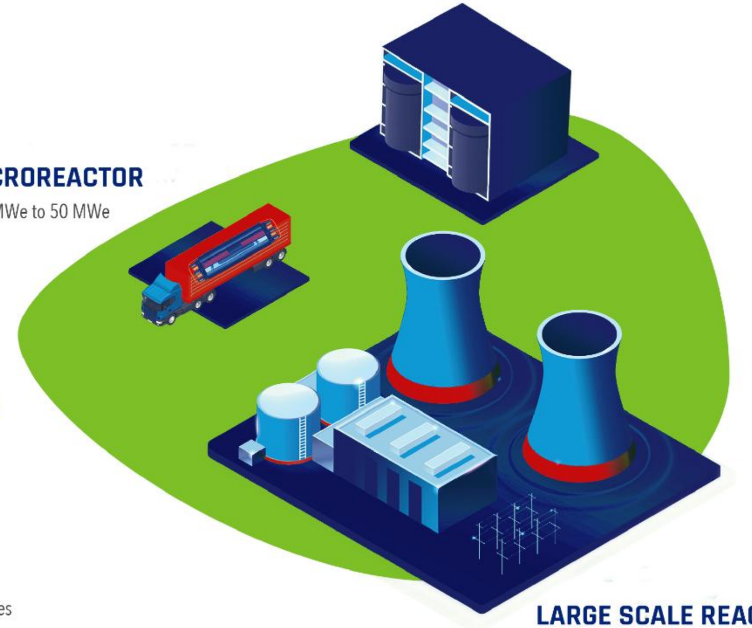
ACTIVE	PASSIVE	INHERENT
Requires an external input to function	Relies on natural forces, property of materials, or internally stored energy	Relies on fundamental properties or design choices
A valve needs an electrical current to operate or a pump needs electricity to operate	Long term decay heat removal 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

SMALL MODULAR REACTOR
50 MWe to mid-100s MWe

MICROREACTOR
1 MWe to 50 MWe



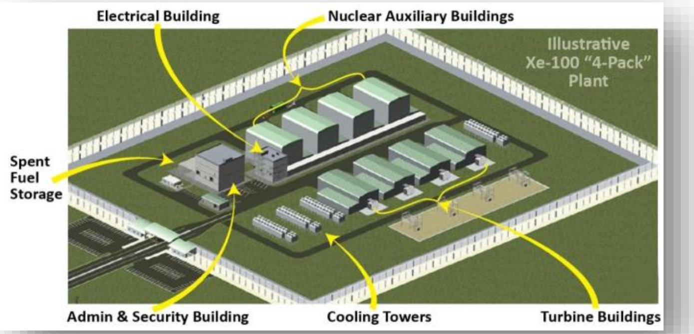
ADVANCED NUCLEAR REACTORS FEATURES:

- Range of sizes
- Smaller footprint
- Advanced manufacturing
- Flexible operation
- Electricity generation and process heat production
- Ability to pair with renewables
- Passive safety features

LARGE SCALE REACTOR
Mid-100s MWe to 1,000+ MWe

VOGTLE PWR

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

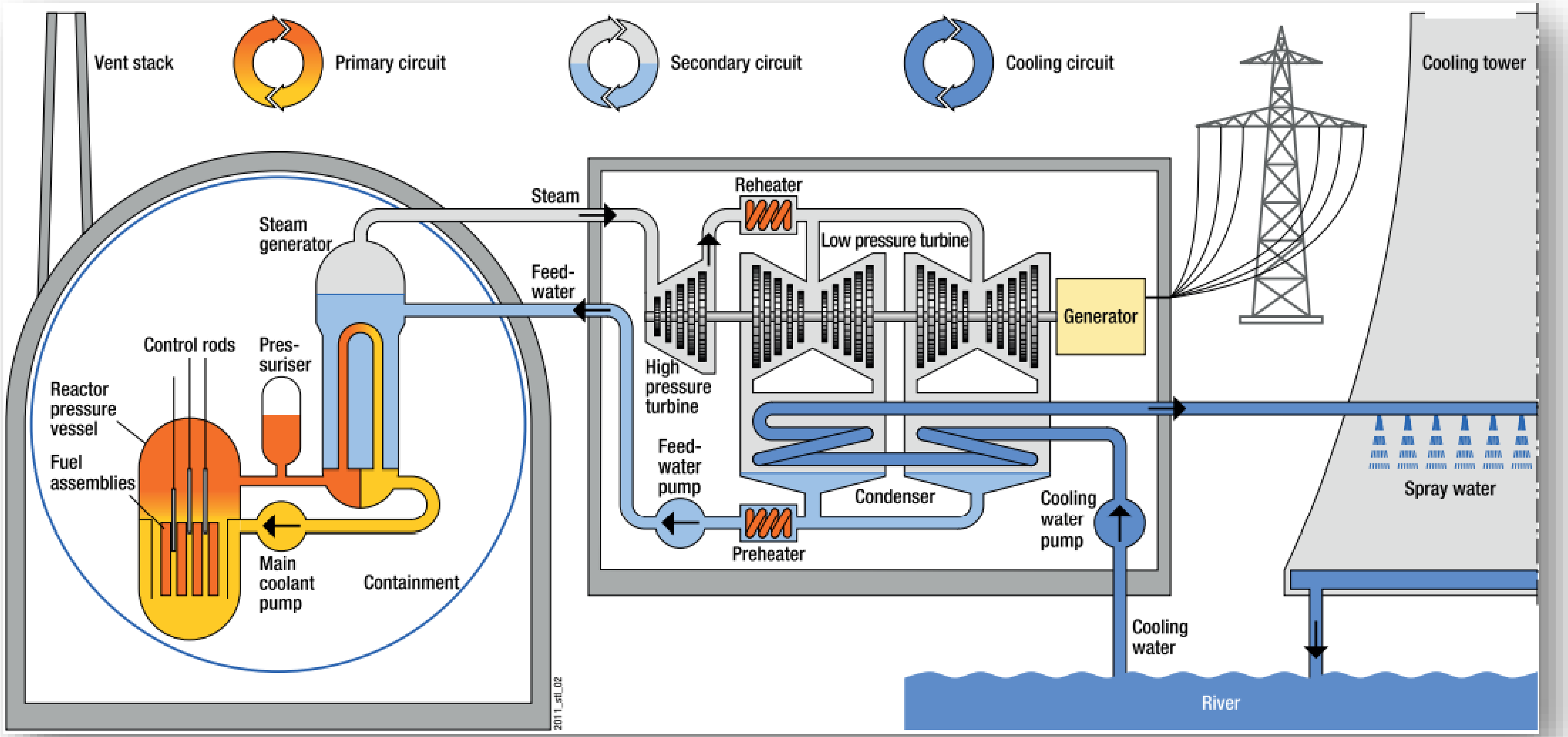


X-ENERGY

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

Water Usage

- All reactors through Gen III+ require a consistent source of water, ~500,000 gpm
- Gen IV designs require less water due to higher efficiency – Natrium uses 90% less water at 16,000 gpm for 4 reactors
- Some Gen IV Designs utilize an air cooled condenser
  - Fans utilize 5 to 7% of the energy production and this can go up with increased outside temperature

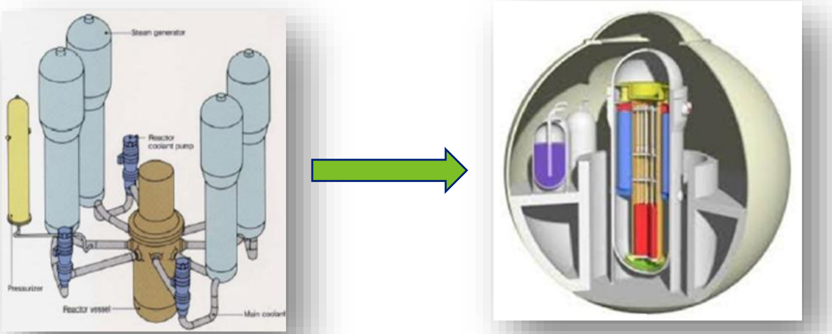


GAIN Gateway for Accelerated Innovation in Nuclear

Small Modular Reactors (SMRs)

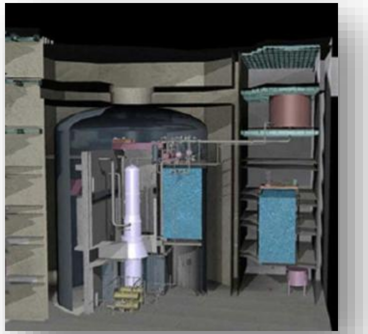
Multi-module Plant Layout Configuration

Simplification by Modularization and System Integration

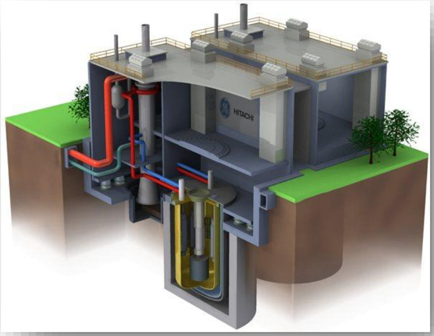


Enhanced Safety Performance through Passive Safety Systems

- Enhanced severe accident features
- Passive containment cooling system
- Pressure suppression containment



Underground Construction for Enhanced Safety and Seismic Resilience



GAIN Gateway for Accelerated Innovation in Nuclear

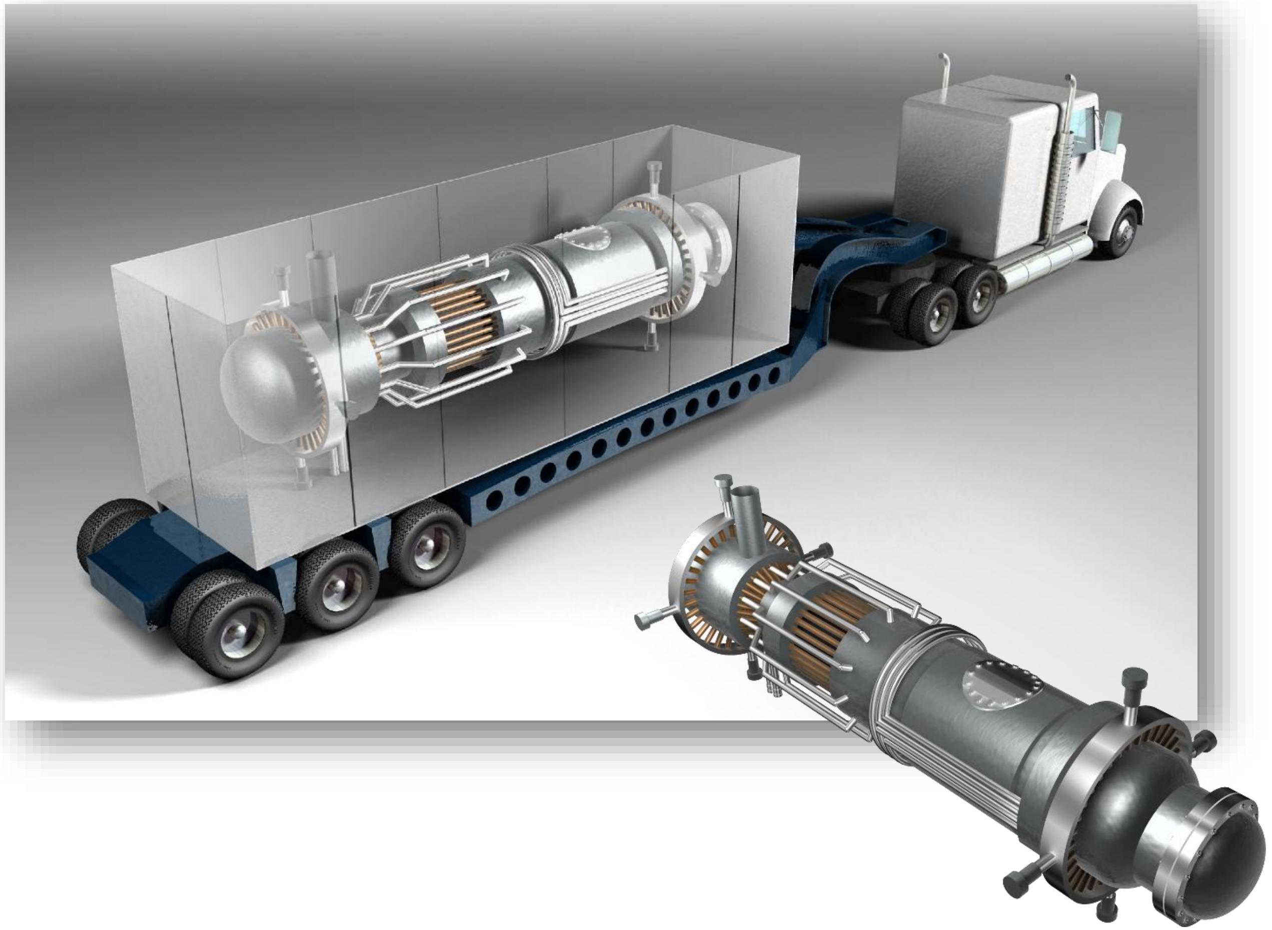
Microreactors

SMALL AND TRANSPORTABLE
Fits on the back of a semi-truck and can be deployed to remote locations and military bases for reliable heat and power

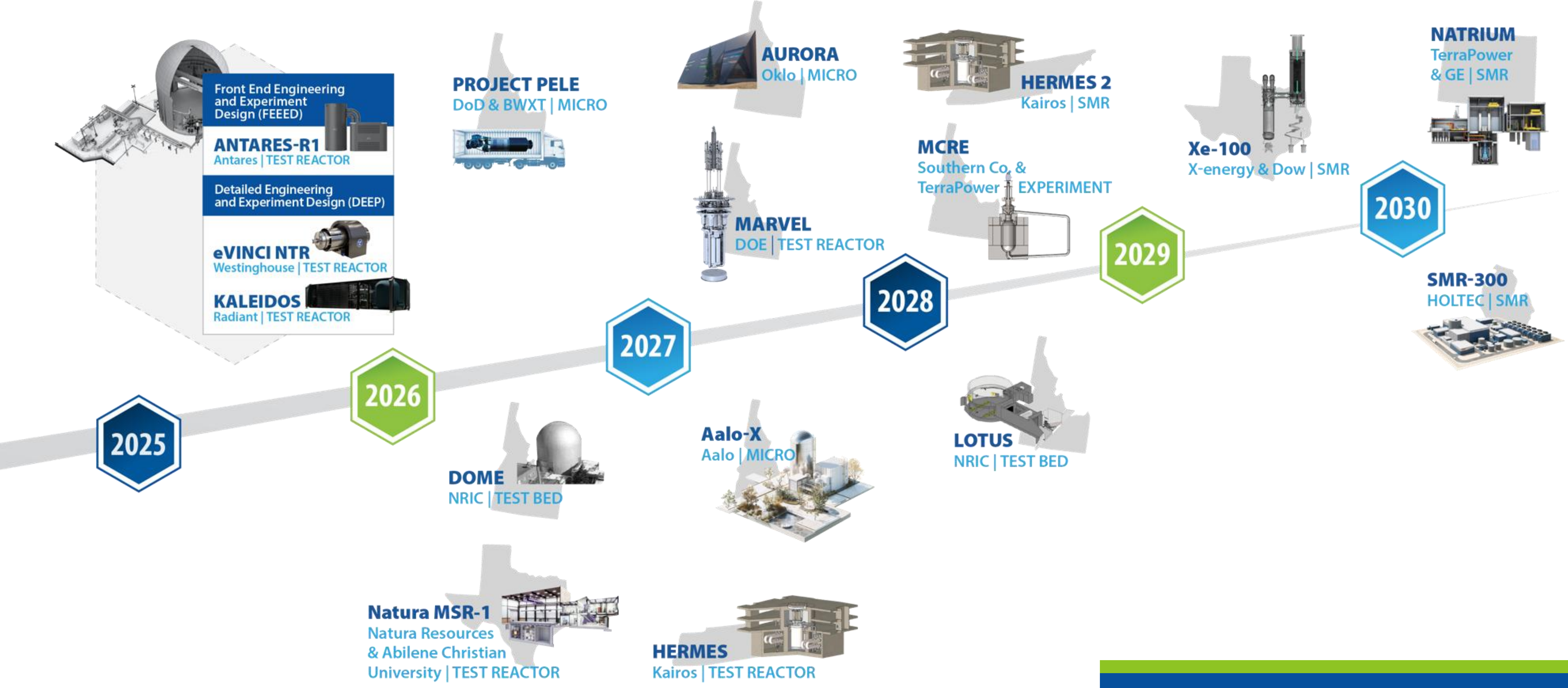
FACTORY FABRICATED
Components can be assembled in a factory and shipped, eliminating difficulties associated with large-scale construction

FAST ON-SITE INSTALLATION
Can be connected and generating power within a week of arriving on site

SIMPLE SELF-REGULATING DESIGN
Fail-safe and self-regulating designs that require fewer components, maintenance and operators



Accelerating advanced reactor demonstration and deployment



GAIN Gateway for Accelerated Innovation in Nuclear

Developers and Reactors

- Currently tracking over 30 developers with over 40 reactor designs in the US
- Includes all varieties (water, gas, sodium, lead, salt) and sizes (from 100s kWe to 100s Mwe)

U.S. NUCLEAR REGULATORY COMMISSION ACTIVITIES

Pre-Application Engagement

13 NON-WATER MODERATED DESIGN

4 WATER MODERATED DESIGN

Licensing

1 COMMERCIAL

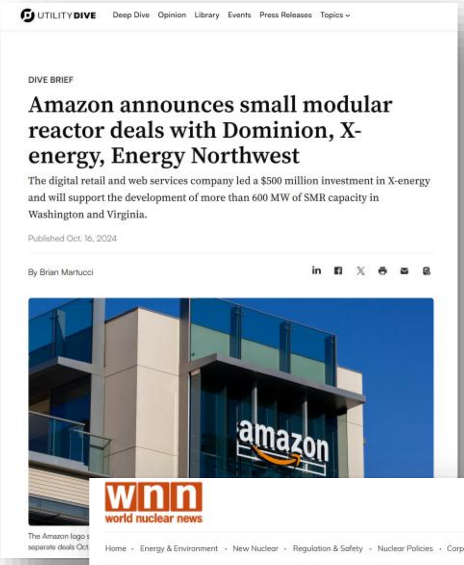
3 RESEARCH/TEST

Current Projects

- GE Hitachi's BWRX-300 for Ontario Power Generation (Application submitted)
- Tennessee Valley Authority – mantnch River (Pre-Application CP)
- Duke – Belews Creek (Early Site Permit)

DOE Support of Advanced Reactors: X-energy XE-100

- Funded by DOE’s Advanced Reactor Demonstration Program (ARDP) with $1.23 billion over 7 years through cost-shared partnership.
- ARDP project has the goal to build a 2-unit XE-100 demonstration plant
- X-energy plants are designed to deliver both power and high temperature heat at 585 C
- Joint venture with Dow Chemicals to site their first four units at or inside Dow's chemical facility in Seadrift, Texas with planned operation by 2029
- Utility Energy Northwest and X-Energy plan to deploy up to 12 units in central Washington State, with first unit online by 2030
- TRISO-X Fuel Fabrication Facility in Oak Ridge, Tennessee operational by 2025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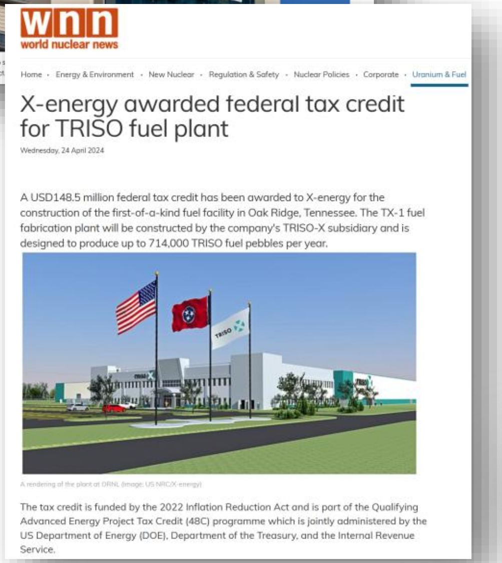
DIVE BRIEF

Amazon announces small modular reactor deals with Dominion, X-energy, Energy Northwest

The digital retail and web services company led a $500 million investment in X-energy and will support the development of more than 600 MW of SMR capacity in Washington and Virginia.

