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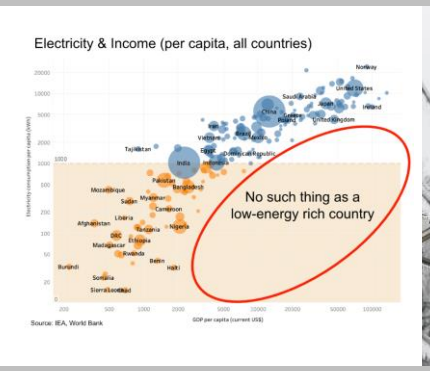
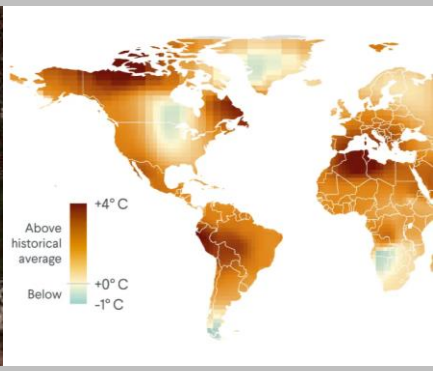
INAC 2024 Round Table:

Ongoing projects and near-future opportunities and challenges

Idaho National Laboratory

Idaho National Laboratory (INL) - Addressing the world's most pressing challenges through research, development, and demonstration





VISION

To change the world's energy future and secure our nation's critical infrastructure.

MISSION

Discover, demonstrate and secure innovative nuclear energy solutions, clean energy options and critical infrastructure.

VALUES

Excellence, Inclusivity, Integrity, Ownership, Teamwork, Safety

Our Heritage: *The National Reactor Testing Station drove nuclear innovation in the U.S. and around the world*

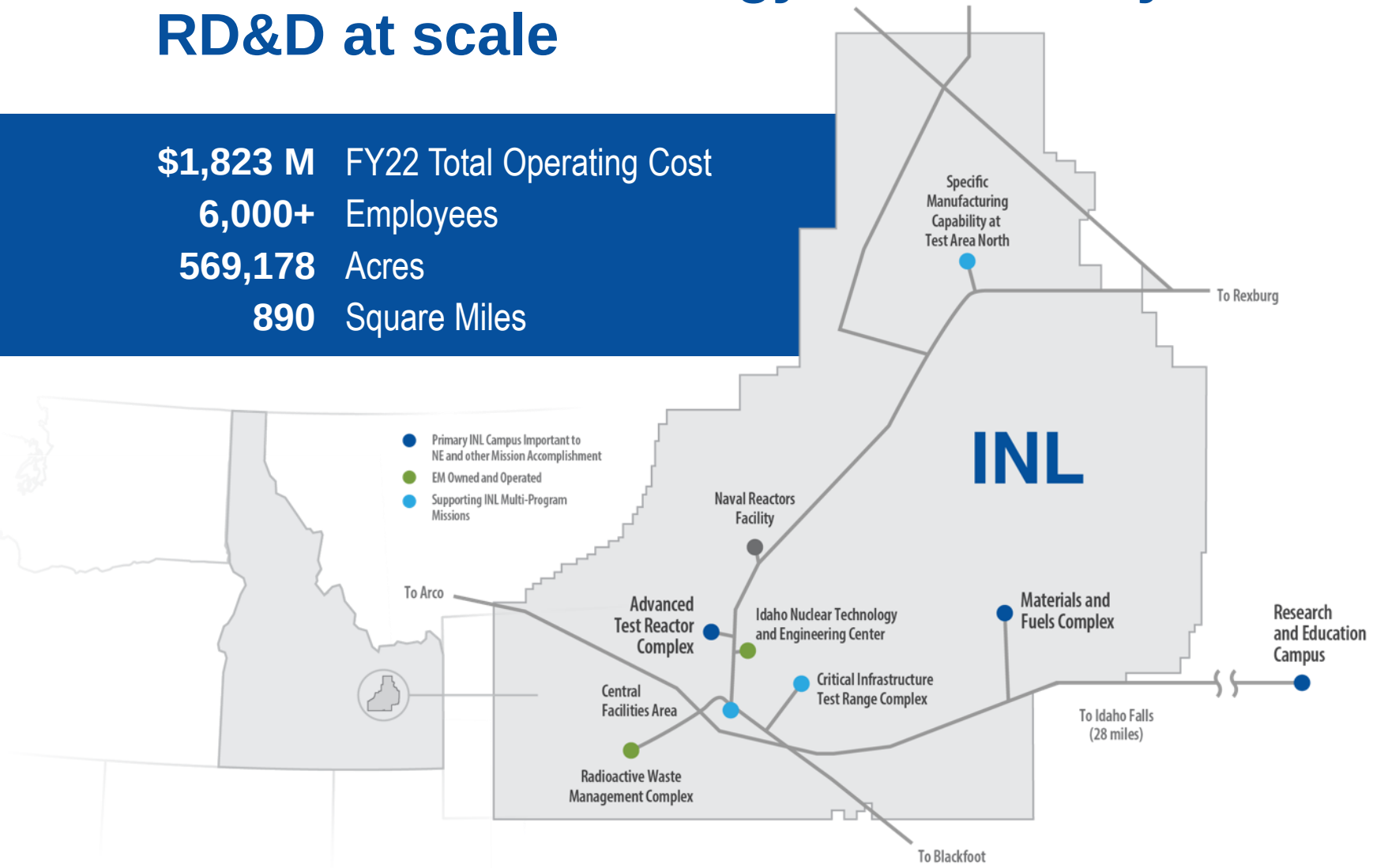
1st

- Nuclear power plant
- U.S. city to be powered by nuclear energy
- Submarine reactor tested; training of nearly 40,000 reactor operators until mid-1990s
- Mobile nuclear power plant for the army

Demonstration of self-sustaining fuel cycle	Basis for LWR reactor safety	Aircraft and aerospace reactor testing	Materials testing reactors

Unique INL site, infrastructure, and facilities enable energy and security RD&D at scale

