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Leveraging Nuclear Energy for Emissions-Free Heat and Power

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Battelle Energy Alliance manages INL for the
U.S. Department of Energy's Office of Nuclear Energy

Idaho National Laboratory

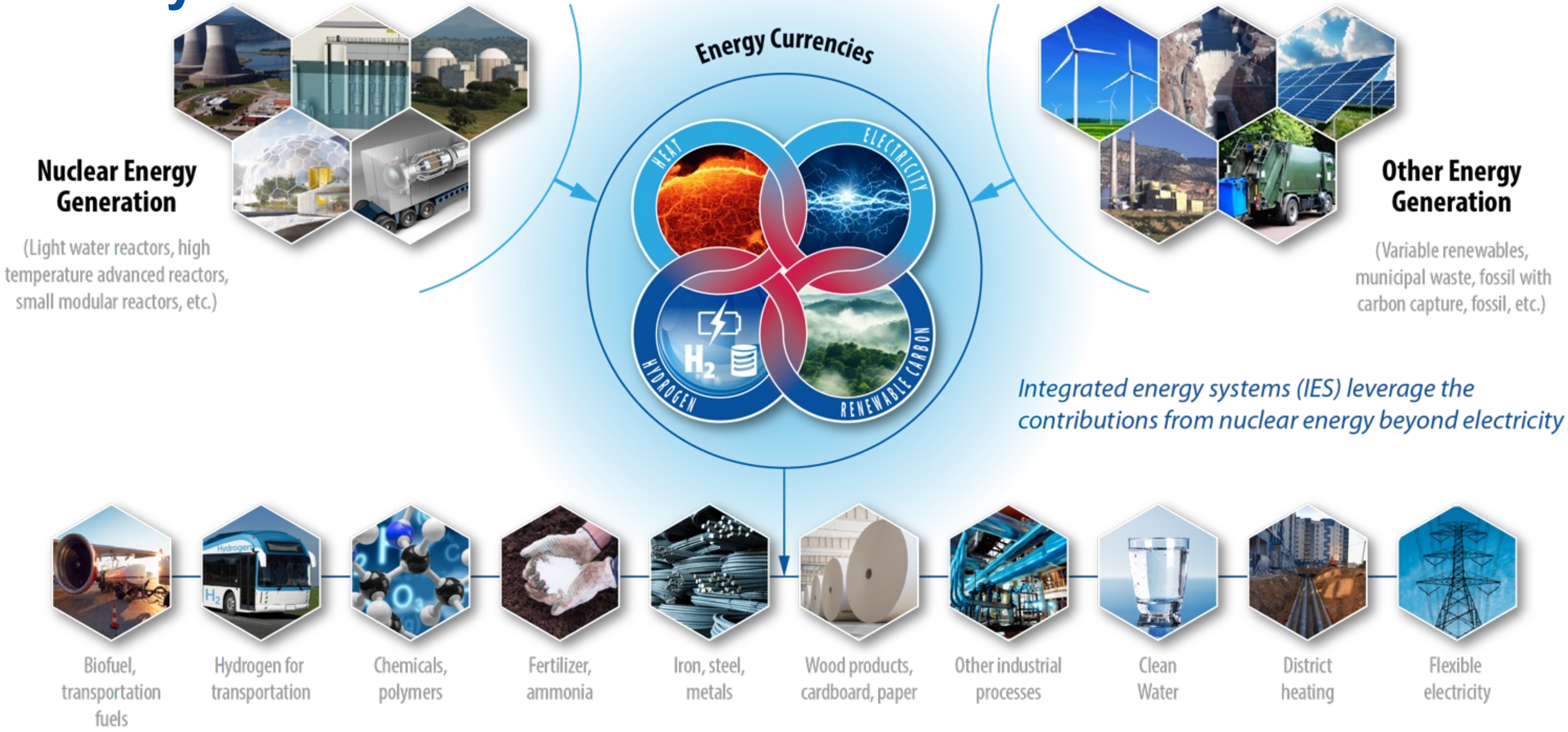
Reduced from INL/CON-24-77543

Key challenges to deep decarbonization

- Providing clean, non-emitting electricity on a dispatchable basis
- Replacing the high-quality heat that is currently provided by fossil fuels to many industrial processes
- Developing a non-emitting source for a key energy carrier (i.e., hydrogen) that can support applications across all energy use sectors, including industry and transportation
- Maintaining reliability, resilience, and affordability

Nuclear energy, working alongside renewables, can meet these decarbonization challenges.