Published Oct. 16, 2024

By Brian Martucci


wnn world nuclear news

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X-energy awarded federal tax credit for TRISO fuel plant

Wednesday, 24 April 2024

A USD148.5 million federal tax credit has been awarded to X-energy for the construction of the first-of-a-kind fuel facility in Oak Ridge, Tennessee. The TX-1 fuel fabrication plant will be constructed by the company's TRISO-X subsidiary and is designed to produce up to 714,000 TRISO fuel pebbles per year.

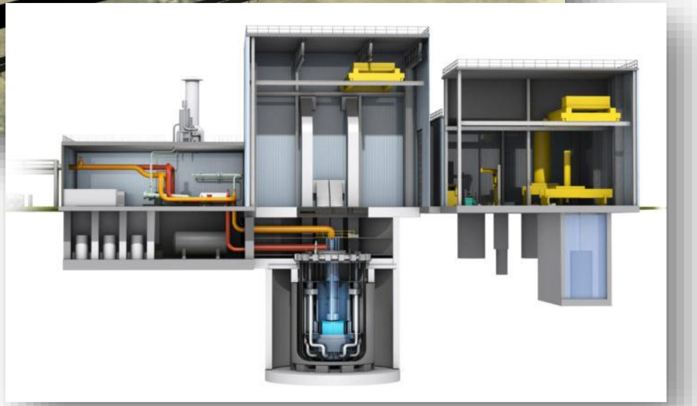
A rendering of the plant at ORNL (image: US NRC/X-energy)

The tax credit is funded by the 2022 Inflation Reduction Act and is part of the Qualifying Advanced Energy Project Tax Credit (48C) programme which is jointly administered by the US Department of Energy (DOE), Department of the Treasury, and the Internal Revenue Service.

GAIN Gateway for Accelerated Innovation in Nuclear

DOE Support of Advanced Reactors: Natrium

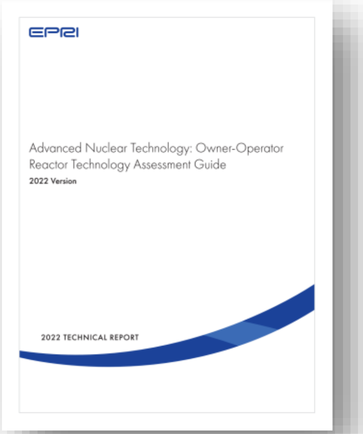
- Funded by DOE's Advanced Reactor Demonstration Program (ARDP)
- Single-unit, 345 Mwe pool-type sodium fast reactor using High-Assay Low-Enriched Uranium (HALEU) metal fuel
- TerraPower selected Kemmerer, Wyoming as demonstration reactor site in November 2021
- TerraPower submitted its construction permit application March 2024 to the NRC, making this the first construction permit application for a commercial advanced reactor to the NRC
- Utility PacifiCorp added two further units to its Wyoming plans in April 2023, in addition to the demonstration unit
- New MoU in July 2023 between Centrus and TerraPower will ensure HALEU availability to meet 2030 operation date at Centrus' HALEU production facility in Piketon, OH
- Construction Permit Submitted 3/28/24



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

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

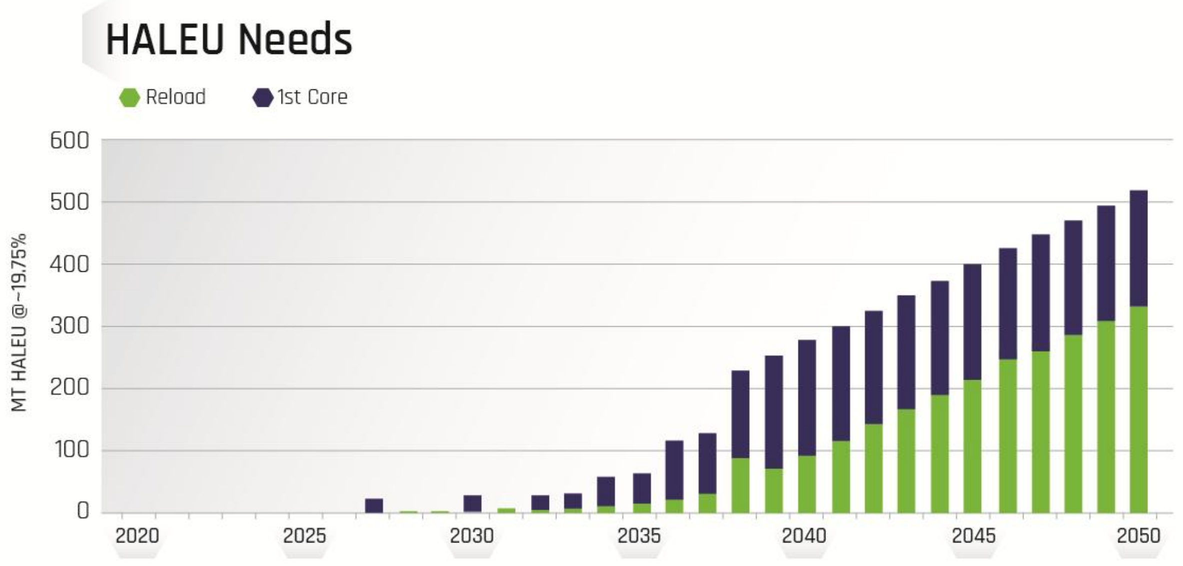
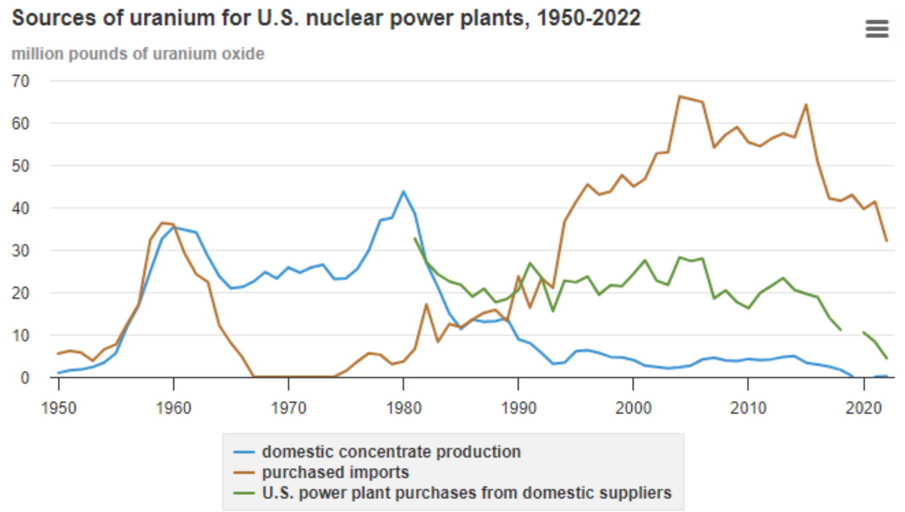


Figure 31. Projected HALEU Needs for Advanced Non-LWRs to 2050[126]



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

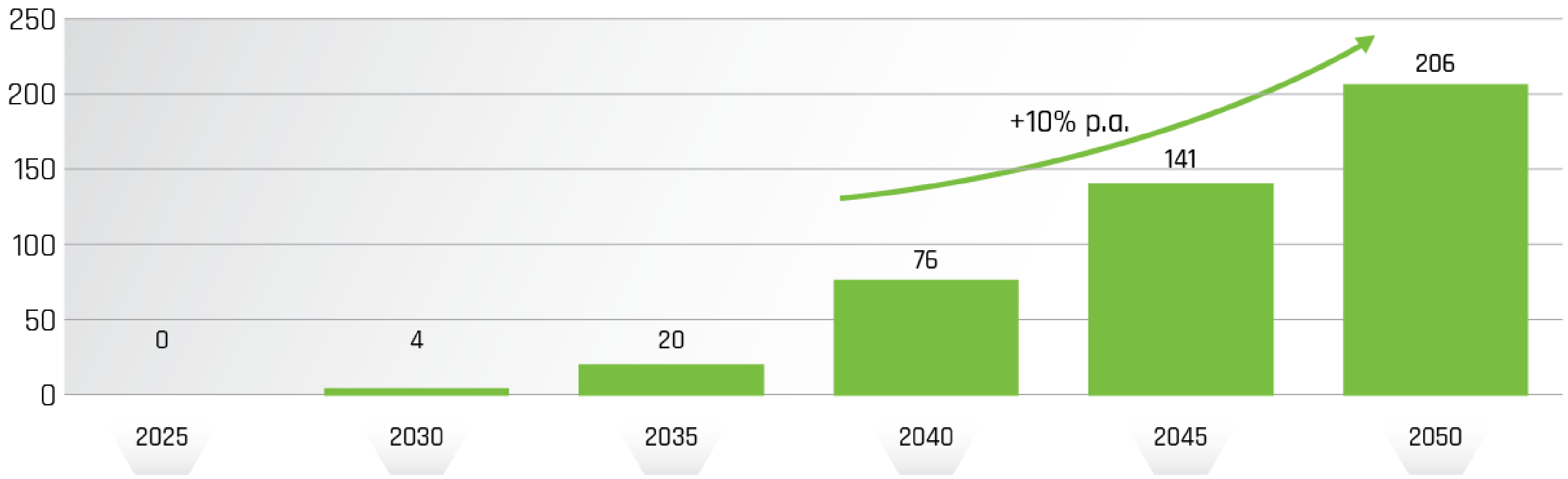
Owners and operators of U.S. civilian nuclear power reactors purchased 40.5 million pounds of U_3O_8e (equivalent) from U.S. and foreign suppliers during 2022.

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

Required Nuclear Buildout – 200 GW by 2050

- Annual industrial capacity additions:
  - 2 GW per year 2029 – 2034
  - Ramping to 13 GW per year from 2035 – 2050 to achieve 200GW by 2050
  - Requires an additional 275,000 workers; currently 100,000 workers



GAIN Gateway for Accelerated Innovation in Nuclear

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

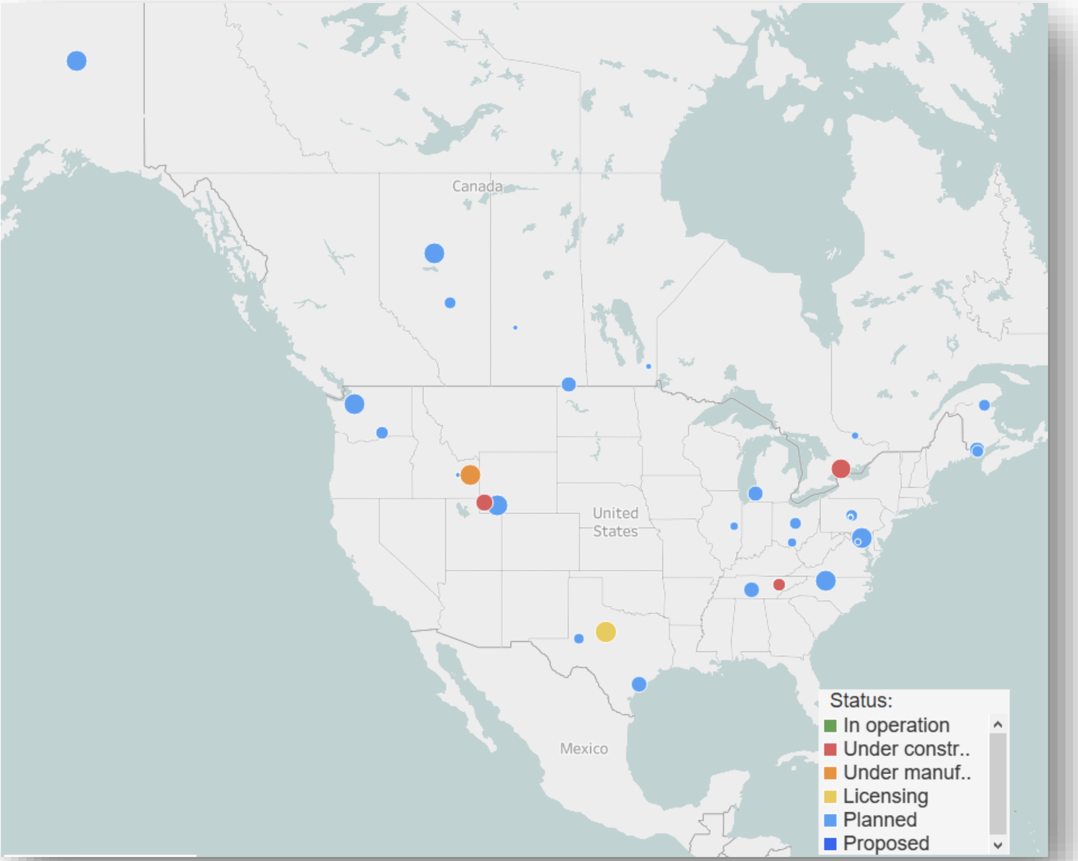
Source: International Energy Agency. Electricity 2024. Organisation for Economic Co-operation and Development (OECD). January 2024. https://www.iea.org/reports/electricity-2024. Accessed October 2024.