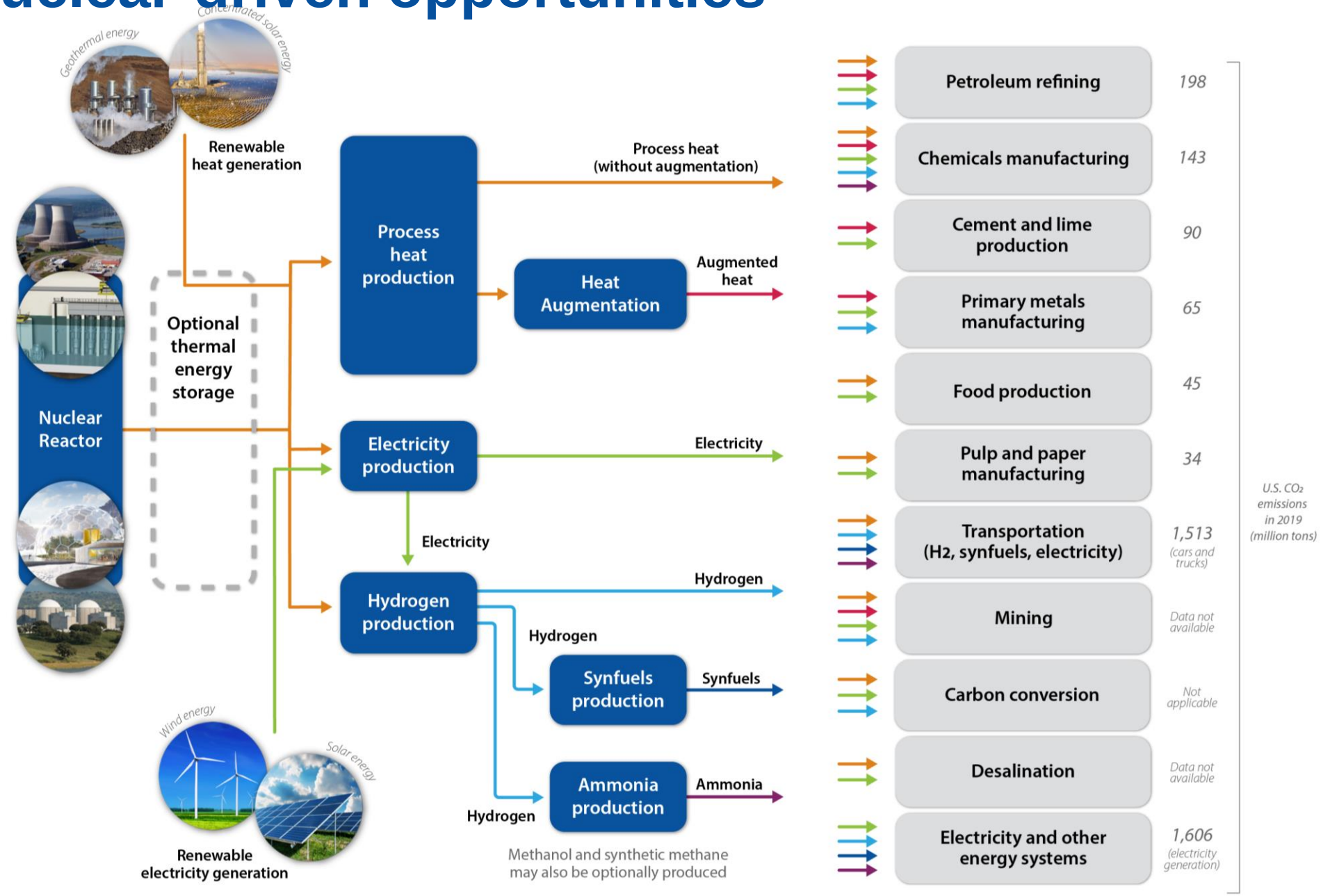
$1,823 M	FY22 Total Operating Cost
6,000+	Employees
569,178	Acres
890	Square Miles



4	Operating reactors
12	Hazard Category II & III non-reactor facilities/ activities
50	Radiological facilities/activities
17.5	Miles railroad for shipping nuclear fuel
44	Miles primary roads (125 miles total)
9	Substations with interfaces to two power providers
126	Miles high-voltage transmission lines
3	Fire Stations

Potential nuclear-driven opportunities

Reactor sizes align with the needs of each application; heat augmentation can be applied if needed to match process temperature demands.



Source: Adapted from INL, *National Reactor Innovation Center (NRIC) Integrated Energy Systems Demonstration Pre-Conceptual Designs*, April 2021

Advanced Reactors by Coolant

Includes only companies that are engaged in formal licensing or pre-licensing activities with the Nuclear Regulatory Commission for power-producing reactors.

- HALEU (High-assay low-enriched uranium is 5-20% U-235)
- Fast neutron reactor

GAS: Gas is used to transfer heat from the core. Helium is favored because it is inert and does not react with other materials or deteriorate components.

Micro Modular Reactor (3.5-15 MWe)
- Fuel: TRISO
- Company: Ultra Safe Nuclear Corp.

Fast Modular Reactor (44 MWe)
- Fuel: Uranium oxide
- Company: General Atomics

Xe-100 (80 MWe per module)
- Fuel: TRISO
- Company: X-energy

Energy Multiplier Module (265 MWe)
- Fuel: Uranium carbide
- Company: General Atomics

WATER: Highly purified water carries heat from the reactor core.

VOYGR (77 MWe per module)
- Fuel: Uranium oxide
- Company: NuScale Power

SMR-160 (160 MWe)
- Fuel: Uranium oxide
- Company: Holtec International

BWRX-300 (300 MWe)
- Fuel: Uranium oxide
- Company: GE-Hitachi

AP300 (300 MWe)
- Fuel: Uranium oxide
- Company: Westinghouse

MOLTEN SALT: Melted (or molten) salt transfers the heat, which has a high boiling point, so the reactors can run at higher temperatures and lower pressures. Fuel can be in the salt or in solid form.

Fluoride Salt-Cooled High-Temperature Reactor (140 MWe)
- Fuel: TRISO (solid fuel)
- Company: Kairos Power

Integral Molten Salt Reactor (195 MWe)
- Fuel: Uranium molten fluoride
- Company: Terrestrial Energy

Molten Chloride Fast Reactor (310 MWe)
- Fuel: Molten salt
- Company: TerraPower

LIQUID METAL: Liquid metal, often sodium or lead, transfers the heat in these reactors. Liquid metals do not slow down neutrons and are typically used for fast neutron reactors.