Nuclear energy offers multiple opportunities to decarbonize industry



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

*Energy storage includes electrical batteries, chemicals and thermal storage.

The U.S. Department of Energy is doubling down on the commitment to clean energy

- Energy Earthshots™ will accelerate breakthroughs of more abundant, affordable, and reliable clean energy solutions within the decade. They will drive the major innovation breakthroughs that we know we must achieve to solve the climate crisis, reach our 2050 net-zero carbon goals, and create the jobs of the new clean energy economy. (https://www.energy.gov/policy/energy-earthshots-initiative)

IES can have direct impact on achieving at least three of the DOE Earthshot Goals

Hydrogen Shot ← Goal: <\$1/kg clean H_2 by 2031; Clean H_2: <4 kg CO_2/kg H_2

Long Duration Storage Shot

Carbon Negative Shot

Enhanced Geothermal Shot

Floating Offshore Wind Shot

Industrial Heat Shot ← Goal: 85% lower industrial GHG emissions by 2035

Clean Fuels & Products Shot ← Goal: >85% reduction in GHG emissions by 2035

Affordable Home Energy Shot

ENERGY earthshots U.S. DEPARTMENT OF ENERGY

Historical Examples of Nuclear Energy Use for Non-Grid Applications

Past Experience—Use of Nuclear Heat

- **Over 750 reactor-years of experience – accounts for less than 0.5% of the total nuclear thermal output of over 440 reactors**
  - Mostly water-cooled reactors

- ***District Heating:*** 43 reactors, ~500 reactor years
  - Average 5% thermal output; range 5 to 240 MWth
  - Typically, <150º C
- ***Desalination of water:*** 17 reactors, ~250 reactor years
  - Mostly using thermal processes (multi-effect distillation and multi-stage flash), <130º C
- **Industrial Process Heat:** 7 reactors
  - Typically based on medium pressure steam, <250ºC

IAEA - "Opportunities for Cogeneration with Nuclear Energy" NP-T-4.1, 2017

IAEA - "Guidance on Nuclear Energy Cogeneration" NP-T-1.17, 2019

NEA – "Beyond Electricity: The Economics of Nuclear Cogeneration", 2022

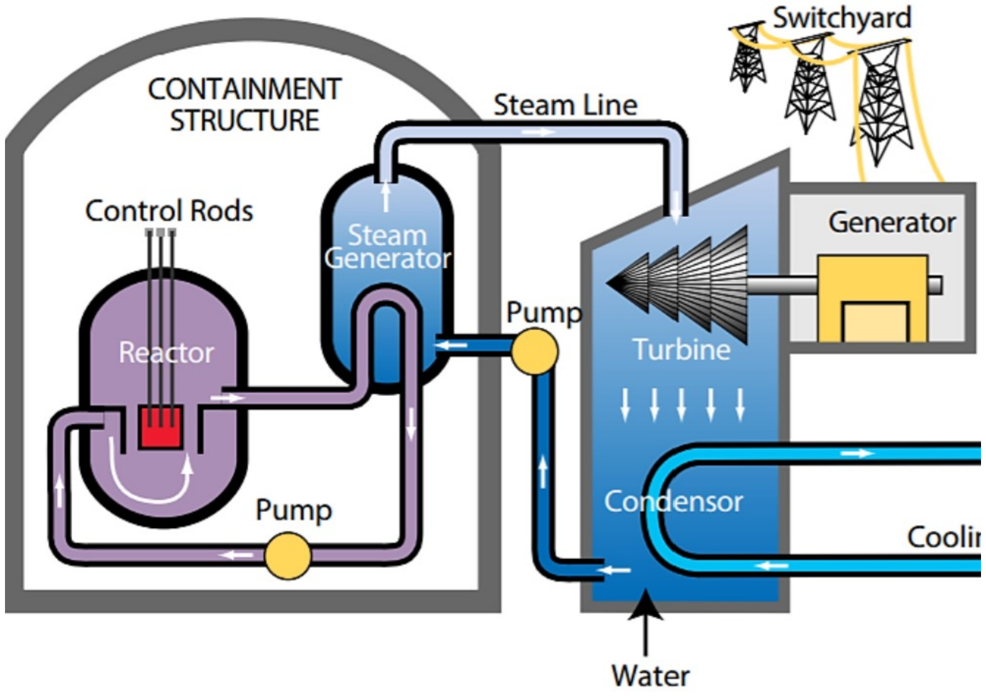
Examples of past experience in *operational* nuclear cogeneration