THIRD WAY

Google turns to nuclear to power AI data centres

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

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

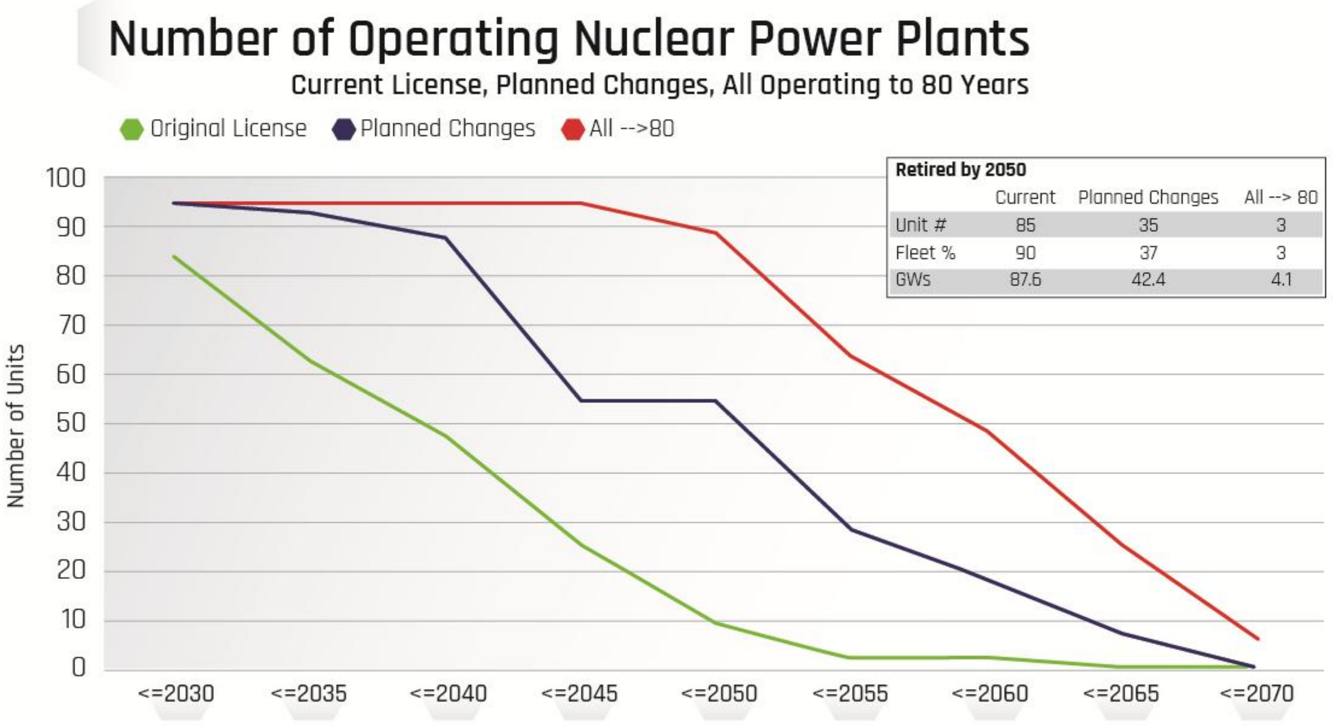
18

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

Current State of the Nuclear Industry

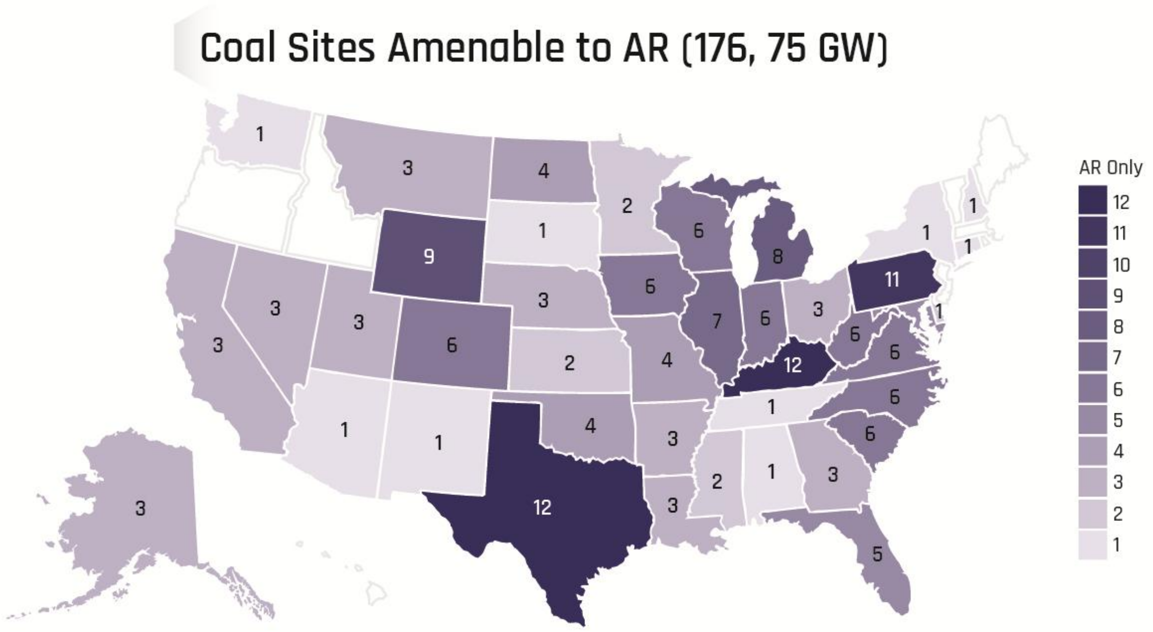
- 94 reactors online in the U.S.
- Third largest source of domestic electricity supplying approximately 18.2% of the electricity in the United States.
- Prior to 2021, 12 units prematurely closed, and all units would only operate to their original 40-year license.
- As of 2024, the value of the nation's existing assets has been recognized, and there has been increasing investment to support our energy needs.
- To date, six units have approved license extension to 80 years.

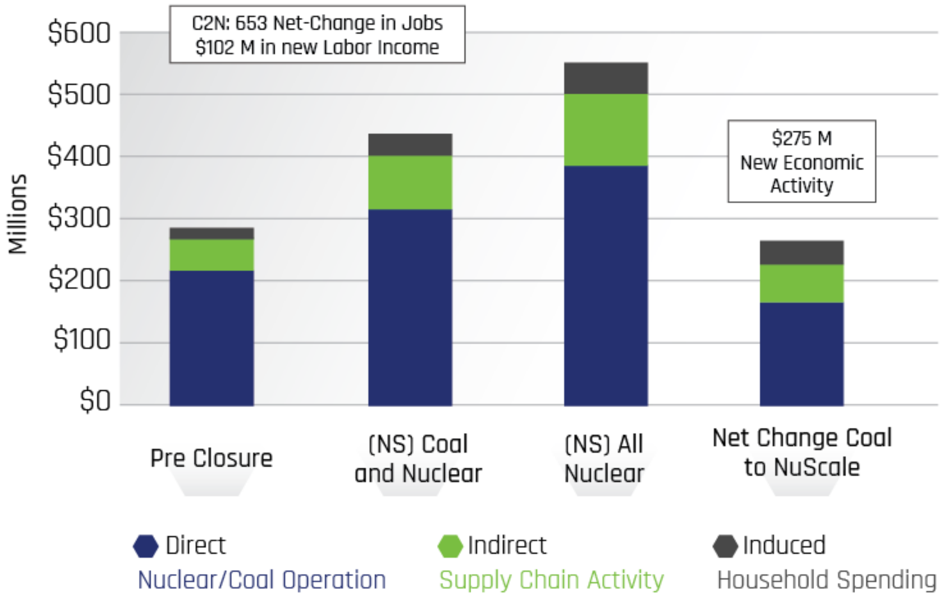


	Current	Planned Changes	All --> 80
Unit #	85	35	3
Fleet %	90	37	3
GWs	87.6	42.4	4.1

2022 DOE Report: Investigating Benefits and Challenges of Adding Nuclear to existing Coal Sites

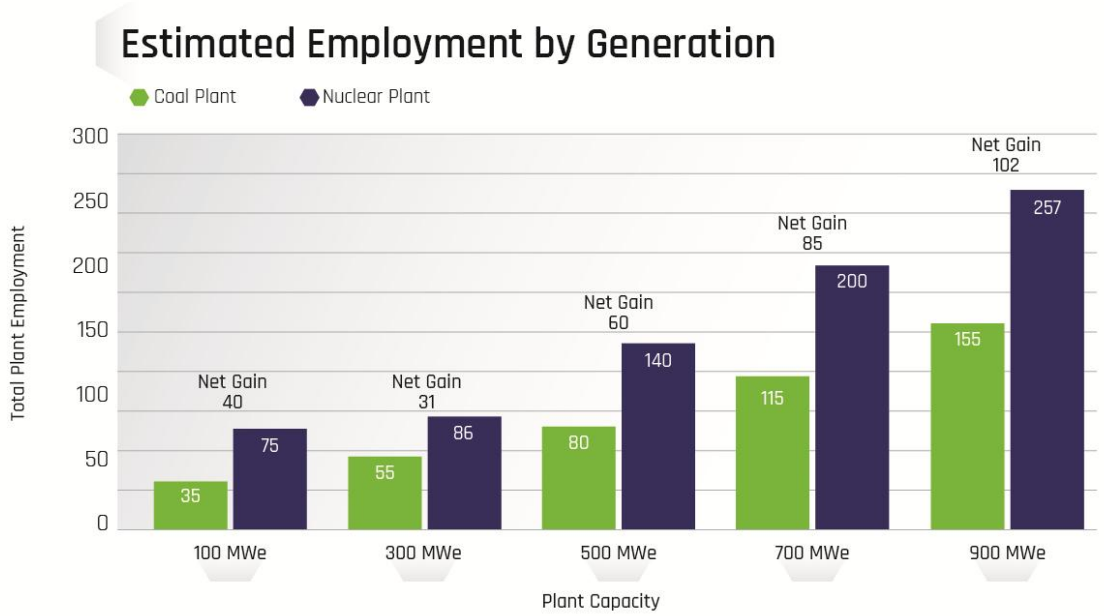
- 80% of evaluated coal sites suitable for advanced reactor
- Estimates on overnight capital cost savings from repurposing viable coal infrastructure range from 15% to 35%

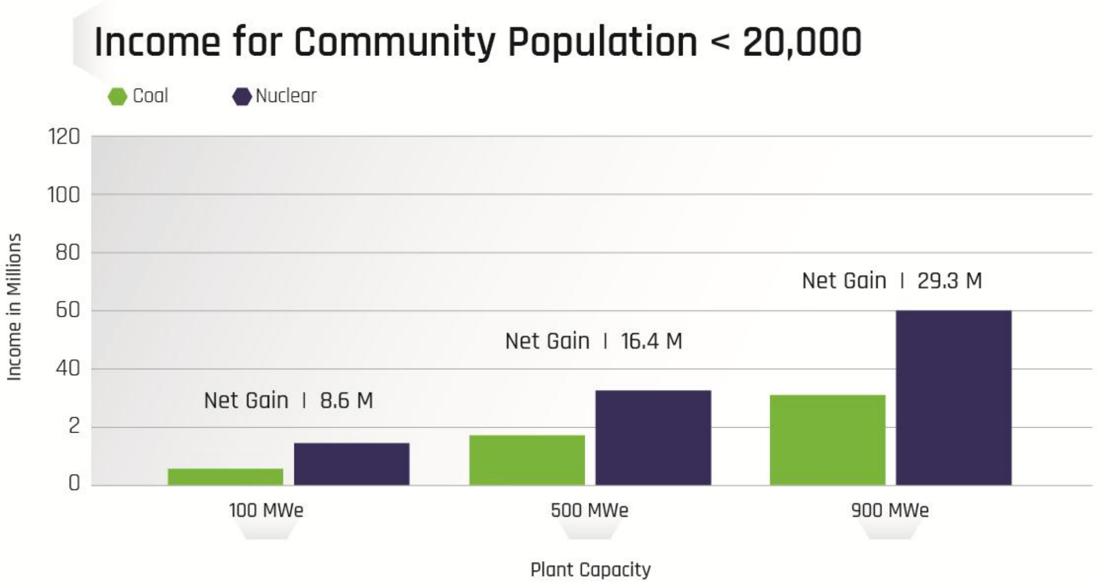




What does nuclear power addition offer a community?

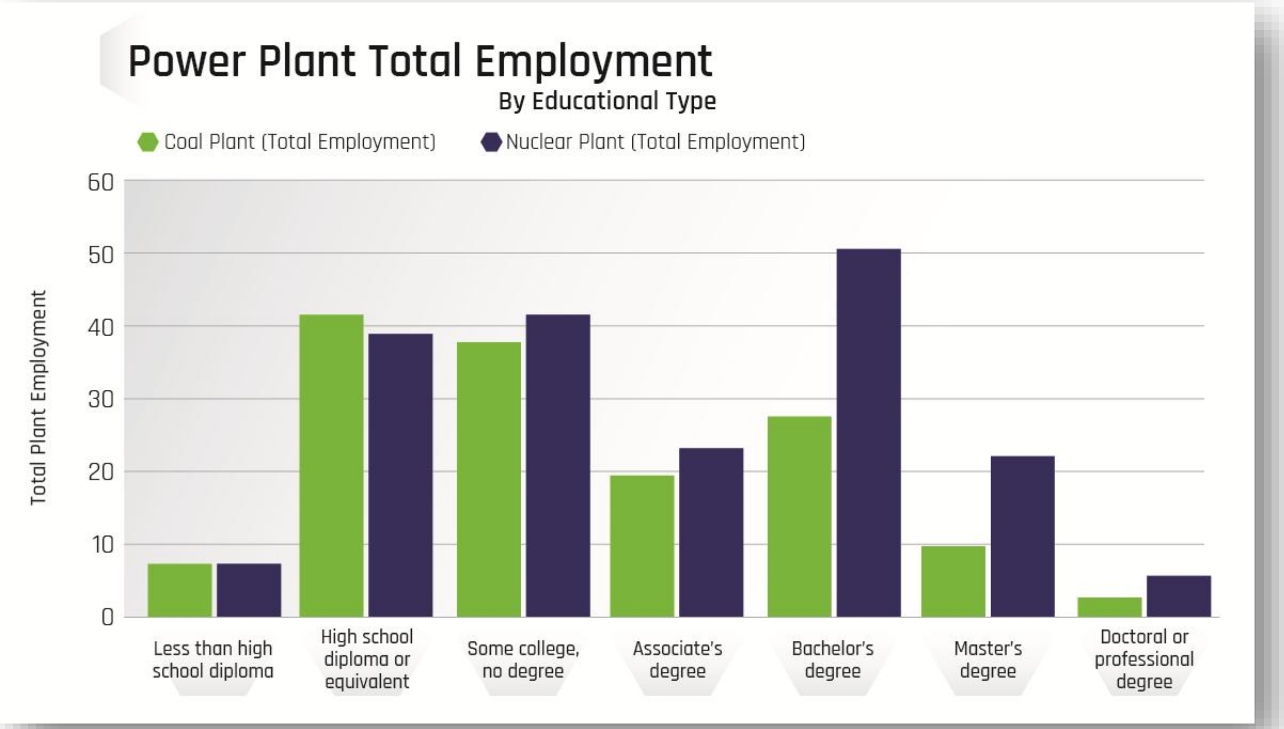
- Nuclear can bring lasting jobs to a plant for 40-80 years
- There are both direct jobs created as well as indirect and induced jobs
- Many other technologies such as wind, solar, and gas only bring construction jobs
- For every $100 of electricity produced, $50 of economic activity occurs in suppliers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





Overlap in job types and education levels

- Compared occupation codes shows the similarity in roles from each power plant type.
- Many occupations at a coal power plant have the educational background to work at the nuclear power plant.
- Analysis does not account for nuclear, industry-specific training.



45%

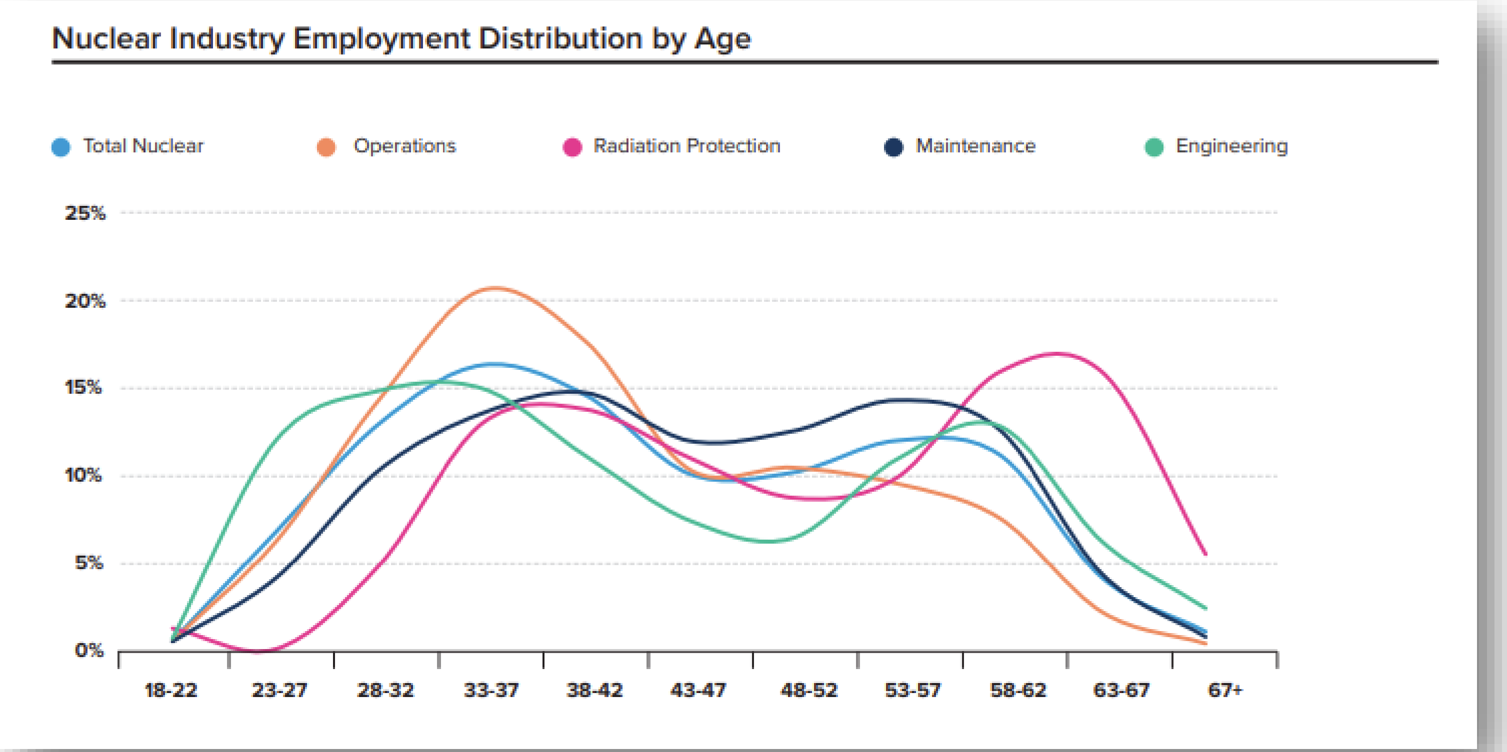
of added nuclear jobs share identical occupation codes with a coal plant

72%

of the added jobs share similar occupation codes

Current nuclear workforce and workforce trends

- Current nuclear workforce is younger due to replacement of retired individuals
- Decrease in overall workforce since the Pandemic
- Increasingh turnover rate of individuals in the nuclear field with less than 10 years experience
- Recruitment and retention of new workforce will be challenging



275,000

workers required to construct and operate additional 200 GW of electricity by 2050

GAIN Gateway for Accelerated Innovation in Nuclear

GAIN nuclear feasibility studies

CORONADO GENERATING STATION

Location: St. John’s AZ
Owner: Salt River Project (SRP)
Results:

- The site has ample, developable land for potential nuclear deployment.
- SRP will need to assess water availability, local ecology, and continue community engagement going forward.

GHENT GENERATING STATION

Location: Ghent, KY
Owner: Louisville Gas and Electric, Kentucky Utilities (LG&E, KU)
Results:

- The site is capable of hosting small and medium-sized reactors, but site topography and potential coal combustion residue will limit the amount of developable land, and therefore total capacity.