Aurora (15 MWe)
- Fuel: Uranium metal alloy
- Company: Oklo

ARC-100 (100 MWe)
- Fuel: Uranium metal alloy
- Company: ARC Clean Technology

Natrium (345 MWe)
- Fuel: Uranium metal alloy
- Company: TerraPower

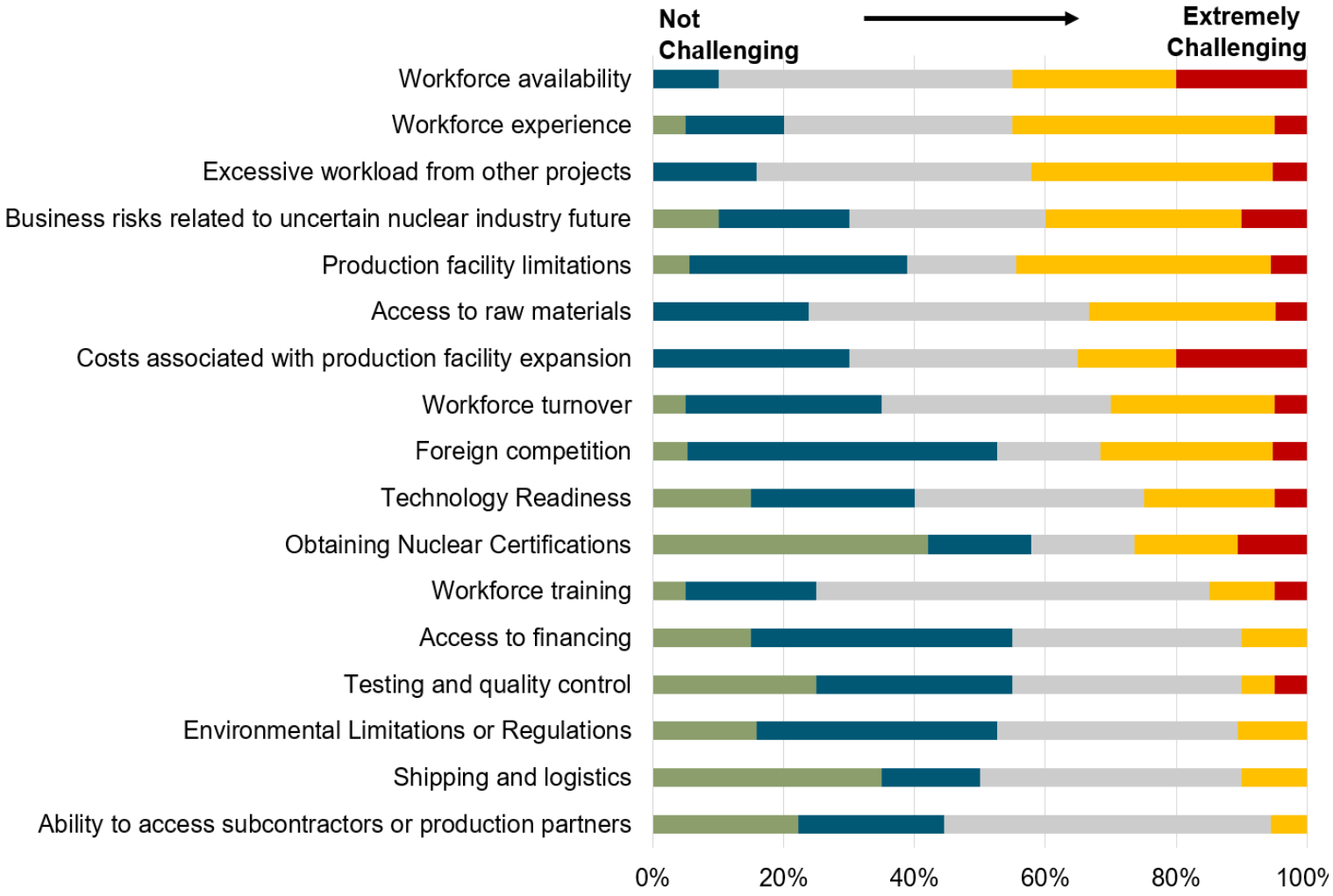
HEAT PIPES: Heat pipes made from steel alloys transfer heat away from the reactor core with no moving parts.

eVinci (5 MWe)
- Fuel: TRISO
- Company: Westinghouse

Significant reactor deployment faces technical, geopolitical, policy, and economic challenges

SMR Challenges in the U.S.