summarized by Gen-IV International Forum signatory countries

- UK Calder Hall Magnox (heat supported onsite nuclear fuel plant, shut down in 2003)
- Norway Halden BWR (steam for the Saugbrugs paper factory, shut down in 2018)
- Switzerland Gösgen PWR (transport of steam over 2 km to a cardboard factory)
- Canada Bruce A CANDU (district and industrial heating, cogeneration stopped in 1997)
- Germany Stade PWR (heat to a salt refinery, nuclear plant shut down in 2003)
- Switzerland Beznau (district heating)
- Multiple Eastern European countries (district heating)
- >200 reactor-years operating experience with seawater desalination (mostly Japan, India, Kazakhstan; MSF, MED, RO technologies)
- Recent example: Haiyang Nuclear Power Plant, China, district heating to Haiyang City (2021), desalination planned

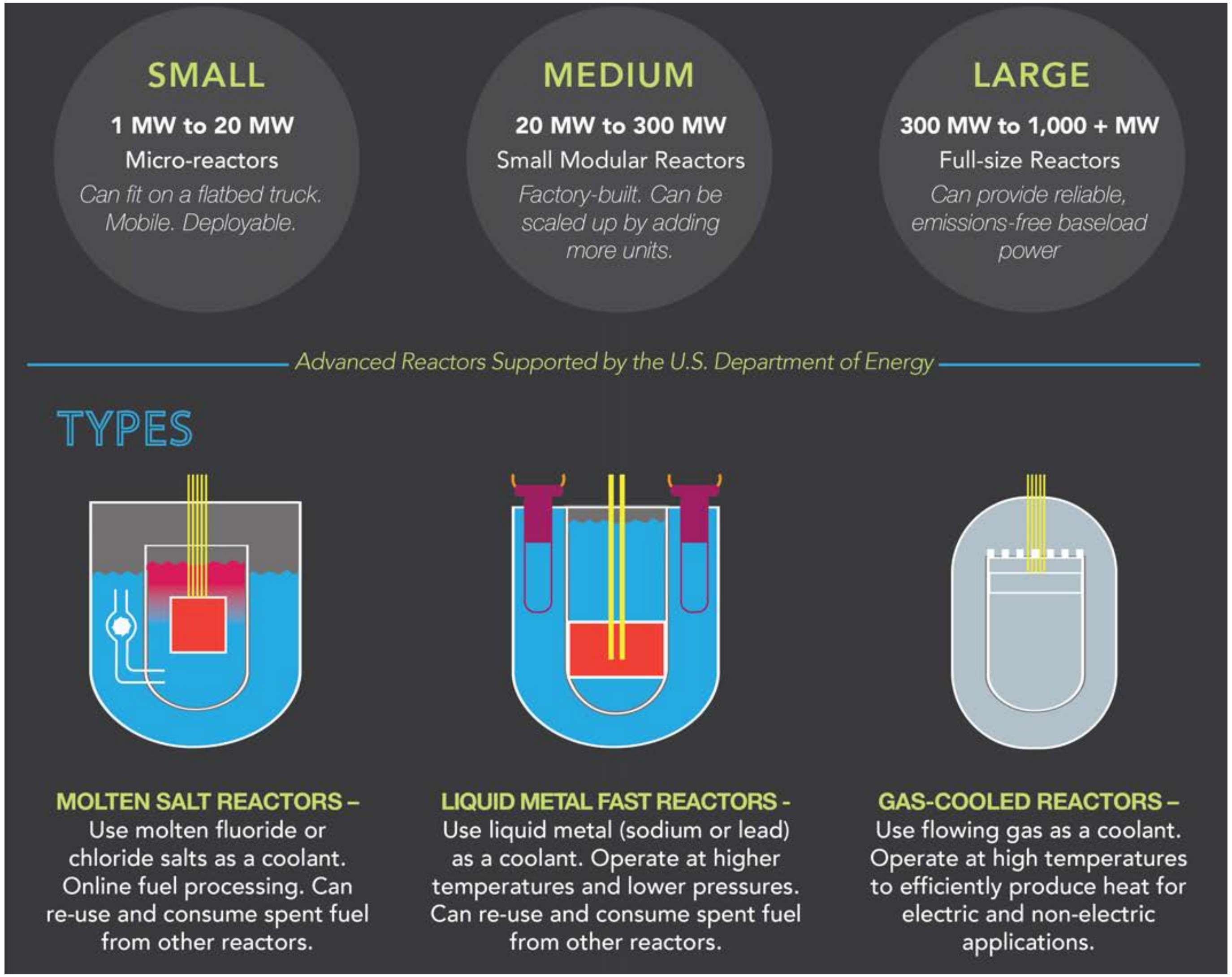
See Summary Report from the *GIF NEANH Virtual Workshop and Information Exchange on Development of Cogeneration Applications of Gen IV Nuclear Technologies*, July 2022.