Active pilot studies on adding nuclear to coal sites

SPRINGERVILLE GENERATING STATION

Location: Springerville, AZ
Owner: Tucson Electric Power
Scope: Extrapolating site analysis from neighboring site

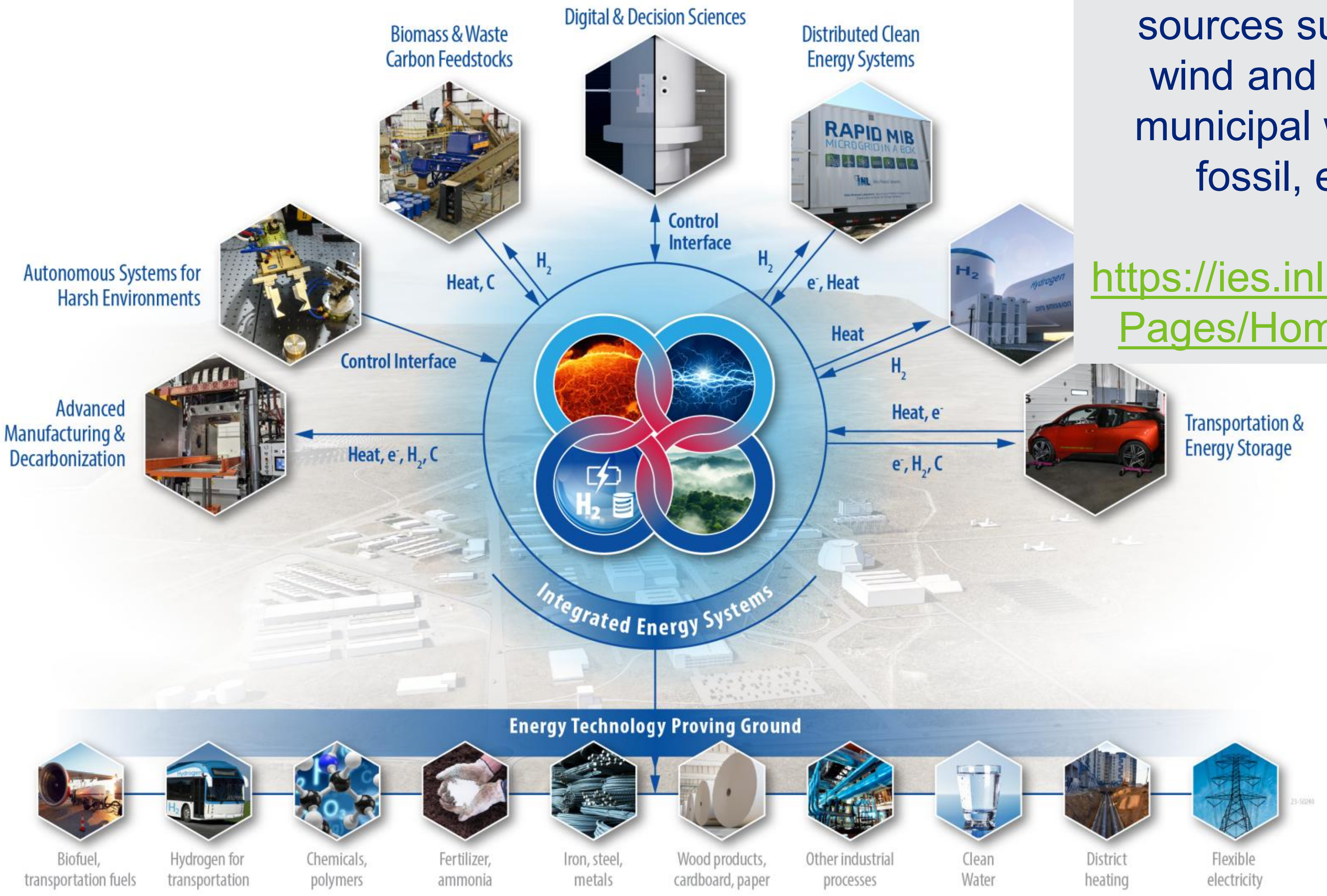
COLSTRIP GENERATING STATION

Location: Colstrip, MT
Owner: Northwestern Energy
Scope: Assess the feasibility of different technology options at Colstrip Power Plant.
Baseline: Uninterrupted coal plant operations.
High-level investigation of site viability for nuclear deployment in NWE service territory

Future energy systems – transforming the energy paradigm

Light water reactors, high temperature advanced reactors, small modular reactors, microreactors, etc.

Integrated energy systems (IES) leverage the contributions from nuclear fission beyond electricity



Variable energy sources such as wind and solar, municipal waste, fossil, etc.

https://ies.inl.gov/SitePages/Home.aspx

Funding opportunities for communities

energywerx

- Facilitating collaboration between DOE, national labs, and external providers
- Coordinating rapid prototyping, demonstration, deployment, and/or manufacturing
- Providing technical assistance for domestic small businesses, academic institutions, and other non-traditional partners
- Performing technology, market research and scouting

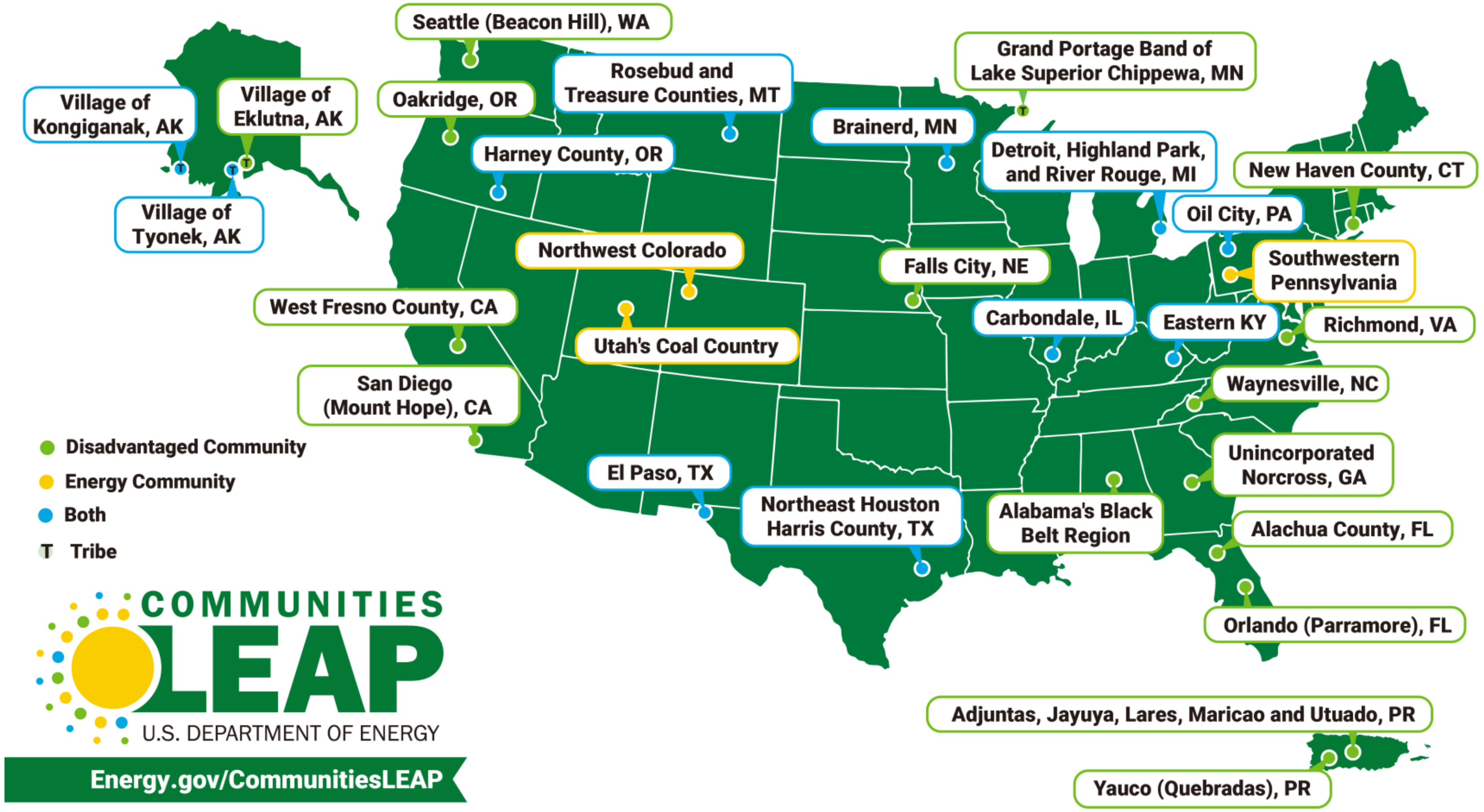
COMMUNITIES LEAP
U.S. DEPARTMENT OF ENERGY

- The Communities Local Energy Action Plan (C-LEAP) drives community-wide economic benefits through DOE.
- Open to low-income, energy-burdened communities facing direct economic impacts from energy plant retirements.

GAIN Gateway for Accelerated Innovation in Nuclear

DOE C-LEAP funding opportunities

- C-LEAP communities exploring nuclear:
  - Eastern Kentucky
  - Northwest Colorado
  - Rosebud and Treasure Counties, Montana
  - Southwestern Pennsylvania
  - Utah's Coal Country



Funding opportunities for private sector

Title 17 Clean Energy (Title 17)

Financing for:

- Innovative energy and innovative supply chain (1703)
- State Energy Financing Institution (SEFI)-Supported (1703)
- Energy Infrastructure Reinvestment (EIR, 1706)

Tribal Energy (TELGP)

Financing for:

- Tribal energy development projects

Advanced Transportation (ATVM)

Financing for:

- Manufacturing of advanced technology vehicles several modes of ATVs, components and EV charging infrastructure

CO2 Transportation Infrastructure (CIFIA)

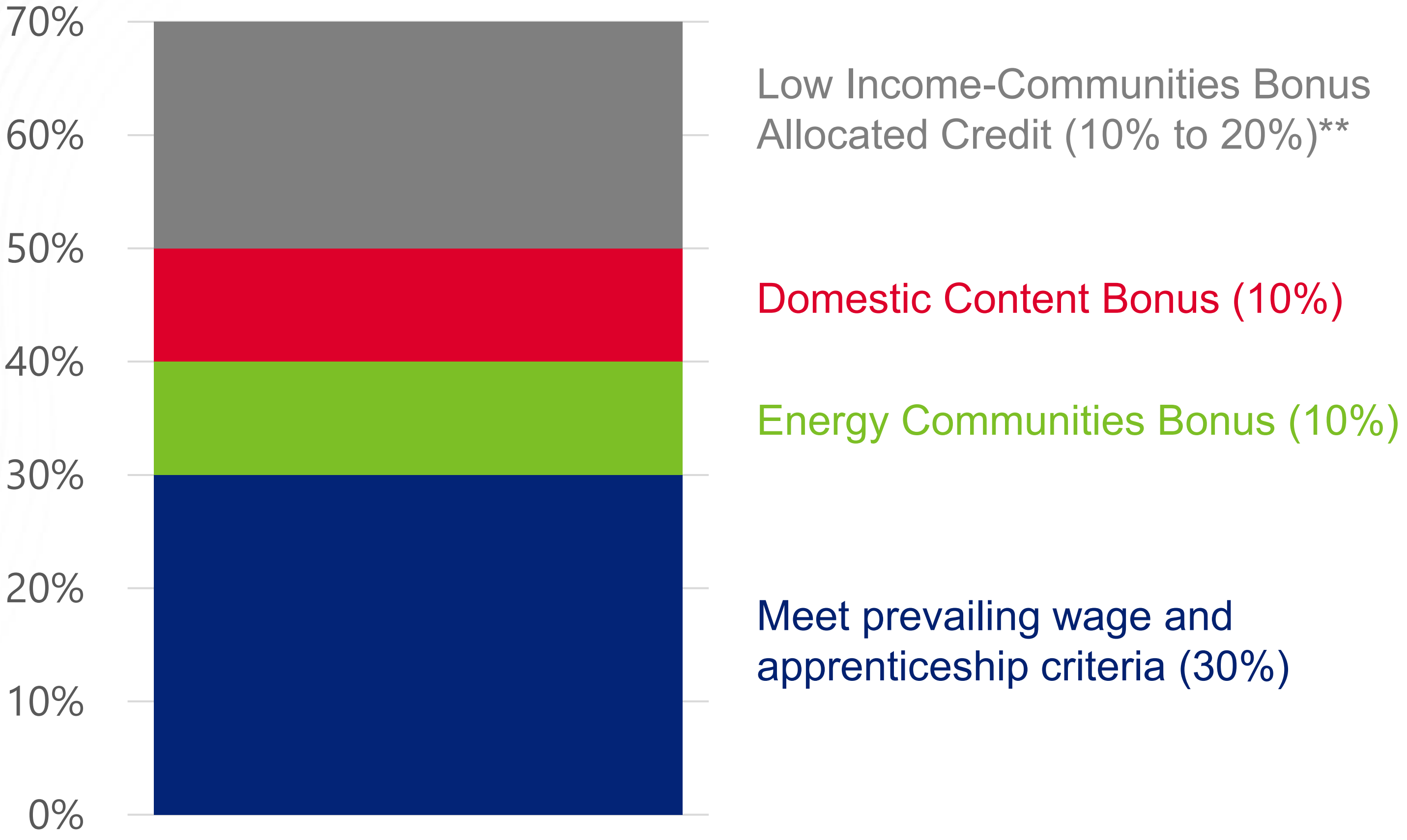
Financing for:

- Large-capacity, common carrier CO2 transportation projects

The Bridge to Bankability

- Providing financing for technologies to go the last mile to reach full market acceptance

Example: Investment Tax Credit Stacking



Credit is 5x lower if not meeting prevailing wage and apprenticeship criteria

**48(e) tax credits are limited and allocated by DOE in coordination with IRS through an application process

- ***Tax credit bonuses can stack*** with the underlying tax credit creating significant opportunity for eligible projects.

EXAMPLE

- 1 MW community solar facility costing $1 million could earn a 70% tax credit worth $700,000 if eligible for all applicable tax credit and bonuses
- If it is owned by an applicable tax-exempt entity, this could be a direct cash payment from the IRS

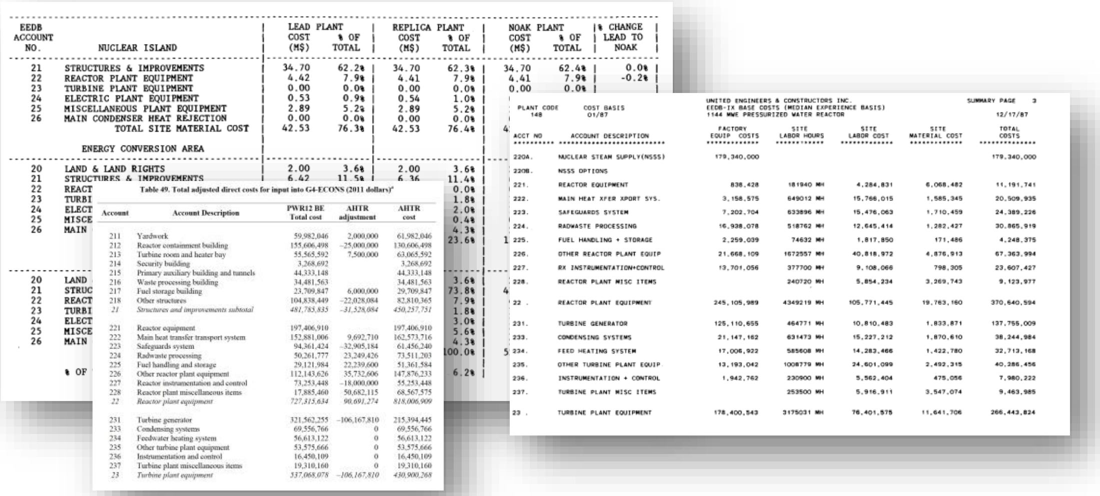
Nuclear power and economic opportunity

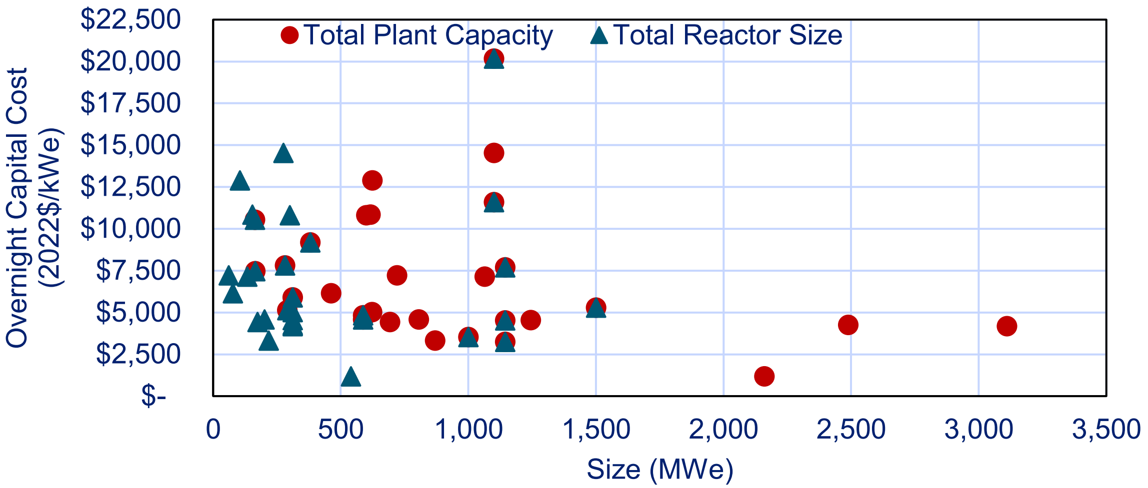
- The Inflation Reduction Act (IRA) established the Production Tax Credit (PTC) and Investment Tax Credit (ITC) applicable to nuclear energy.
- These credits are set to be available the later of 2032 or until annual greenhouse gas emissions from electricity production equal or fall below 25% of 2022 emissions.
- Taxpayers must select either the PTC or ITC, as they cannot benefit from both simultaneously.