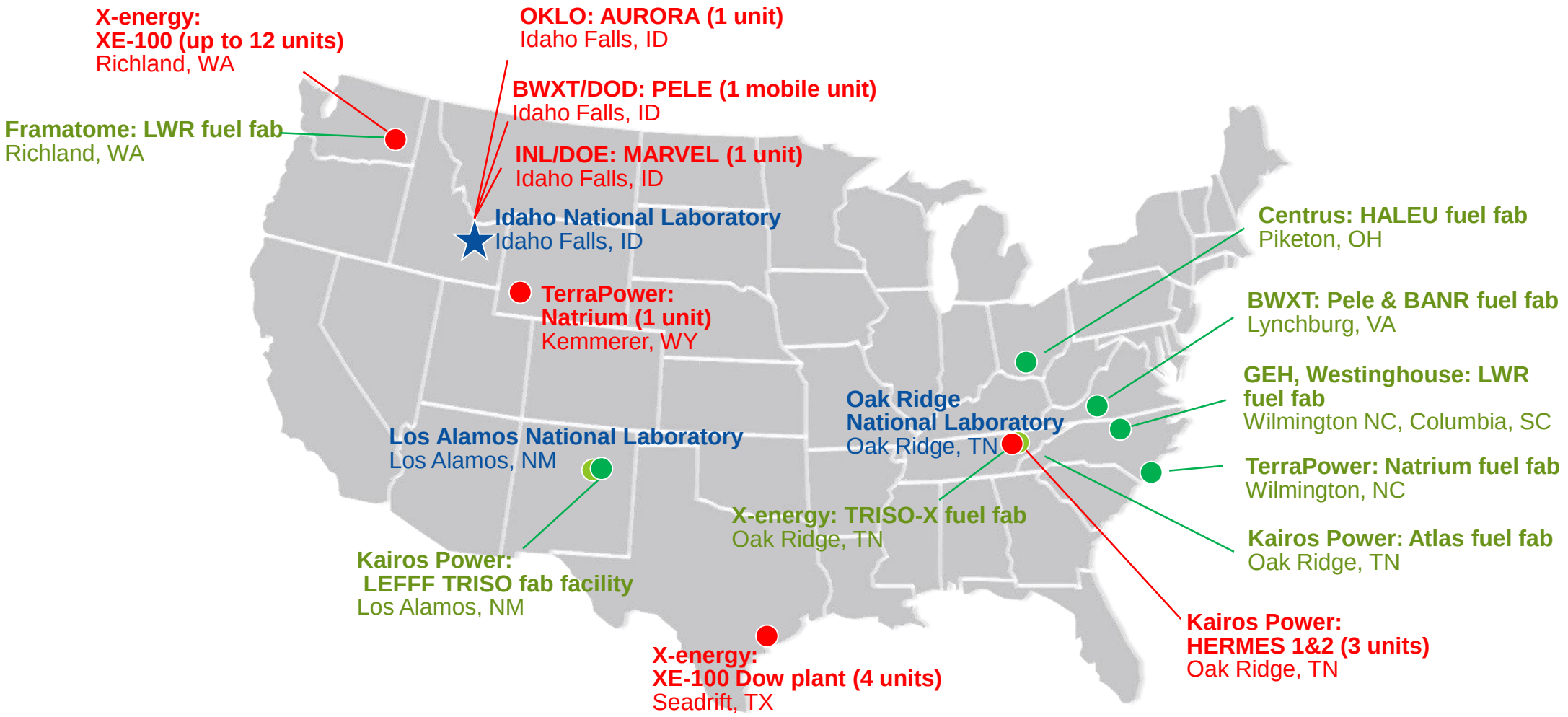
- *Supply chain:* reactor vessel, graphite helium, salts
- *Fuel:* HALEU availability, fuel qualification (fabrication, irradiation, PIE)
- *Licensing:* NRC or DOE authorization
- *Siting:* Permits, community interactions, transmission lines
- *Workforce:* GAIN survey report



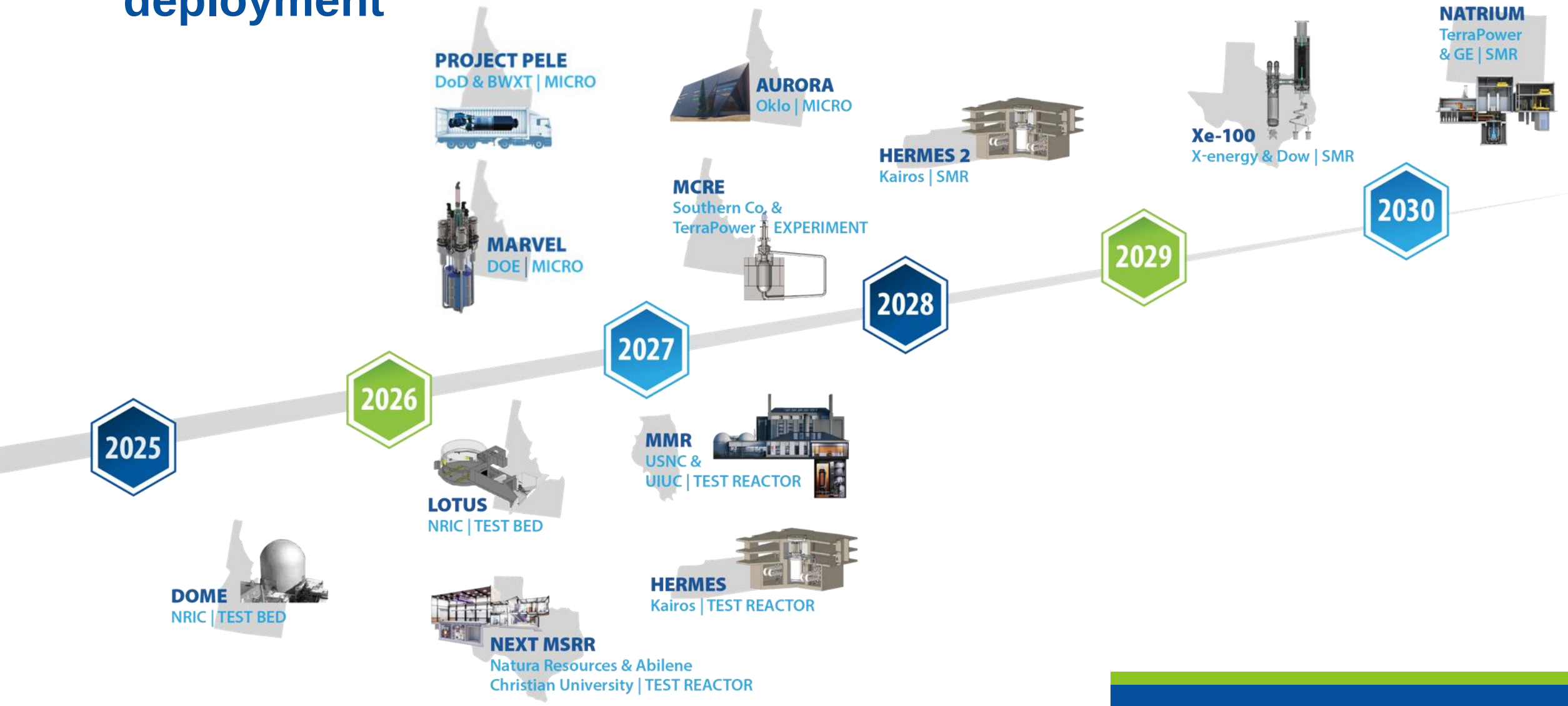
"GAIN Advanced Reactor Supply Chain Assessment": https://www.osti.gov/biblio/1973747.