Nuclear reactor designs—traditional and advanced



Light Water Reactor: Primary system coolant is water

https://www.linquip.com/blog/nuclear-power-plant-guide/

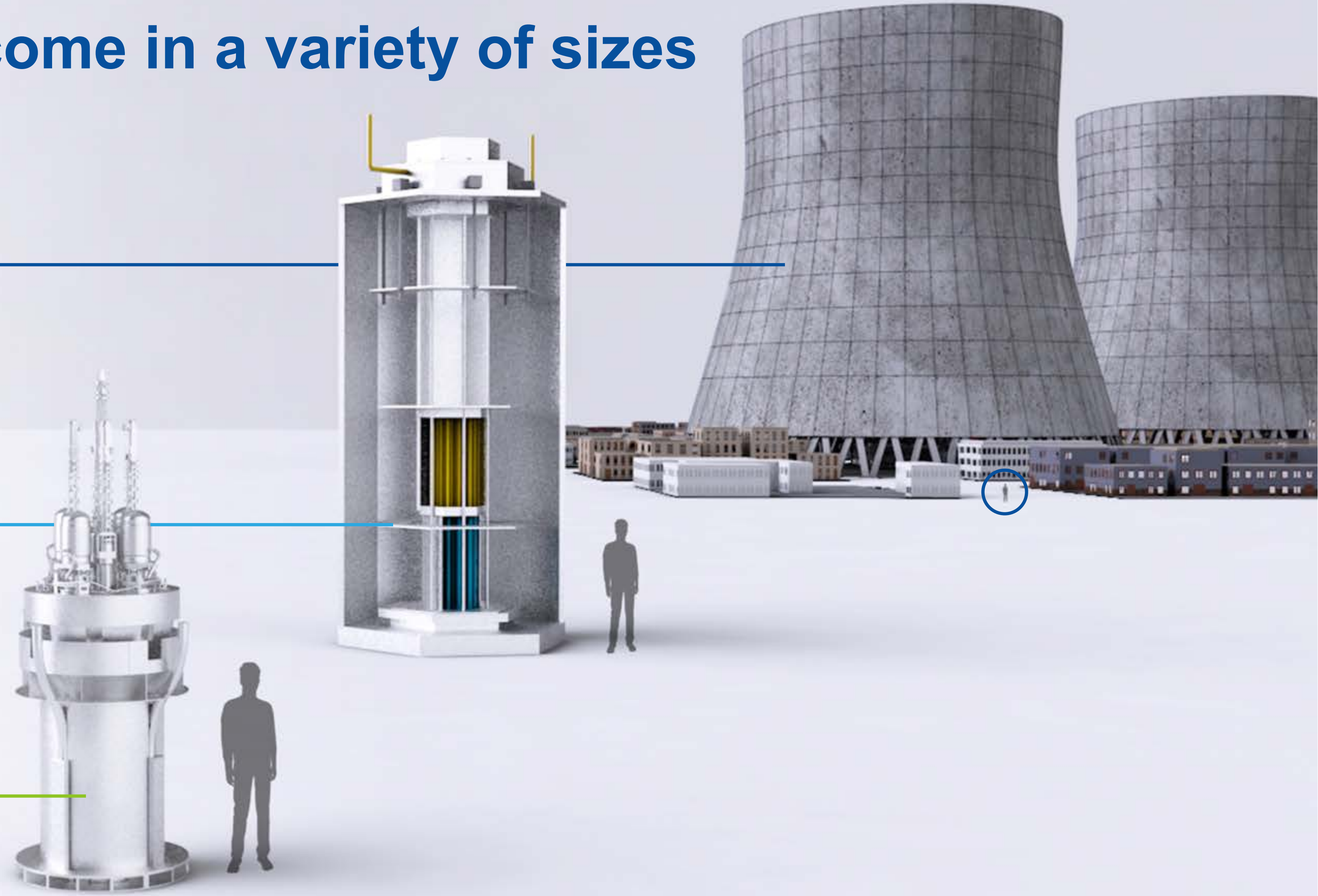


Advanced reactors come in a variety of sizes

Large-Scale Reactor
300 MW – 1,000+ MW
1,500 ACRES

Small Modular Reactor
20 MW – 300 MW
50 ACRES