Production Tax Credit	Investment Tax Credit
Section 45Y • Dollar amount per megawatt hour produced (USD/MWh) • Claim for 10 years after the facility is built (between 2025 – 2032)	Section 48E • Percentage of total Capital Expenditures (CAPEX) • Claim once
Section 45U • Dollar amount per megawatt hour produced (USD/MWh) for existing nuclear power plants • Claimed between 2023 – 2032	

GAIN Meta-Analysis of Advanced Reactor Cost Estimation

- Meta-study of advanced reactor cost estimation reports with goals of
  - Providing high-level costs for NREL Annual Technology Baseline and other databases
  - Making detailed Code of Account-based database openly available on GAIN website
- Focused on detailed bottom-up estimates to ensure cross comparison
- Compiled, mapped, and processed all datasets analyzing trends and potential ranges for users
- Conducted weekly focus group meetings that included representatives from utilities, academia, think tanks, NGOs, vendors



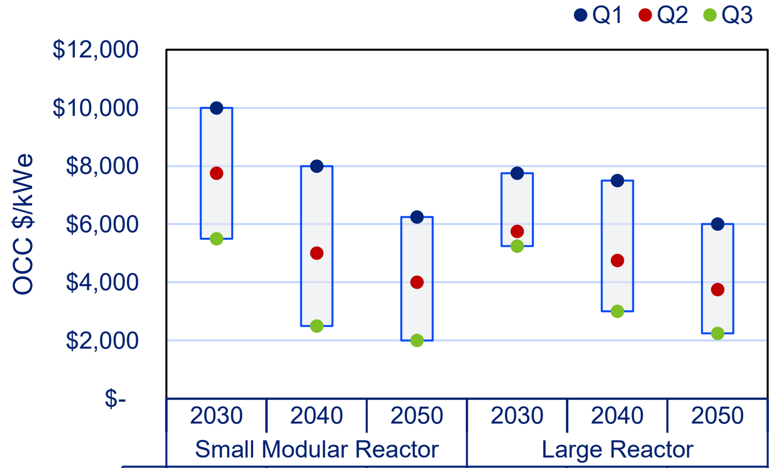


Reference cost ranges for large and small modular reactors

- Costs are shown as between-of-a-kind (BOAK) or costs after first-of-a-kind demonstrations have taken place, but before nth-of-a-kind learning as materialized
- The INL report behind these values includes important information to energy mix planners about how to adequately capture advanced nuclear technology (e.g., capital costs, construction times, ramp rates)

	Large Reactor			SMR		
	Advanced	Moderate	Conservative	Advanced	Moderate	Conservative
Nuclear Fuel Costs ($/MWh)	9.1	10.3	11.3	10.0	11.0	12.1
Nuclear Fuel Costs ($/MBTU)	0.88	0.99	1.09	0.97	1.06	1.17
Fixed non-fuel O&M ($/kWe-yr)	126	175	204	118	136	216
Fixed O&M ($/MWh) @ 93% capacity factor	15.5	21.5	25.1	14.5	16.6	26.5
Variable non-fuel O&M ($/MWh)	1.9	2.8	3.4	2.2	2.6	2.8
Total O&M ($/MWh)	26	35	40	27	30	41

Reference O&M costs for large reactors and SMRs

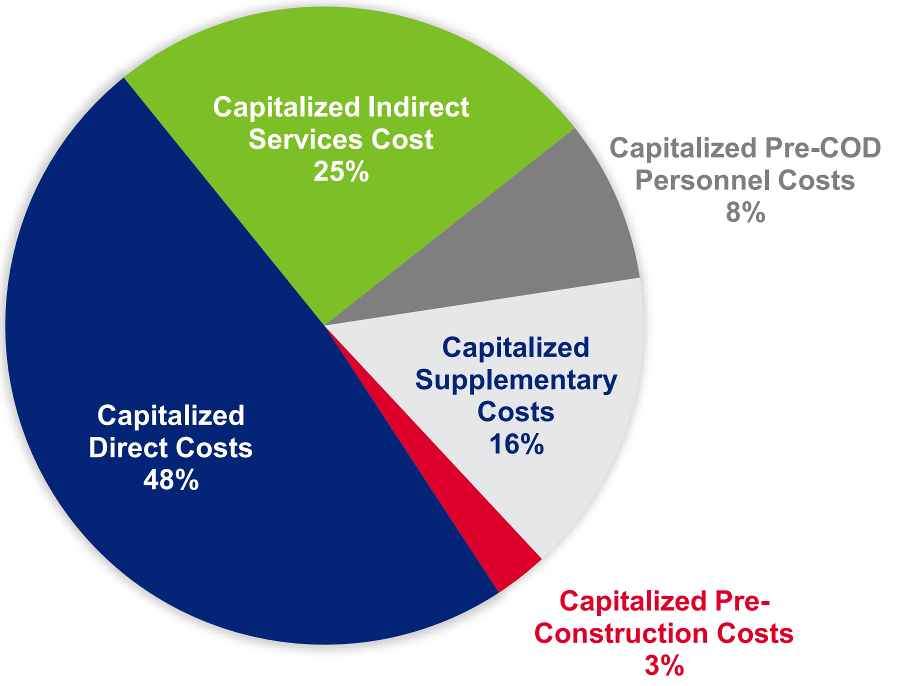


	Small Modular Reactor 2030	Small Modular Reactor 2040	Small Modular Reactor 2050	Large Reactor 2030	Large Reactor 2040	Large Reactor 2050
Q1	$10,00	$8,000	$6,250	$7,750	$7,500	$6,000
Q2	$7,750	$5,000	$4,000	$5,750	$4,750	$3,750
Q3	$5,500	$2,500	$2,000	$5,250	$3,000	$2,250

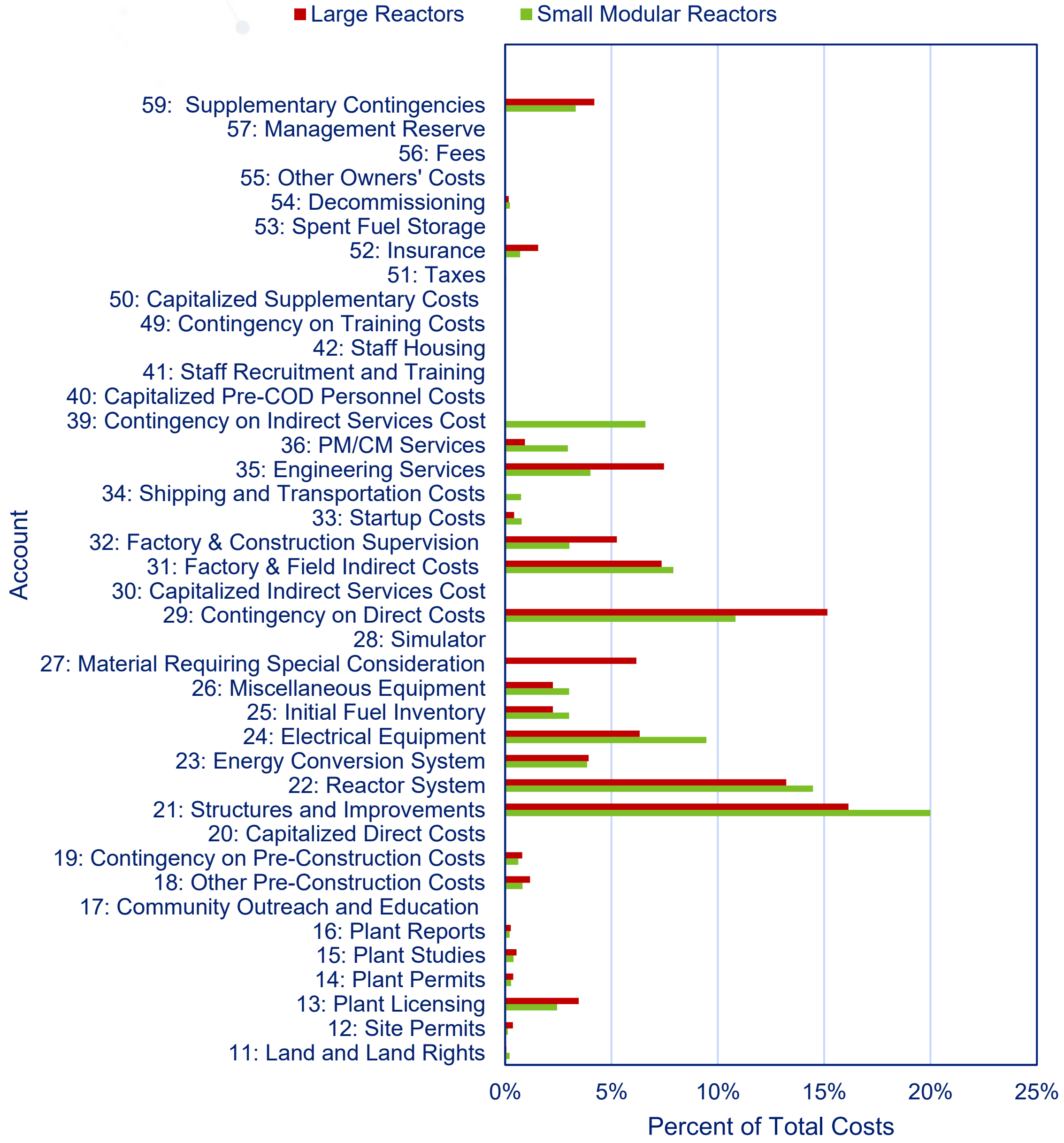
Reference overnight capital costs (OCC) for large reactors and SMRs

Detailed breakdown of cost drivers

- Direct costs are unsurprisingly largest cost contributor (48%), followed by indirect costs (25%), and supplementary costs (16%) namely initial core load.

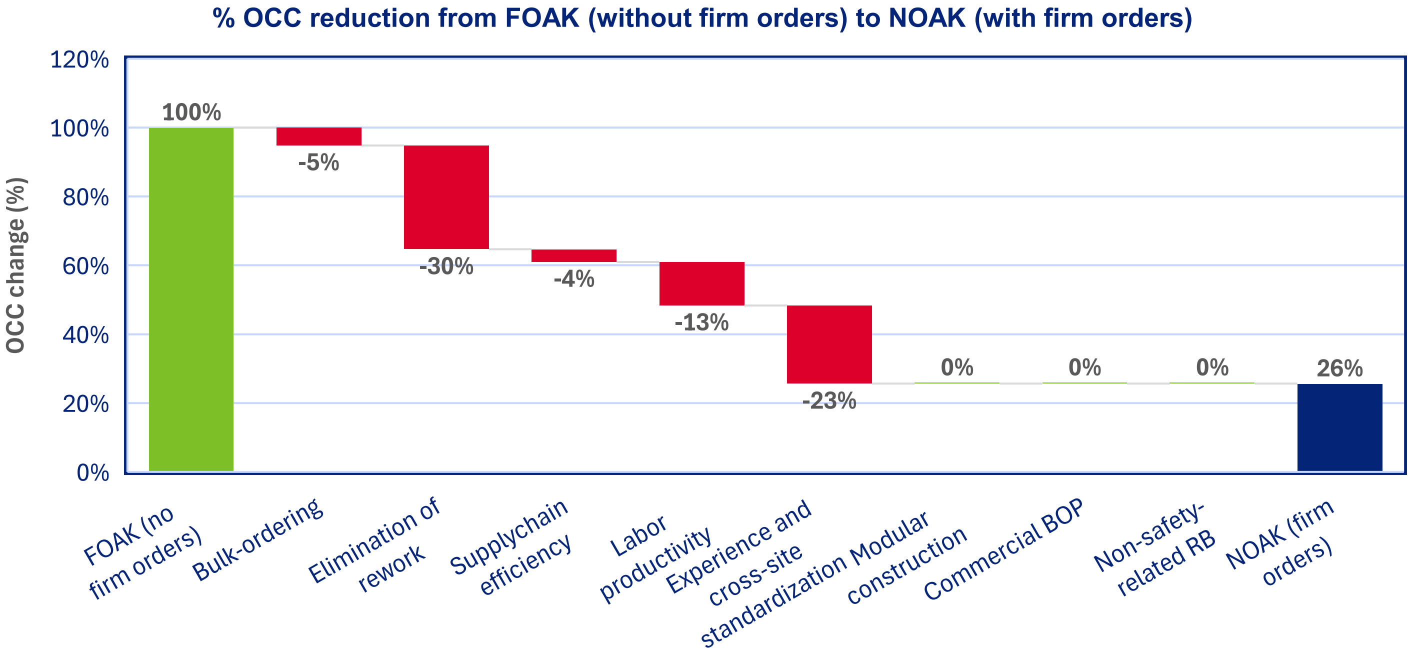


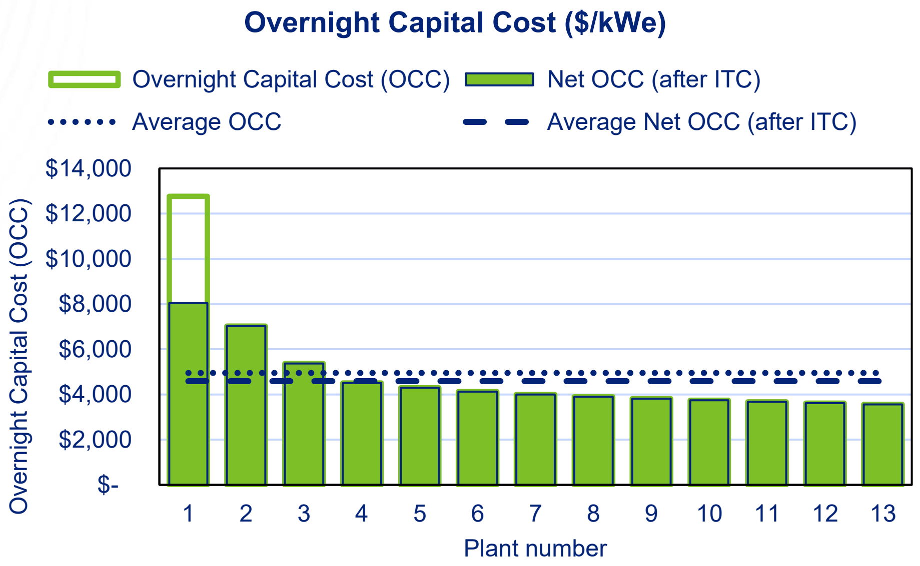
Nuclear cost categories and their contributions to total costs



Cost reduction pathways

- Tool to evaluate various pathways towards cost reduction and untangles the effects from learning rate
- Provides a useful framework to explore cost drivers and areas where stakeholders can explore impact of levers on cost projections





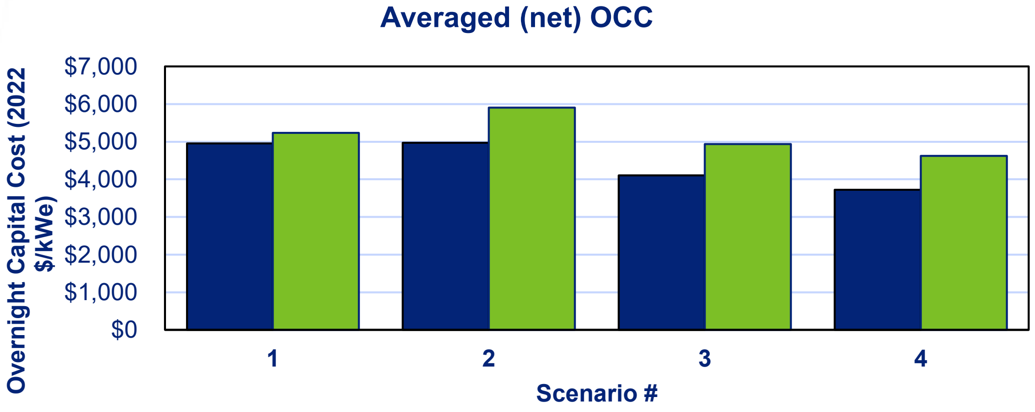
Number of Firm Orders	13
Interest Rate	6%
Design Completion	80%
Design Maturity (0, 1, 2)	1
Supply Chain Proficiency	0.5
A/E Proficiency	0.5
Construction Proficiency	1

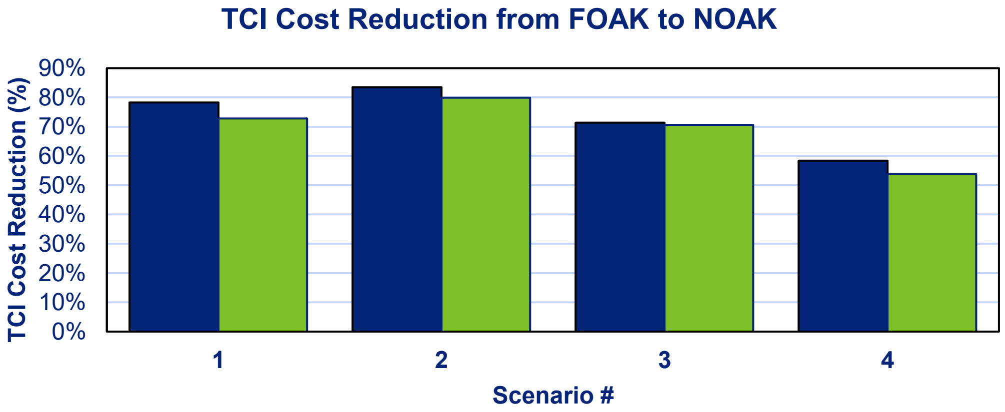
Cross-Site Standardization	80%
Modular Civil Construction	TRUE
Commercial-Grade BOP	TRUE
Non-Safety-Related Reactor Building	FALSE
ITC Amount	40%
Number units with ITC	1

Cost reduction scenarios considered in study

- Two advanced reactor design considered: **reactor design A (High temperature Gas Rx)** and **reactor design B (Sodium Fast Reactor)**
- Four scenarios considered to highlight different paths towards cost-competitive nth OCC of $3,600/kWe (based on DOE Liftoff 2023)

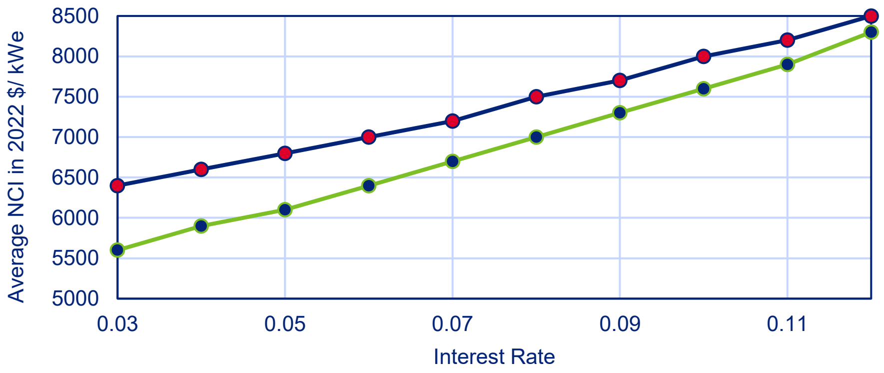
1. **REALISTIC LEVERS**
2. **BAD FOAK EXECUTION,** ***but larger order book to balance average costs with scenario 3***
3. **SCENARIO 1 WITH *four units qualifying for ITC***
4. **OPTIMISTIC SCENARIO**