What more needs to be done in the U.S.?

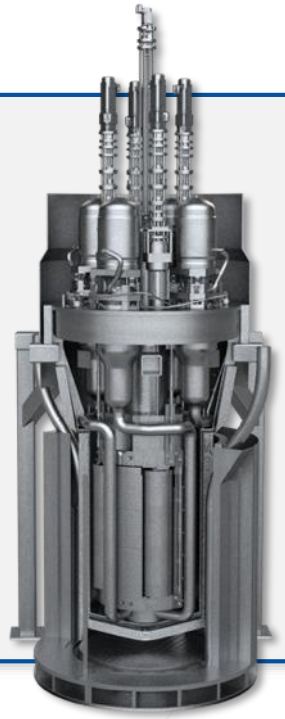
U.S. SMR Projects: Reactors and Fuel Fabrication Facilities



Accelerating U.S. advanced reactor demonstration & deployment

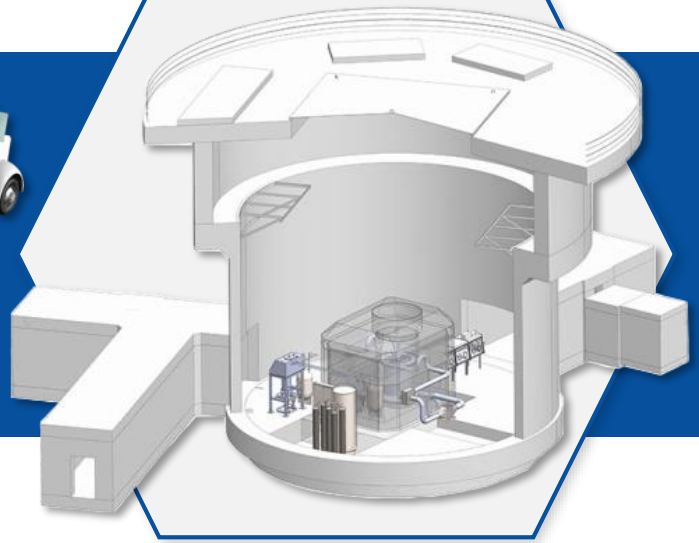


Over the next several years, we will demonstrate the first new reactors on the INL site in over 40 years



Microreactor Application Research, Validation and EvaLuation Project *(MARVEL)*

Department of Defense Strategic Capabilities Office Project Pele



Molten Chloride Fast Reactor Experiment *(MCRE)*

Obrigado! / Thank you!

IDAHO NATIONAL LABORATORY

75TH ANNIVERSARY

Battelle Energy Alliance manages INL for the U.S. Department of Energy's Office of Nuclear Energy. INL is the nation's center for nuclear energy research and development, and also performs research in each of DOE's strategic goal areas: energy, national security, science and the environment.

INL Idaho National Laboratory | www.inl.gov

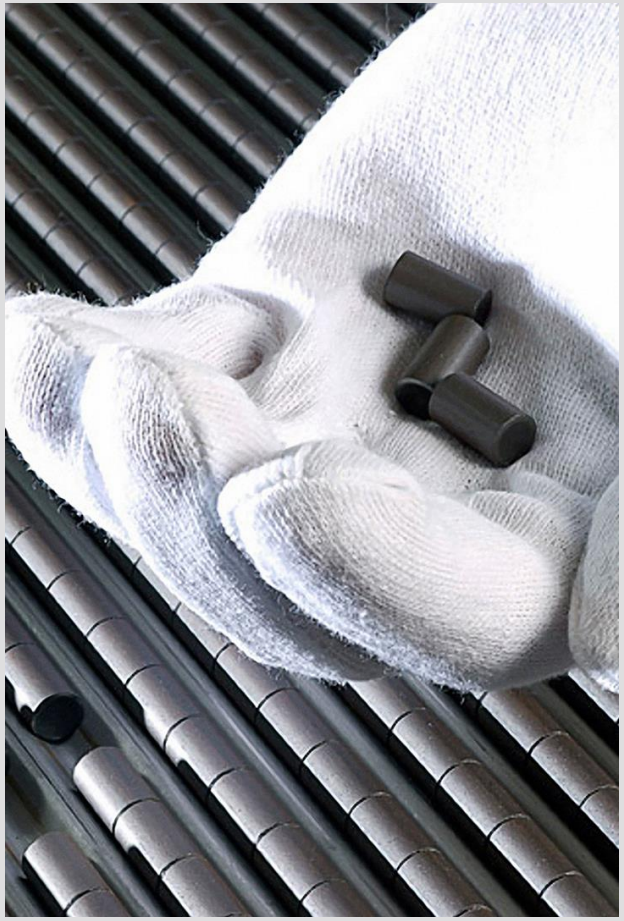
Backup Slides

One uranium fuel pellet (about 10 g) creates as much energy as:

1 URANIUM FUEL PELLET

HAS AS MUCH ENERGY AS

- **17,000** CUBIT FEET OF NATURAL GAS
- **149** GALLONS OF OIL
- **1** TON OF COAL

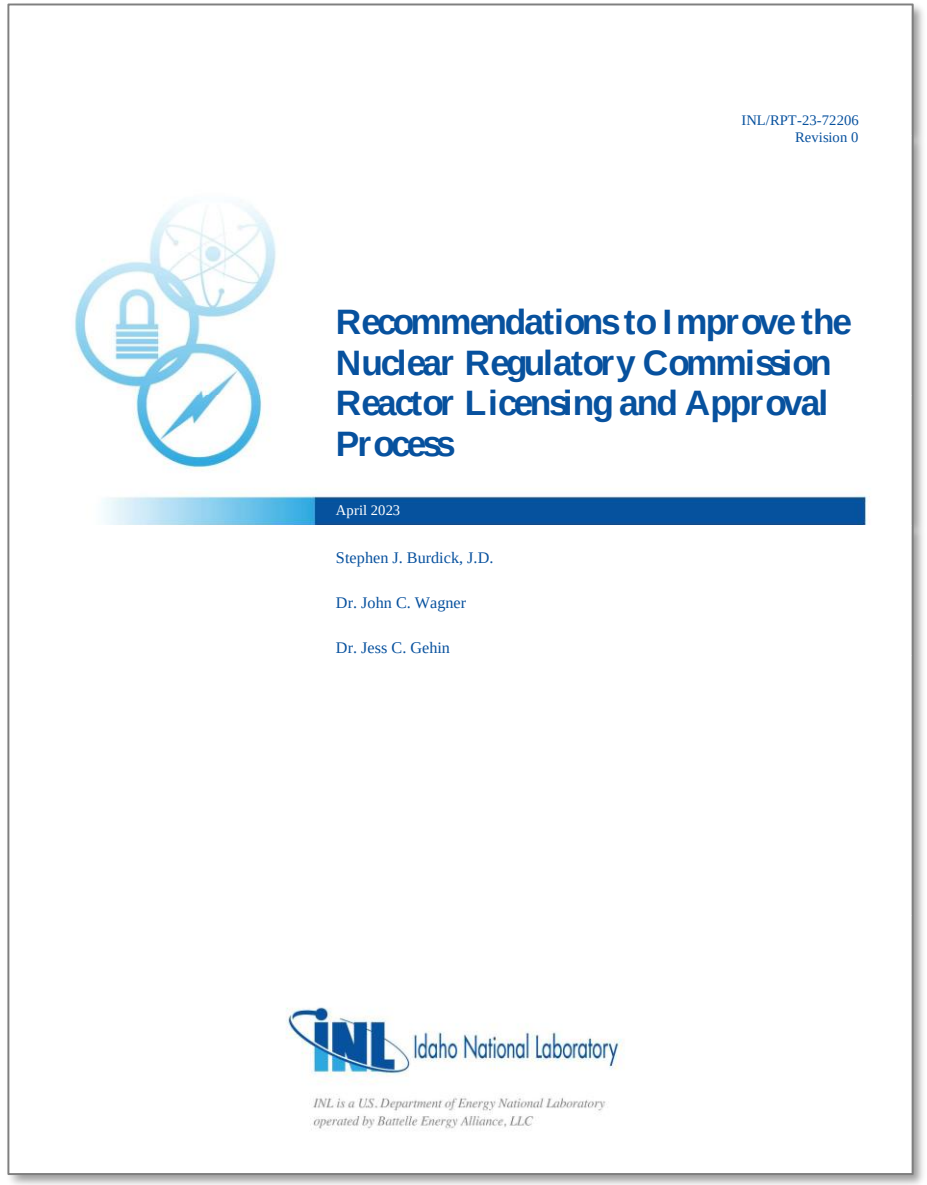


Regulatory Certainty

- Concerns about long regulatory review and burdens periods could impact schedule.
- NuScale 50 MWe design first SMR design certification
- Kairos Power test reactor construction license approved
- Developers engaging in pre-licensing activities with NRC and in Canada with CSNC

Approaches to Address:

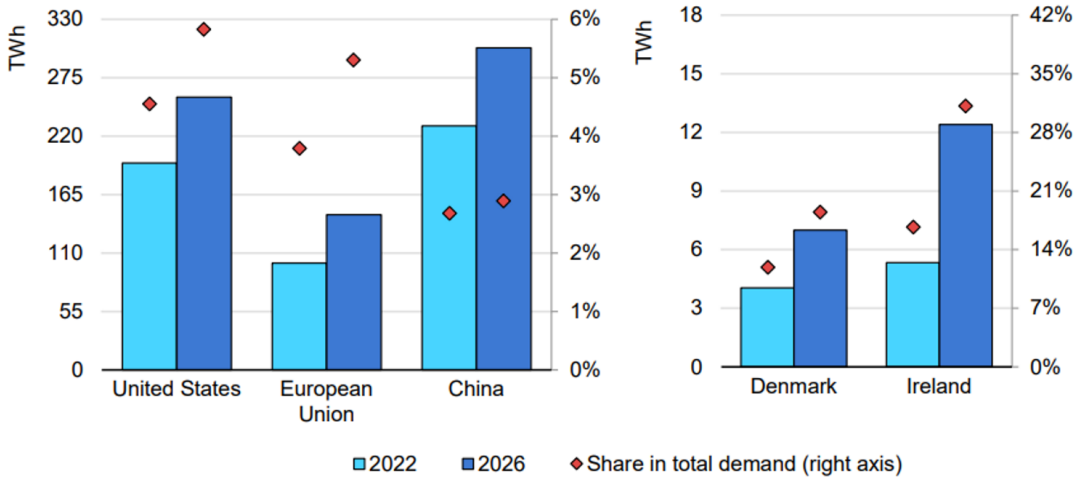
- NRC working on new rule “Part 53” to create technology-neutral licensing framework
- ADVANCE Act being pursued in Congress to increase regulatory certainty
- INL recommendations to improve regulatory process



Transforming our energy system provides an opportunity for a secure and resilient clean energy future

Demand for new nuclear goes beyond traditional baseload electricity supply to a centralized grid.

- Current nuclear plants are utility-owned, large one-gigawatt units that supply baseload electricity to a centralized grid.
- To help decarbonize energy generation, new plants must be more flexible and service different users such as
  - microgrids
  - data centers
  - energy-intensive industrial processes
  - desalination plants.
- A few key characteristics of new reactors:
  - Ability to integrate with other renewable energy sources (ex: solar, wind)
  - Provide heat along with (or instead of) electricity
  - Ability to be co-located with the end user
  - Smaller thermal output (~ 1 – 300 MW range instead of GW)