Microreactor
1 MW – 20 MW
LESS THAN AN ACRE

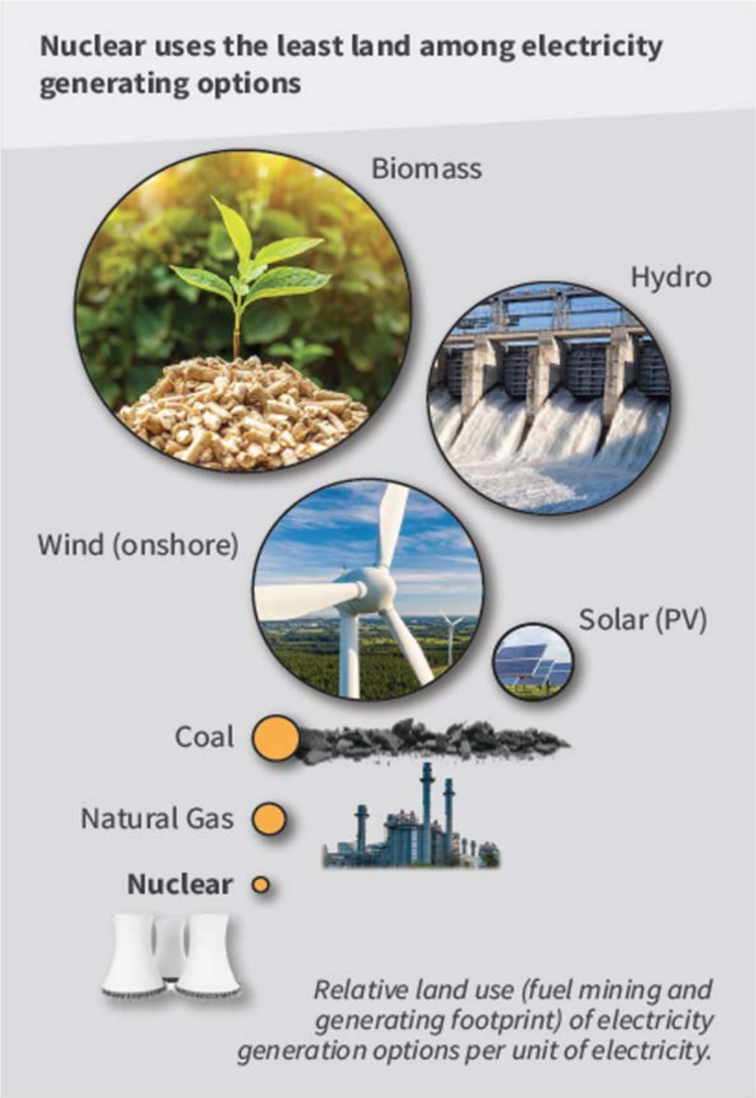


Deployment flexibility

IES

Integrated Energy Systems

Artist renditions courtesy of GAIN and Third Way, inspired by the *Nuclear Energy Reimagined* concept led by INL. Learn more about these and other energy park concepts at thirdway.org/blog/nuclear-reimagined