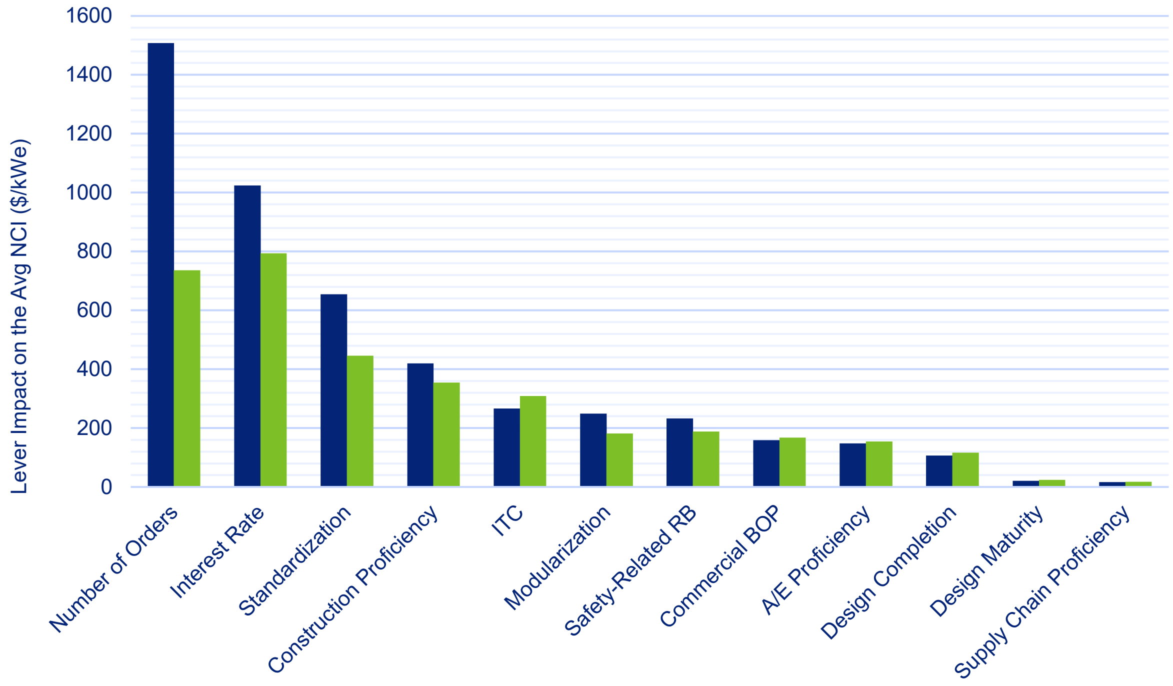




Cost reduction scenarios considered in study, cont.

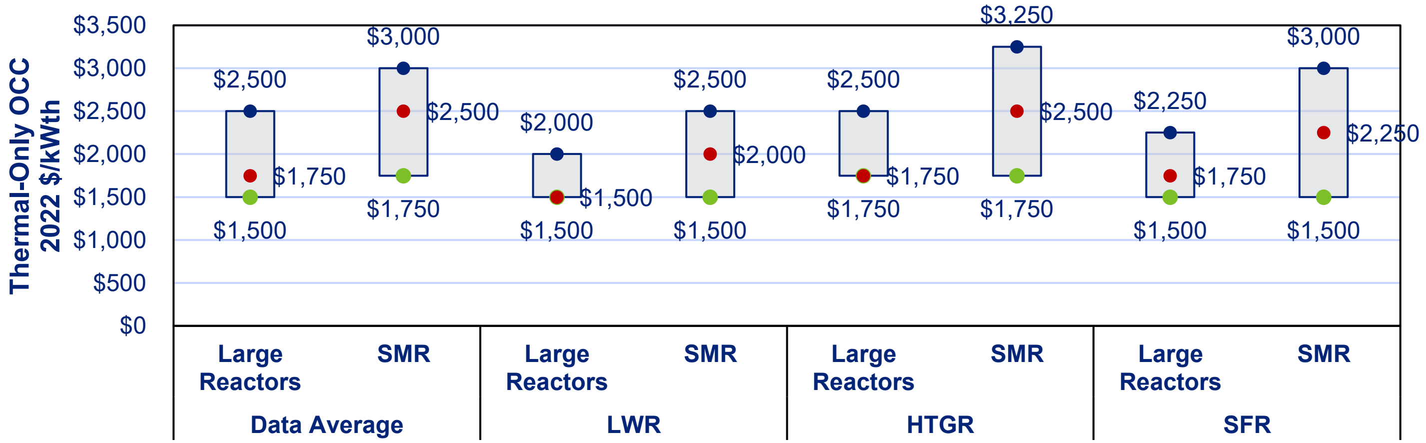
- Sensitivity analysis shows biggest contributors: Order book, interest rates, standardization, construction proficiency, ITC, and modularization

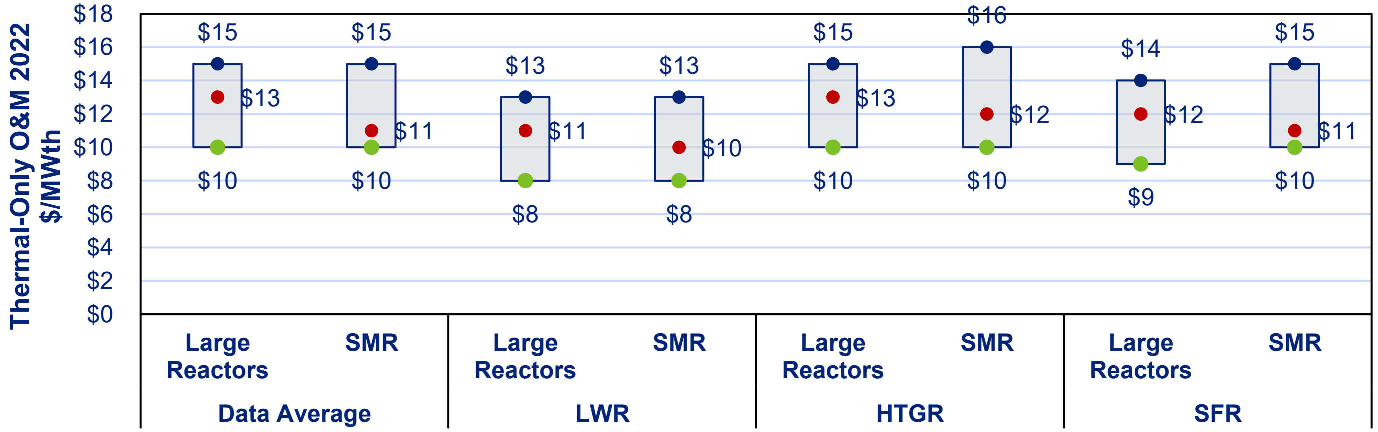




Additional considerations in meta-analysis

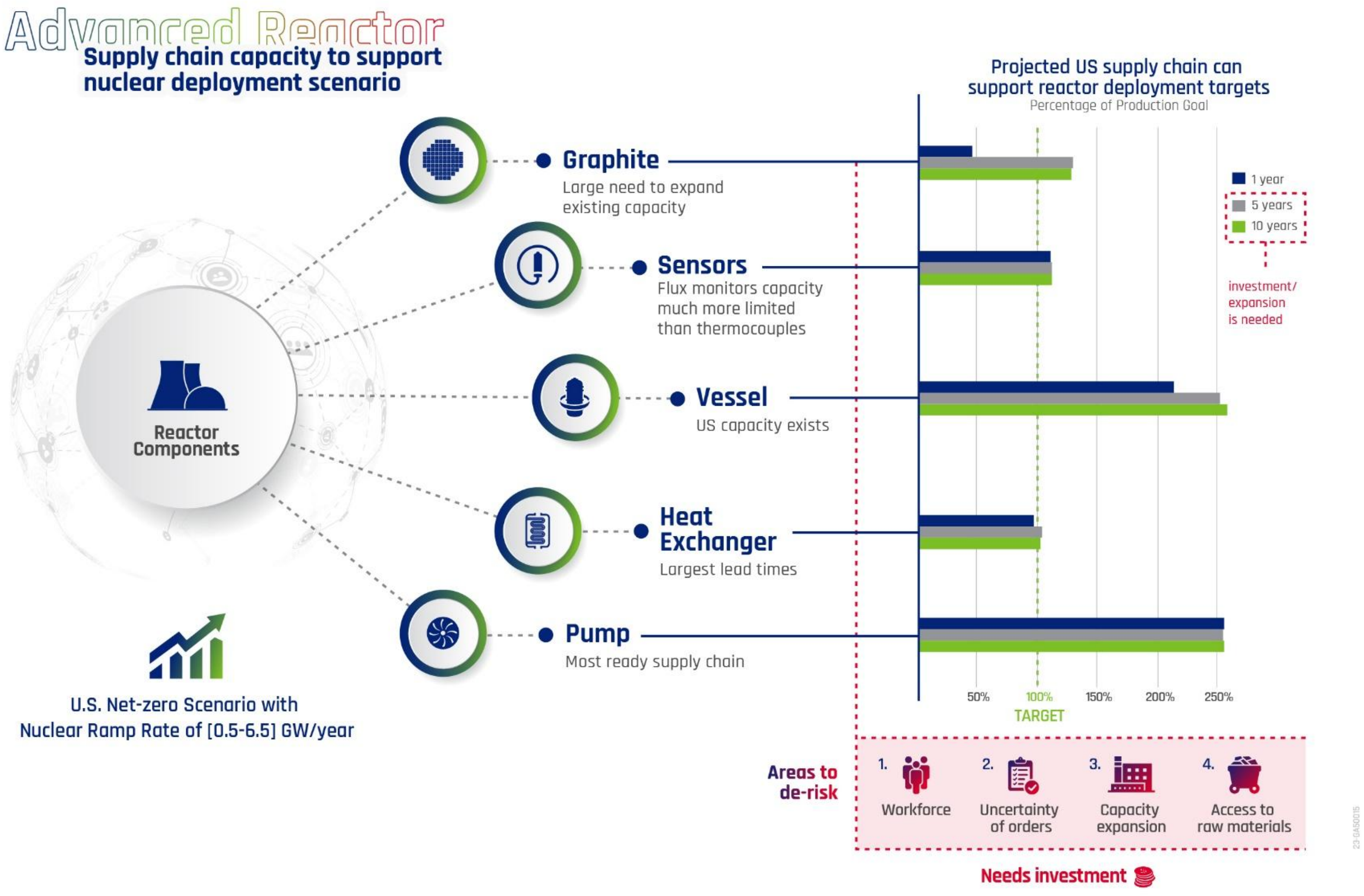
- Multi-unit plant impact
- Thermal-only non-electric applications was also considered
  - Accounted for no-turbomachinery multiplier
  - Adjusted for thermal efficacies
- Survey of ramp rate capabilities of advanced reactors also provided
- Impact of subsidies (namely from Inflation Reduction Act) accounted for
- Coal-to-nuclear considerations
- LCOE calculation





Overview of Supply Chain Assessment

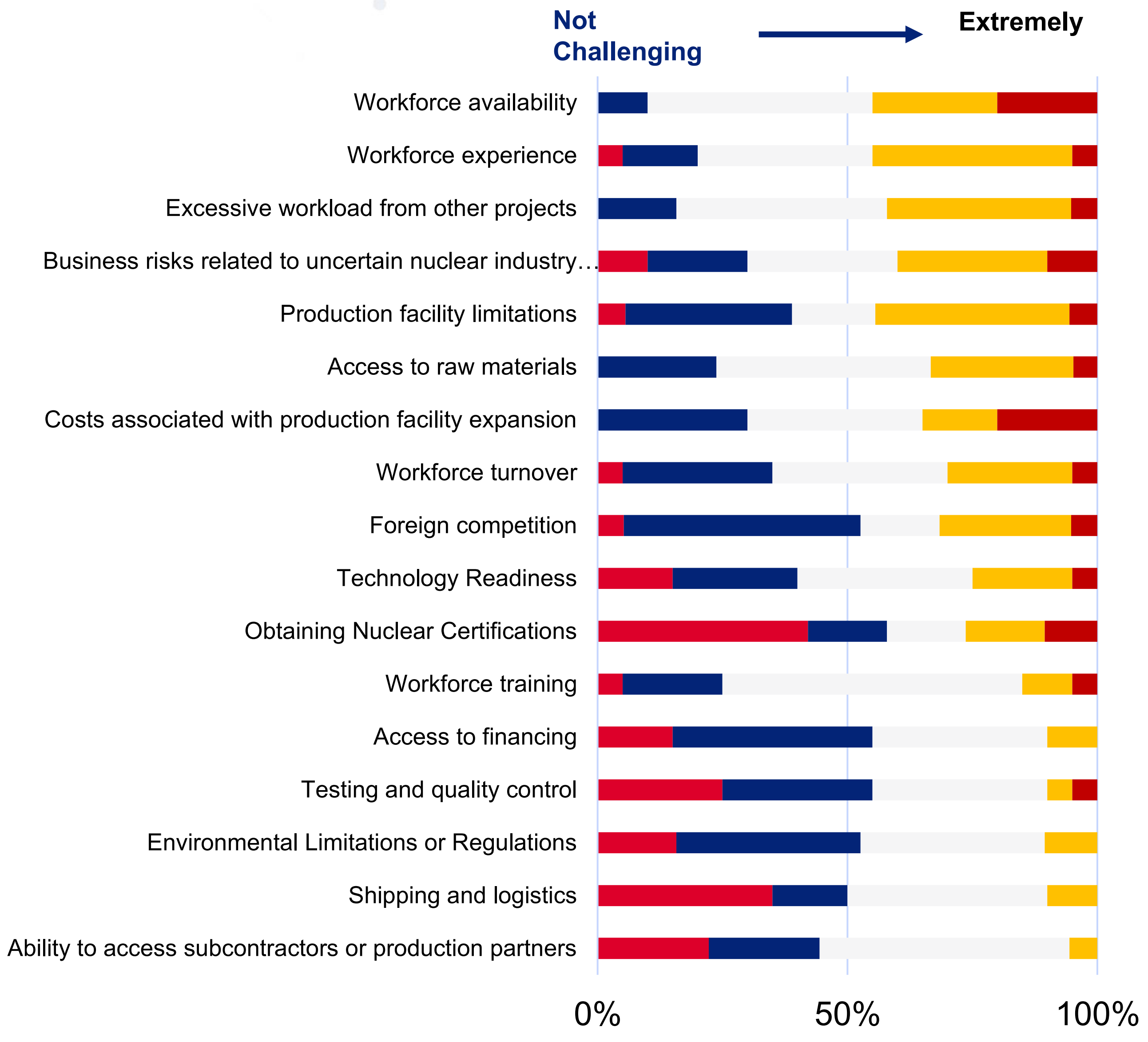
- Builds on the prior DOE supply chain work
- Assessed the capacity of certain critical nuclear components
- Mapped aggressive projections for nuclear deployments rates to component production targets
- Surveyed 20+ companies on ability to meet production targets
- Initial findings:
  - We have an initial US capacity
  - Supply chain can ramp up with caveats



Some concerns noted

- Largest concerns are related to workforce issues:
  - Availability
  - Experience
  - Turnover
- Additional concerns include:
  - Uncertainty of demand
  - Other non-nuclear commitments
  - Production facility limits
  - Access to raw material
  - Cost of expansions/upgrades

1. Workforce
2. Uncertainty of orders
3. Capacity expansion
4. Access to raw materials



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Takeaways

LIMITATIONS

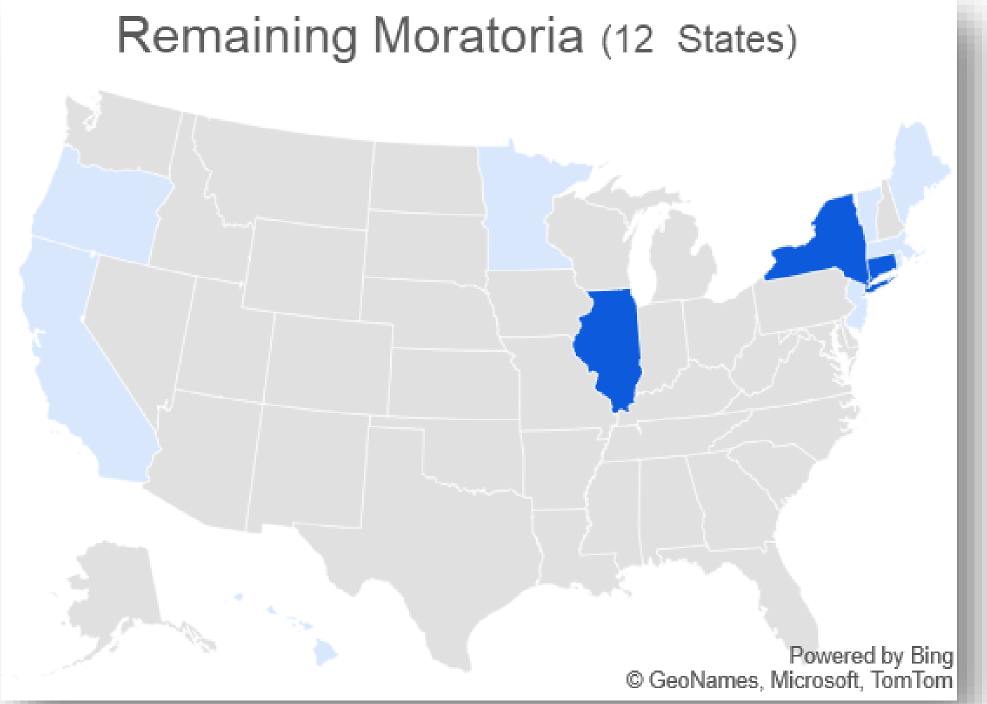
- Information is what suppliers believe they could expand to with ***investment***
- ***Investment amounts were not quantified*** in this work and companies
- Does not help us understand the ***cost competitive*** nature of the suppliers with international competition
- Impact of other ***expanding markets*** may impact the projections
- ***Generic components*** were utilized for this work and reactor specific designs may limit number of suppliers based on specific capabilities
- Does not try to define the ***actual reactor mix*** that may be deployed

KEY FINDINGS

- Supply chain has some ***initial capacity*** to get started
- Assuming limitations are addressed, ***targets could be generally met*** across the various categories
- ***Expansion is required*** to meet larger targets and companies will expand operations if they can make the business case and have firm orders for the investment
- Estimated that ***~5-year lead time*** required to expand industrial capacity
- ***Workforce*** is one of the biggest issues in the supply chain companies
- ***Current lead times*** range from 1 to 2 years based on the type of component

Current nuclear restrictions and moratoria

States with Full Moratoria	States with Partial Moratoria
California	Connecticut: Partial repeal; the moratorium does not apply to the state's existing nuclear power plant, meaning new reactors can be constructed only at that site
Hawaii	Illinois: Partial repeal; starting January 1, 2026 construction may begin on a new nuclear power reactor of 300 MW or less
Maine	New York: Partial moratorium; ban on building reactors in Nassau, Suffolk and Queens counties
Massachusetts	
Minnesota	
New Jersey	
Oregon	
Rhode Island	
Vermont	



Permitting and regulatory pathways to state level advanced reactor development

PHASE 1
Legislative actions towards an organized review of state level regulatory framework

Example 1: Through the passage of HB 1465 in 2024, New Hampshire legislators required the state's Department of Energy to study and propose changes in state laws related to nuclear materials.