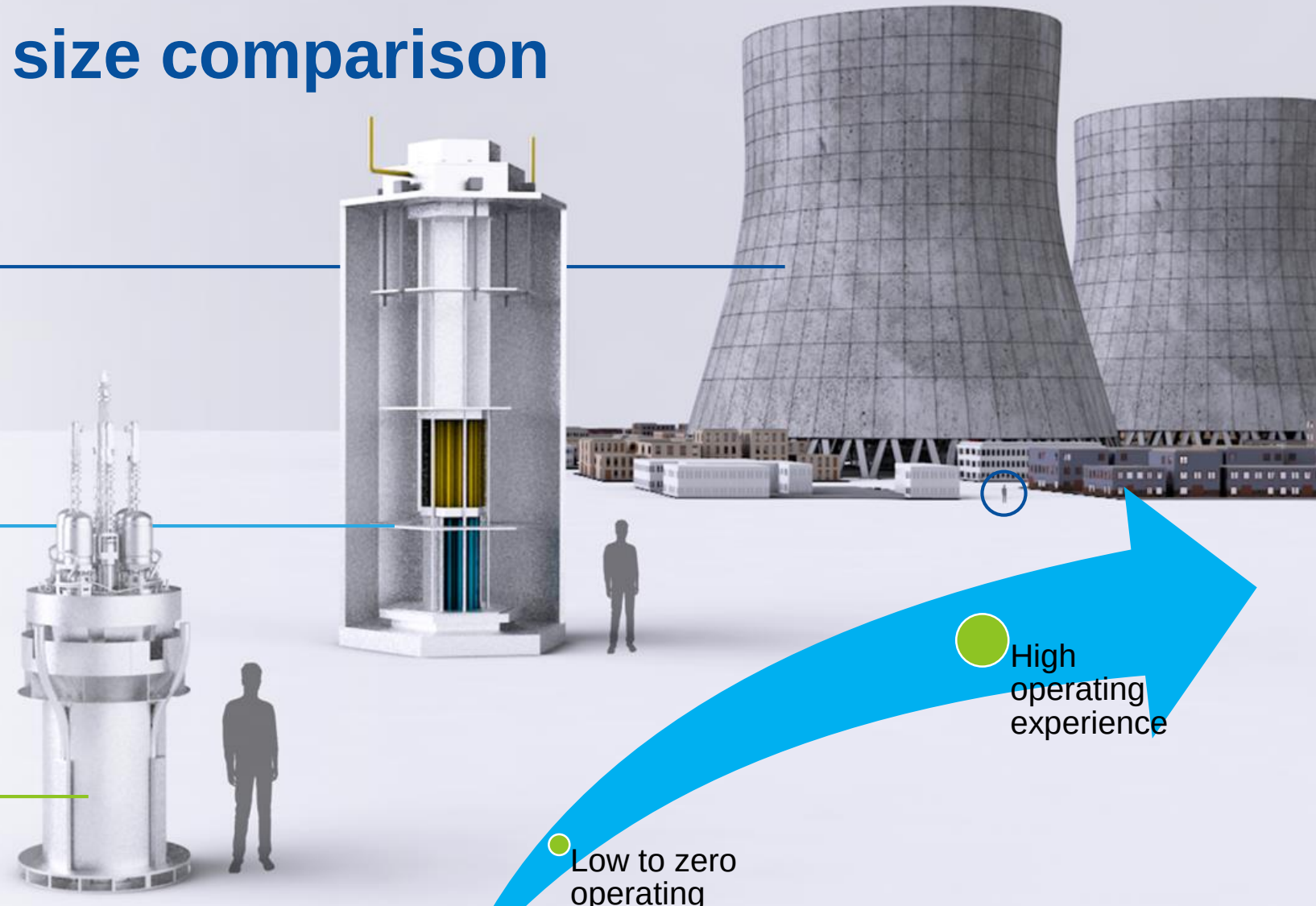
Data centers look to nuclear to meet rising power needs.
Source: Reuters; April 2024

Advanced reactor size comparison

Large-Scale Reactor
300 MW – 1,000+ MW
1,500 ACRES
(607 HECTARES)
EZ*: 10 MILES (16 km)

Small Modular Reactor
20 MW – 300 MW
50 ACRES
(20 HECTARES)
EZ: 0.19 MILES (0.3 km)

Microreactor
1 MW – 20 MW
LESS THAN AN ACRE
(LESS THAN 0.4 HECTARE)
EZ: less than 1 acre / 0.4 hectare



*EZ: Emergency Zone

Cost and Schedule Challenges for First of a Kind Systems

- Vogtle units cost and schedule overruns, Olkiluoto in Finland
- Inflation and supply chain issues increasing costs and schedules

Approaches to Address

- Size nuclear to meet specific needs to reduce capital costs (micro, SMR, large)
- Order and build multiple units to reduce costs through learning and shared infrastructure
- AP1000 has 6+ orders and interest expressed by US Utilities
- Strong interest also in Canada, Poland, Romania, UK, emerging interest in many countries

- U.S. Government stimulating nuclear deployment to levelized support for nuclear:
  - Advanced Reactor Demonstration Program
  - BIL – Civil nuclear credit program to address plant shutdowns
  - IRA – Production Tax Credits and Investment Tax Credits
  - IRA – Hydrogen hubs – 3 of 8 hubs involve nuclear.
  - Loan Programs Office has authority to support reactor and facilities for nuclear energy

Advanced Reactors by Size

Includes only companies that are engaged in formal licensing or pre-licensing activities with the Nuclear Regulatory Commission for power-producing reactors.

- HALEU (High-assay low-enriched uranium is 5-20% U-235)
- Fast neutron reactor

Up to ~50 MWe

Micro Modular Reactor (3.5-15 MWe)
Company: Ultra Safe Nuclear Corp.
Coolant: Gas (helium)
Fuel: TRISO

eVinci (5 MWe)
Company: Westinghouse
Coolant: Heat pipes
Fuel: TRISO

Aurora (15 MWe)
Company: Oklo
Coolant: Metal (sodium)
Fuel: Uranium metal alloy

Fast Modular Reactor (44 MWe)
Company: General Atomics
Coolant: Gas (helium)
Fuel: Uranium oxide

MICROREACTORS

- 1 MWe can power a big-box superstore
- Factory fabricated, readily transportable
- Minimal on-site staffing

10s to mid-100s of MWe

VOYGR (77 MWe per module)
Company: NuScale Power
Coolant: Water
Fuel: Uranium oxide

Xe-100 (80 MWe per module)
Company: X-energy
Coolant: Gas (helium)
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Coolant: Metal (sodium)
Fuel: Uranium metal alloy

Molten Chloride Fast Reactor (310 MWe)
Company: TerraPower
Coolant: Salt (chloride)
Fuel: Molten salt

SMALL AND MEDIUM ADVANCED REACTORS

- 100 MWe can power about 100,000 U.S. homes
- Flexible operation to meet demand
- Major components factory fabricated
- Can add modules as demand increases
- Reduced construction times

22-50375-R16 (Updated Oct. 2023)

Example: United Arab Emirates – Barakah Plant

Nuclear in the news

- 20+ countries launched the Declaration to Triple Nuclear Energy at UN Climate Conference COP28
- Plant Vogtle units 3 and 4 are now operating in U.S.
- Due to strong market conditions, three new uranium mines opened in Arizona and Utah in 2023.
- Canada announces ambitious nuclear construction plans.
- Great British Nuclear drives UK nuclear revival.
- Wave of international agreements and contracts
  (U.S. - Philippines; Poland).