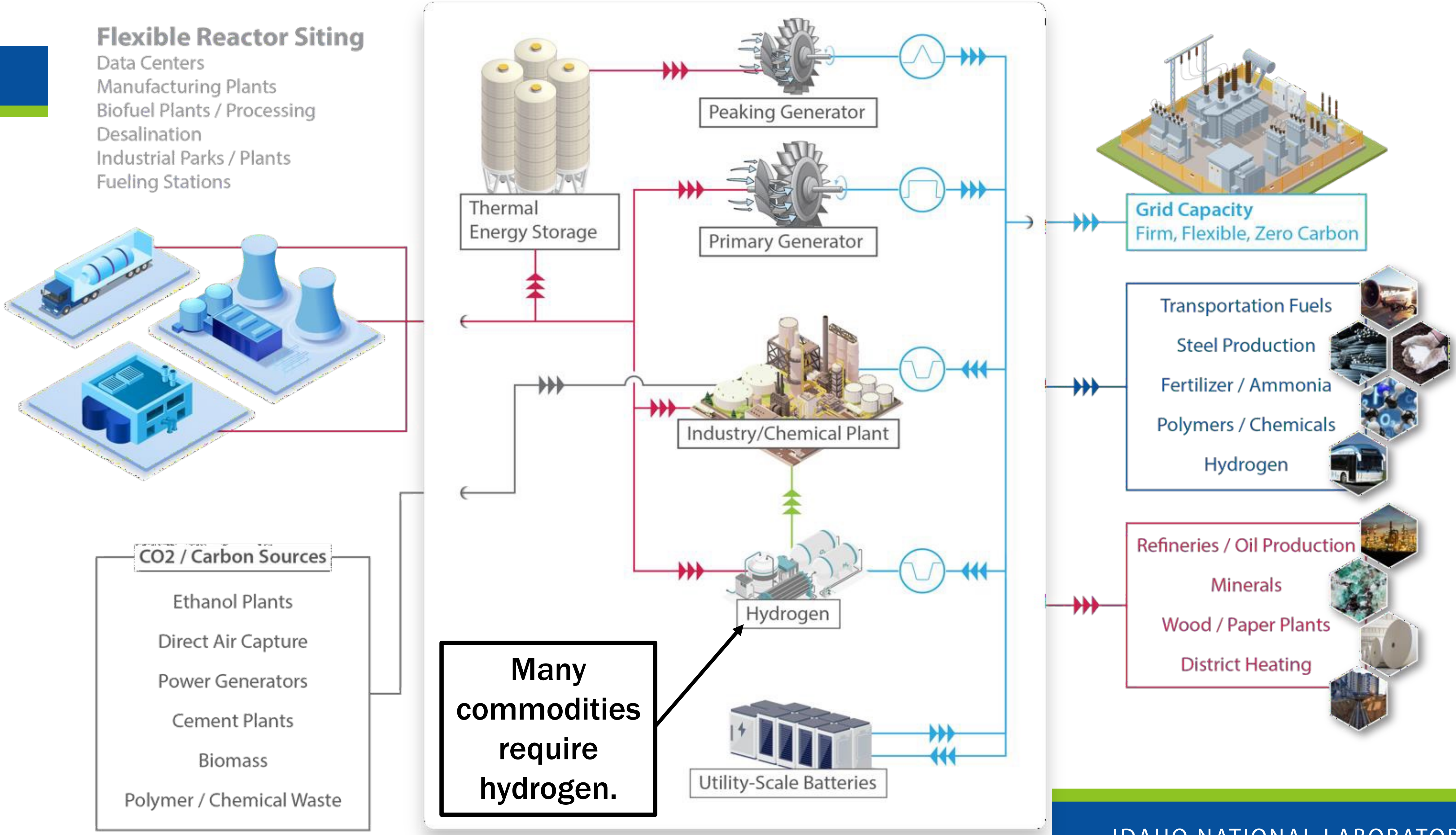


Source: https://world-nuclear.org/information-library/energy-and-the-environment/nuclear-energy-and-sustainable-development.aspx