PHASE 1
Legislative actions towards an organized review of state level regulatory framework

Example 2: Through the passage of SJR 140 in 2024, Kentucky legislators directed the Public Service Commission to review and amend, if necessary, administrative regulations so they do not contain provisions that would impede the commission from effectively regulating nuclear facilities or obstruct the development of the nuclear ecosystem in the state.

Types of legislation introduced related to nuclear waste

- The Department of Energy is using a consent-based siting to address legacy waste from domestic commercial nuclear power
- Consent-based siting focuses on working with communities early and often to determine if hosting a facility to manage spent nuclear fuel aligns with the community's goals and needs.
- Two states are looking at other solutions, e.g., studies and tax provisions, to address spent fuel

Studies Related to Waste	Tax Provisions Related to Waste
Nebraska – LR 363 Interim study to examine the reprocessing and recycling of spent nuclear fuel and to examine the statutes relating to the disposal, transportation, and storage of spent nuclear fuel.	**New Jersey – S 1701** Classifies spent nuclear fuel from a decommissioned nuclear power plant to be considered real property for tax purposes.

2024 state nuclear legislation trends – proposed legislation

Construction Work in Progress/Advanced Rate Recovery

- Missouri
- Virginia

Like-for-like Replacement

- Arizona
- Nebraska
- Oklahoma
- West Virginia

Supply Chain/Workforce Development

- Michigan
- Nebraska
- Washington

Electricity Standard/Tax Credit Inclusion

- Colorado
- Connecticut
- Iowa
- New Hampshire
- Ohio
- Utah
- Washington

Regulatory Rule Promulgation

- Kentucky
- New Hampshire
- New Jersey
- Oklahoma
- West Virginia

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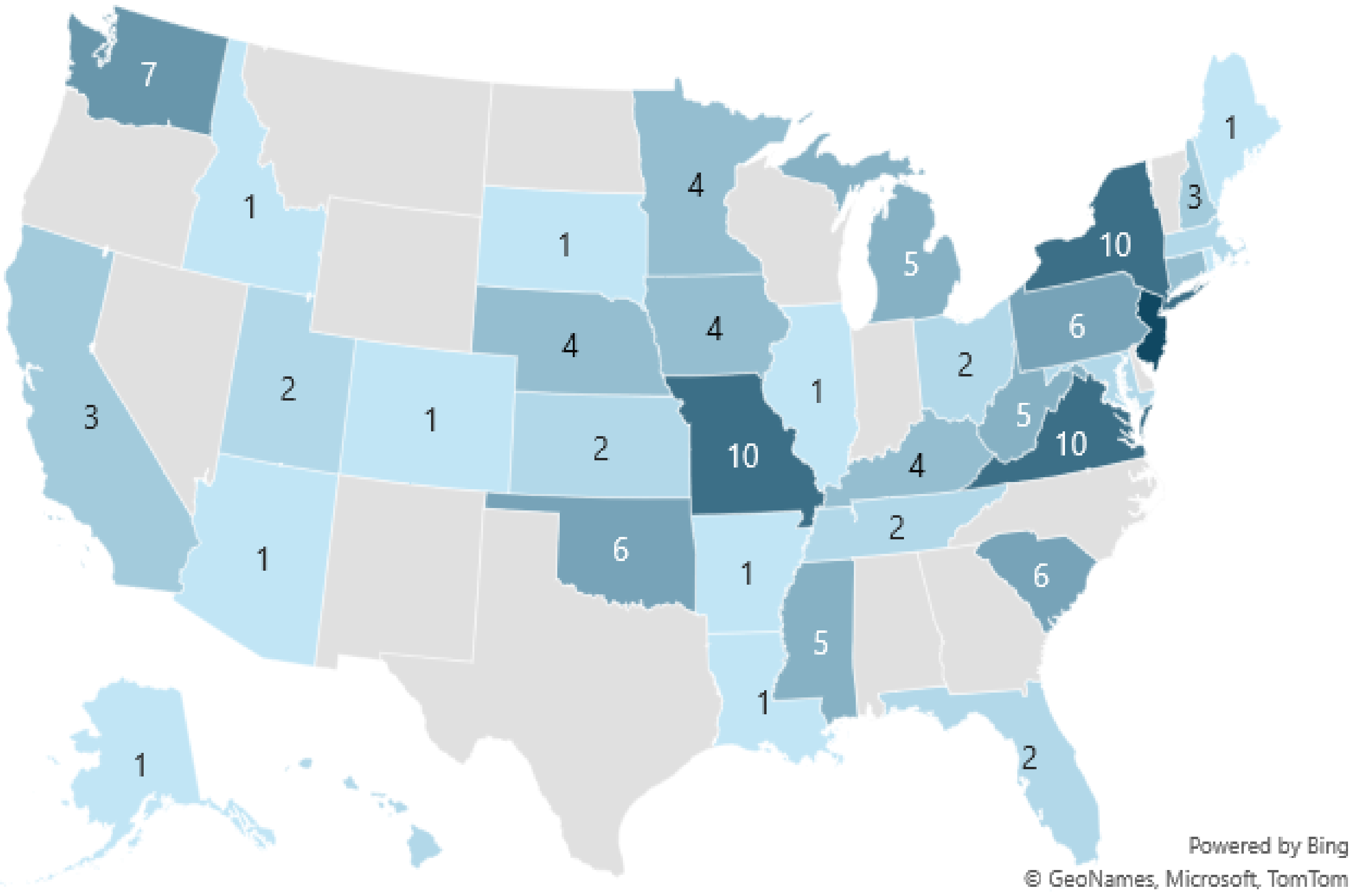
Advanced reactor legislation introduced in 2024

2024 Introduced Legislation by State

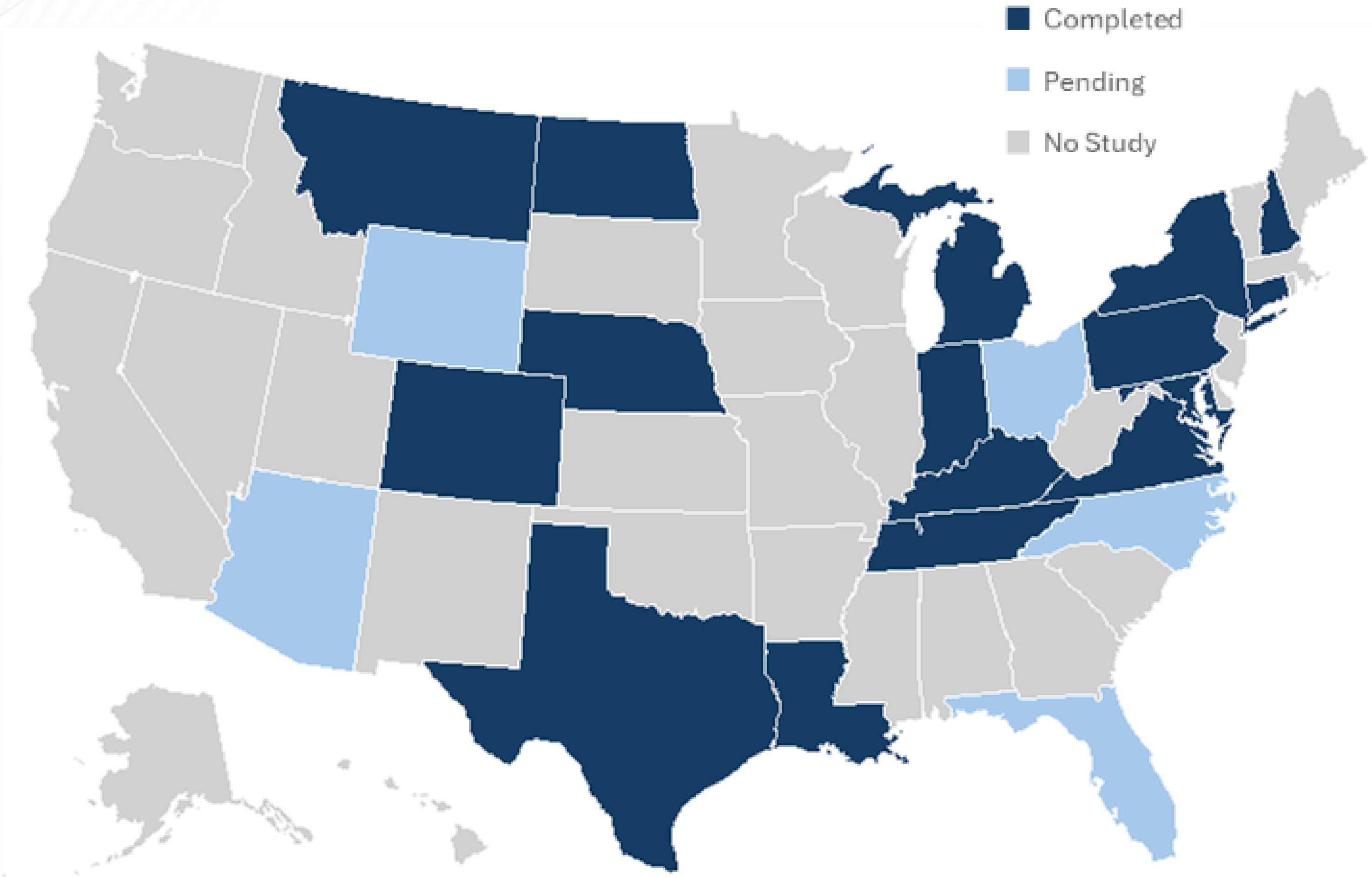


36 states

with at least one bill introduced

Montana, North Dakota, Texas, and Nevada did not have legislative sessions in 2024.

State nuclear feasibility studies and working groups



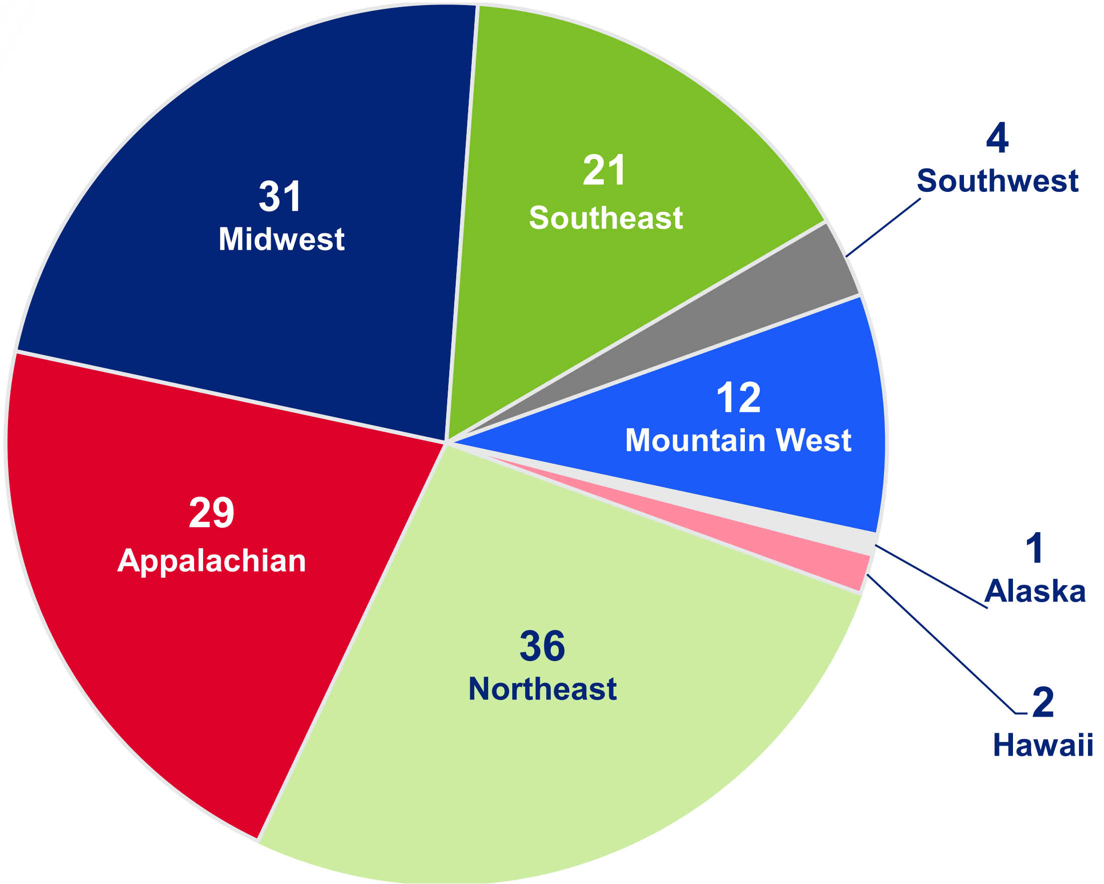
25

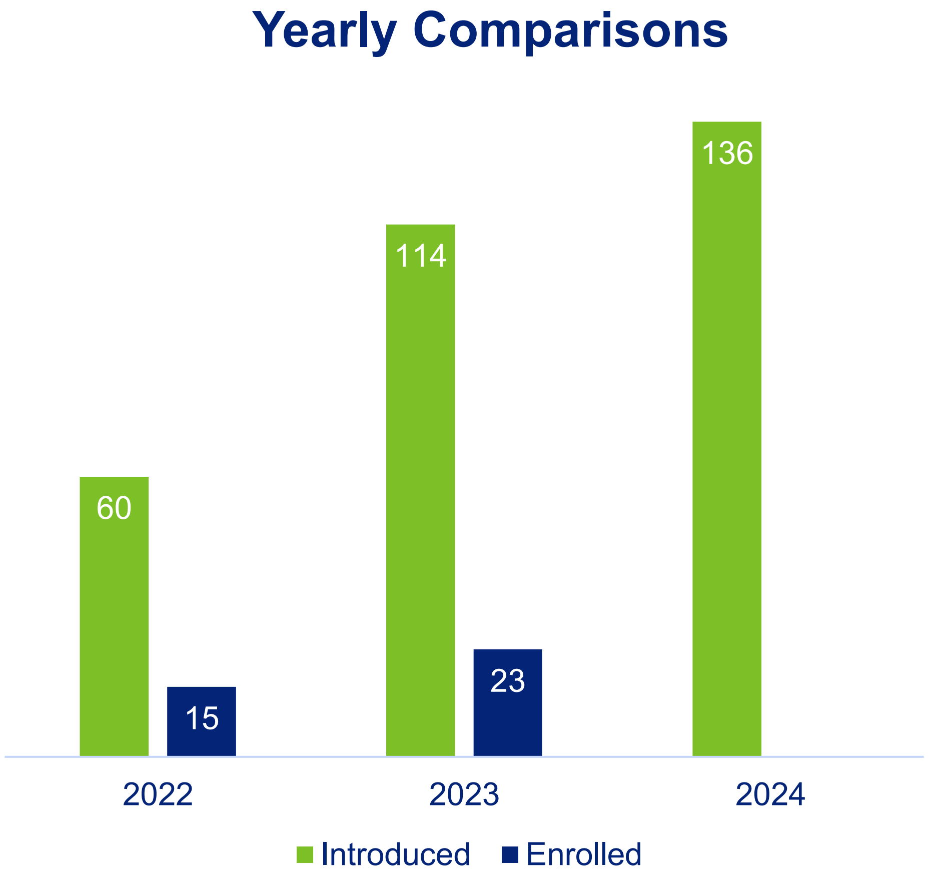
feasibility studies covering a range of topics including policy, technical, and economic analyses

- *18* complete
- *3* pending completion by summer 2025
- *4* committed studies without set due date
- Active working groups in KY, OH, and TN

2024 state nuclear legislation

- As of August 14th, 136 bills introduced in 2024 with 28 enrolled into law.