U.S. domestic nuclear capacity has the potential to scale from ~100 GW in 2023 to ~300 GW by 2050

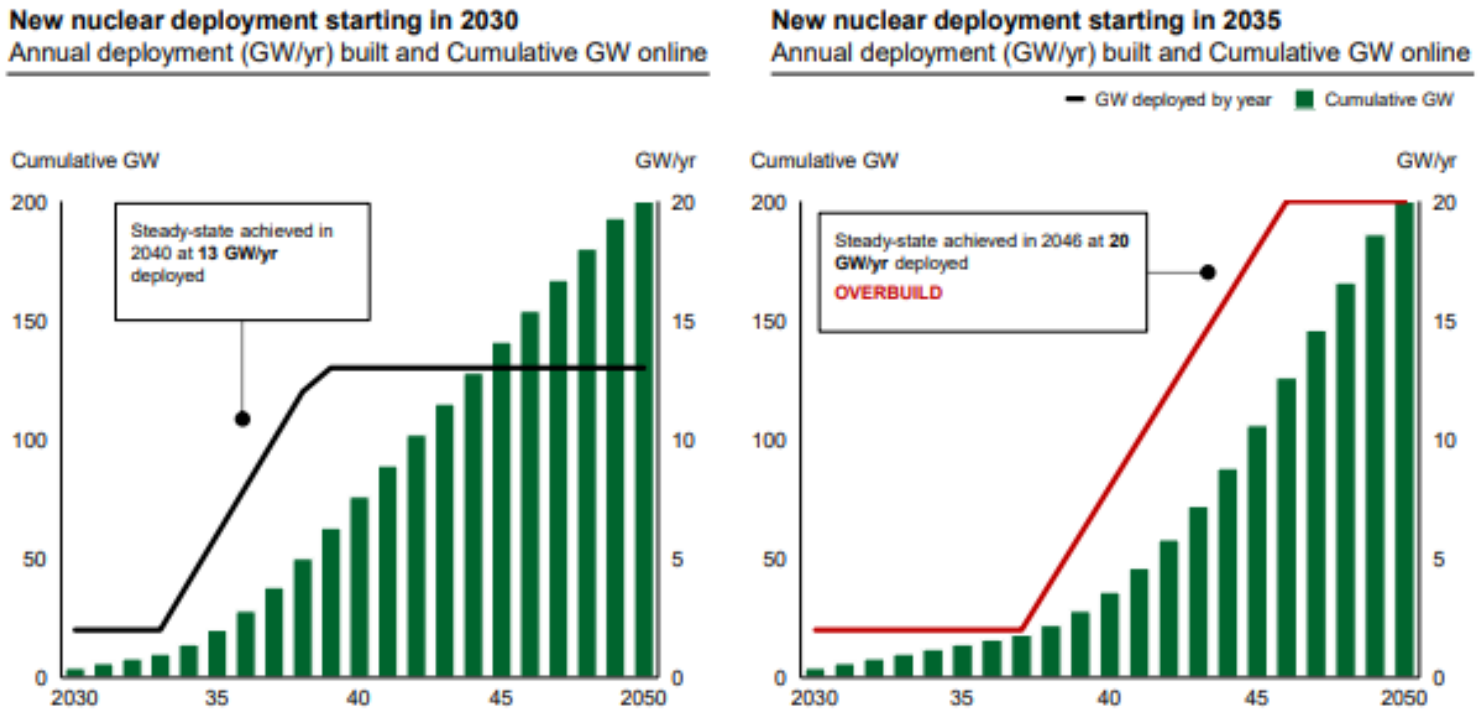
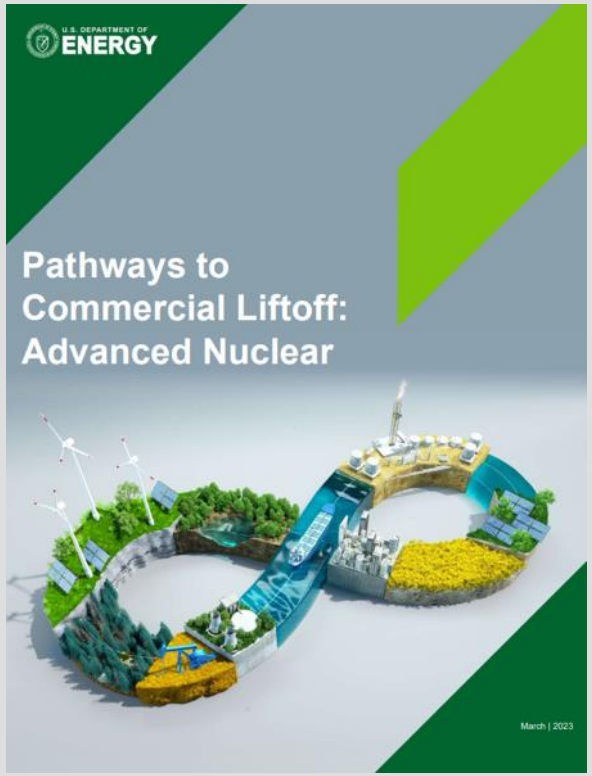


Figure 1: New nuclear build-out scenarios and implications for industrial base capacity requirements



"Power system decarbonization modeling, regardless of level of renewables deployment, suggests that the U.S. will need ~550–770 GW of additional clean, firm capacity to reach net-zero."