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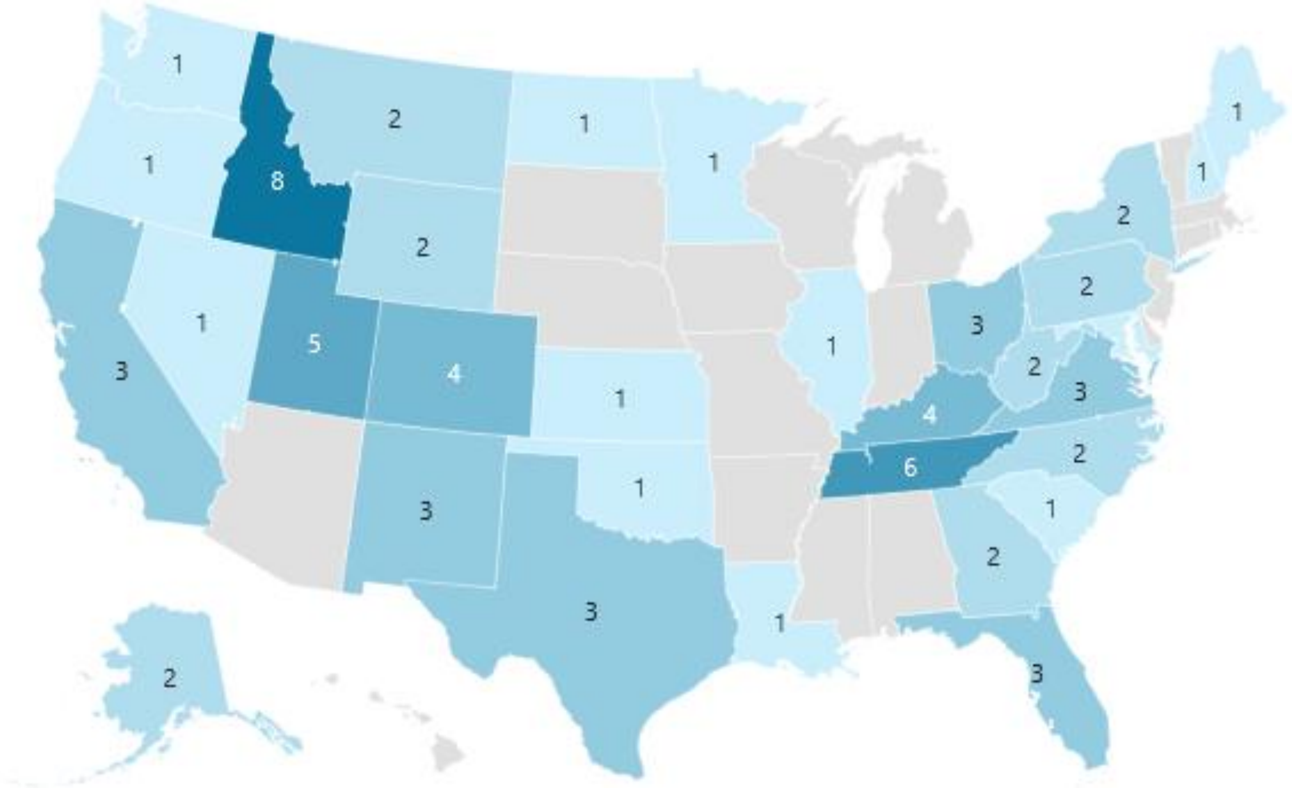
2024 state-level engagements

- GAIN works with nuclear curious states and communities around the nation as they consider advanced nuclear in their energy portfolio.



101
total engagements

52
regional, state and community

49
industry

Licensing and authorization authority

- The U.S. NRC is given "principal licensing and regulation" authority for all reactors, materials facilities, and materials licensed under the Atomic Energy Act, except as specified in AEA Section 110b or other law, including on the following types of DOE facilities:

DEMONSTRATION REACTORS
when operated to generate power for a commercial electrical utility

ANY FUEL FACILITY
under DOE contract that is specifically for the fabricated of mixed plutonium-uranium oxide fuel for use in a commercially licensed reactor

FACILITIES FOR THE RECEIPT AND STORAGE
of high-level waste resulting from licensed activities

ANY FUEL FACILITY
under DOE contract that is specifically for the fabricated of mixed plutonium-uranium oxide fuel for use in a commercially licensed reactor

DEMONSTRATION REACTORS
when operated to demonstrate the suitability of a reactor for commercial application

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Licensing and authorization authority, cont.

- The U.S. Department of Energy's development or operation of nuclear technologies are generally performed on a government-owned or -controlled site and do not provide commercial power or demonstrate the suitability of a reactor for commercial applications

A U.S. NRC license is not required for the construction or operation of facilities under contract with and for the account of the U.S. Department of Energy, e.g.,

DOE R&D REACTORS
operated by DOE and its contractors

ACTIVITIES SUPPORTING TECHNOLOGY OR FUEL
development to demonstrate technology viability or safety at DOE facilities.

Part 50 licensing process

- Two-step process, i.e., this process requires both a construction permit and an operating license

Advantages	Disadvantages
Allows field work, design and licensing to all occur in parallel	Larger risks on the part of the utility as construction starts before a detailed reactor design is complete
Could result in an earlier completion date since construction proceeds at risk	The design-as-you-build approach introduces project risks in the regulatory area since the NRC may impose additional requirements as a condition of receiving an OL
Provides flexibility in completing design and construction	Provides less finality before making a significant financial investment in plant construction
	Requires duplicative licensing and hearing requirements

Part 52 licensing process

- One-step process, i.e., this process requires a combined construction permit and operating license

Advantages	Disadvantages
Incorporates a standard design certification (approved reactor design)	Less construction flexibility
Allows early resolution of safety and environmental issues before field work begins	Potential schedule risk if significant changes to reactor design are needed later
Offers more finality in that regulatory reviews regarding suitability of site or design of the plant are not revisited prior to issuance of the COL	Later start on construction typically results in a later overall completion date

GAIN Gateway for Accelerated Innovation in Nuclear

Early Site Permits

- Early Site Permits mitigate project risk, preserve flexibility and can allow an early start of field work
- Approves a site for nuclear deployment for up to 20 years with a renewal option for an additional 10 – 20 years
- Allows a utility to make progress while technologies continue to advance

TECHNOLOGY AGNOSTIC
The reactor technology does not need to be decided

MULTIPLE TECHNOLOGIES
can be bound using a Plant Parameter Envelope

PART 50 OR PART 52
licensing pathway can be used

LIMITED WORK AUTHORIZATION
can allow site preparation activities to start while the operating license is under U.S. NRC review

ENVIRONMENTAL IMPACT STATEMENT
included as a part of the Early Site Permit

Microreactor regulations

- Based on size and transportability, the timeline for licensing a microreactor may be shorter because of the smaller EPZ, less seismic constraints and shorter environmental review
- Target is six months
- Regulatory costs targeted to be less than 1% of total costs

CHALLENGES

Creating a rapid repeatable licensing process

Adapting the regulatory approach so that the review process considers similarities and is not overburdened by each technology while providing reasonable assurance of health and safety of the public and environment

Establishing performance-based and graded approached based on the advanced reactor design

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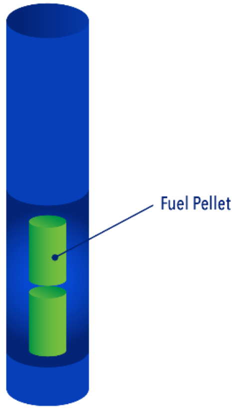
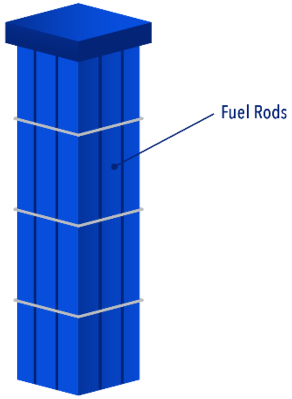
Spent Nuclear Fuel 101

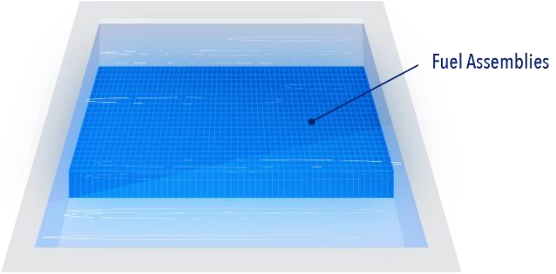
Fuel Rod



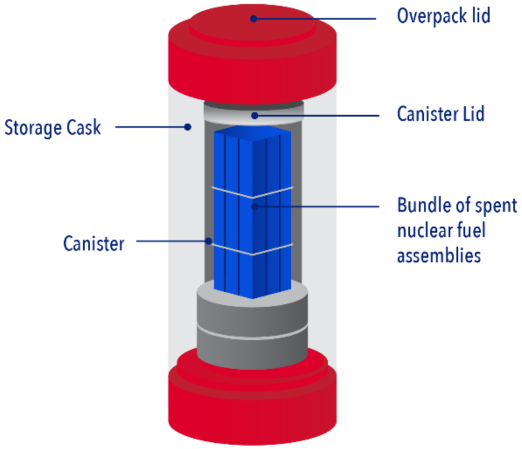
Fuel Assembly



Storage Pool



Dry Cask



IN THE REACTOR

- Small ceramic uranium pellets are stacked inside metal tubes, called fuel rods.
- Fuel rods are bundled together into fuel assemblies that are placed inside the nuclear reactor.

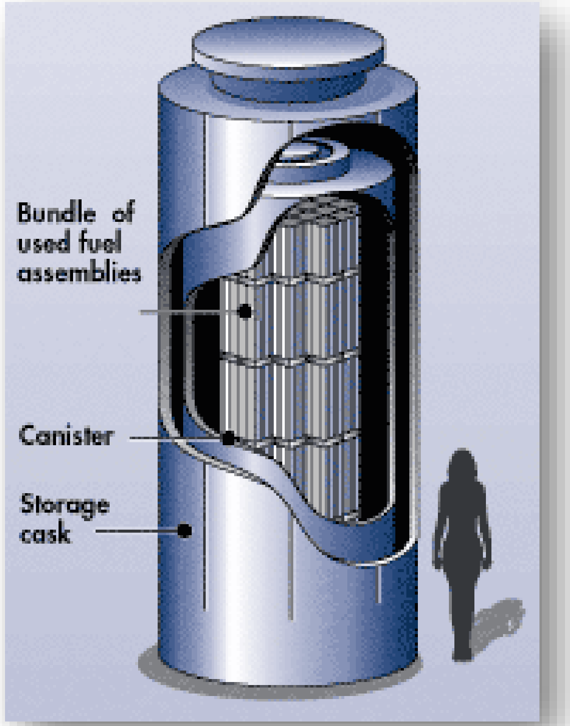
AFTER USE

- Assemblies are moved underwater from the reactor to a storage pool located inside or next to the reactor building
- While the fuel cools, the water in the pool shields workers from radiation emitted from the spent nuclear fuel.

FIVE+ YEARS LATER

- Spent nuclear fuel assemblies are transferred from the pool to dry storage casks.
- The casks are designed and certified to provide radiation shielding.

On-site storage of used fuel

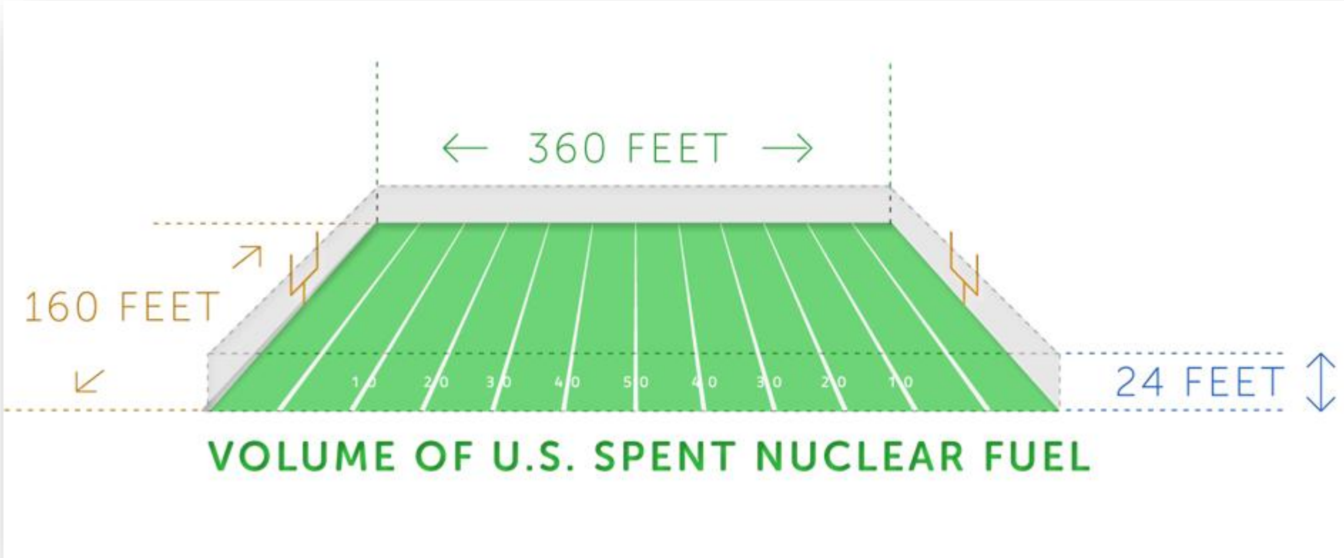


The 57 used fuel casks hold all the fuel from 49 years of the DC Cook Plant in Michigan operations. Both units at DC Cook are still operating.

Spent nuclear fuel

- Spent nuclear fuel is a solid material composed of uranium and fission products.
- The total amount of commercial spent nuclear fuel accumulated in the US since the first reactor started up in 1957 would fit in an area the size of a football field stacked 10 yards high.

A spent nuclear fuel pellet
(about the size of a gummy bear)



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Reprocessing

- The spent nuclear fuel from Gen II, III, and III+ reactors consist of ≥5% spent fuel, (fission products) and ≥95% unspent fuel (useable uranium). Spent nuclear fuel reprocessing, which the U.S. has decades of experience with, allows us to use this unspent fuel
- Currently, small modular reactor manufacturer Oklo and SHINE Technologies are pursuing spent nuclear fuel recycling. France has been reprocessing for 50 years.
- Spent nuclear fuel from EBR-II is being reprocessed to produce HALEU for Oklo's first reactor
- If the regulations supported reprocessing the remaining amount of
- may result in a 95% reduction in total waste – the size of a football field stacked 30 feet high
- There are two processes for recycling – pyroprocessing and PUREX

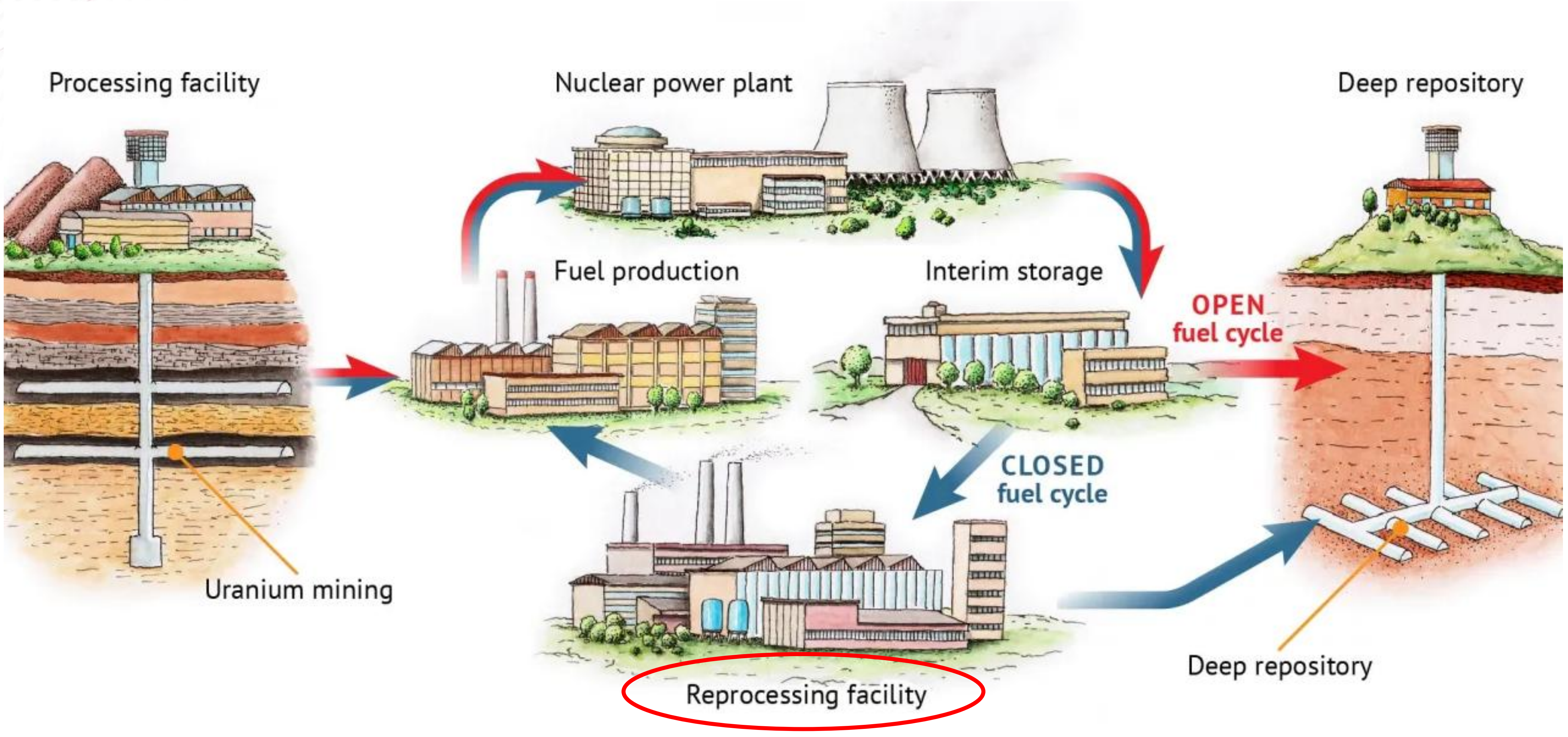
95 percent

The amount of useable uranium still left in spent nuclear fuel

All unspent fuel in this waste could power the U.S. for over

200 years

Reprocessing and the fuel cycle



"Solving the waste problem" and closing the fuel cycle

- An established once-through fuel cycle exists in the U.S.
- Fully closed fuel cycle will still require a final geological repository.
- Reprocessing capabilities exist, e.g., France
  - Options for advanced reprocessing and recycling at various stages of development, making it challenging to implement on industrial scale

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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