Maximizing utilization of clean energy options: Energy systems integration

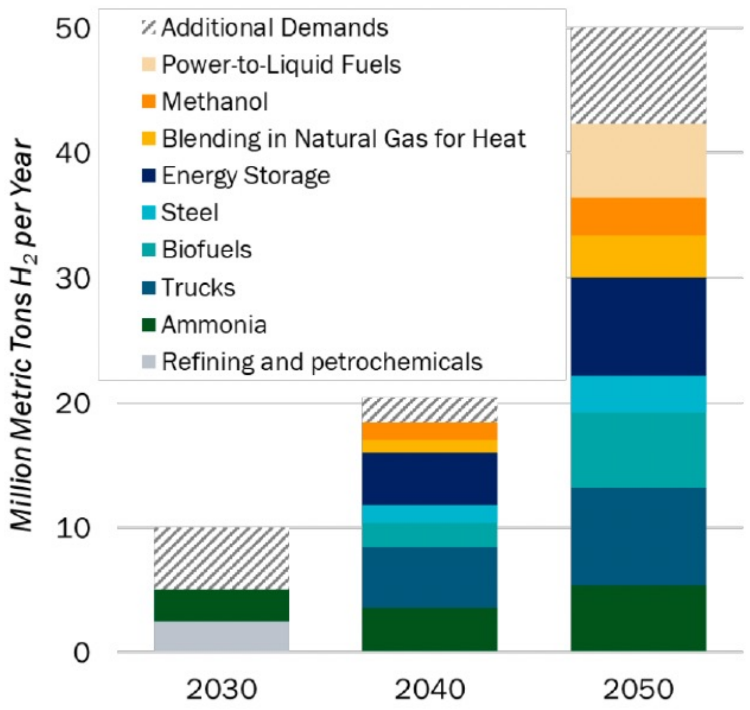
Flexible Reactor Siting

Data Centers
Manufacturing Plants
Biofuel Plants / Processing
Desalination
Industrial Parks / Plants
Fueling Stations



National clean H_2 strategy—The opportunity for clean H_2

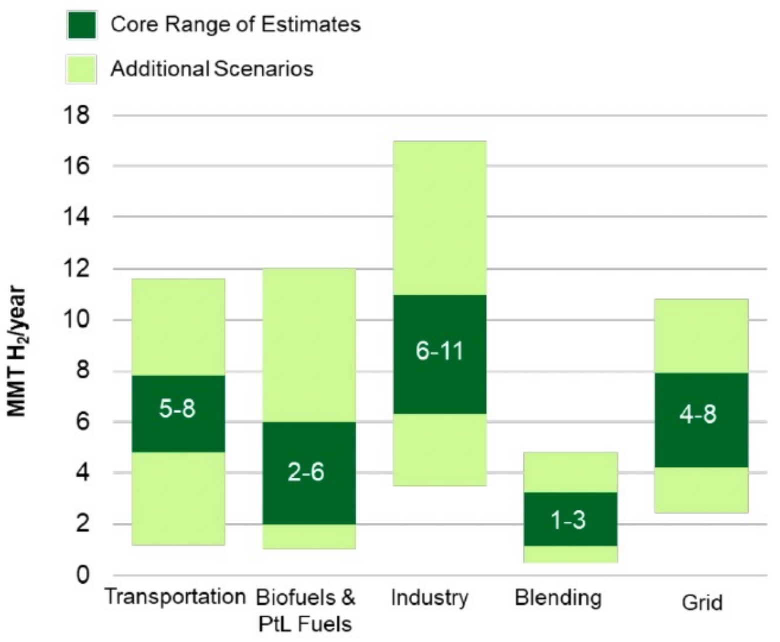
Opportunities for Clean Hydrogen Across Applications



Clean Hydrogen Use Scenarios

- Catalyze clean H_2 use in existing industries (ammonia, refineries), initiate new use (e.g., sustainable aviation fuels (SAFs), steel, potential exports)
- Scale up for heavy-duty transport, industry, and energy storage
- Market expansion across sectors for strategic, high-impact uses

Range of Potential Demand for Clean Hydrogen by 2050



- **Core range: ~ 18–36 MMT H_2**
- **Higher range: ~ 36–56 MMT H_2**

U.S. Opportunity:
10MMT/yr by 2030, 20 MMT/yr by 2040, 50 MMT/yr by 2050

Refs: 1. NREL MDHD analysis using TEMPO model; 2. Analysis of biofuel pathways from NREL; 3. Synfuels analysis based off H2@Scale ; 4. Steel and ammonia demand estimates based off DOE Industrial Decarbonization Roadmap and H2@Scale. Methanol demands based off IRENA and IEA estimates; 5. Preliminary Analysis, NREL 100% Clean Grid Study; 6. DOE Solar Futures Study; 7. Princeton Net Zero America Study

Information provided by DOE-EERE Hydrogen & Fuel Cell Technologies Office, July 2023

Pilot plant hydrogen production demonstration projects

Constellation: Nine-Mile Point Plant

- H_2 production beginning in 2023
- 1 MW_{eDC} nel hydrogen proton electrolyte membrane electrolysis module

Energy Harbor: Davis-Besse Plant

- H_2 production expected in 2024
- 2 MW_{eDC} Cummins proton electrolyte membrane electrolysis module

Xcel Energy: Prairie Island Plant

- H_2 production expected in 2024
- Bloom Energy high temperature solid-oxide electrolysis module

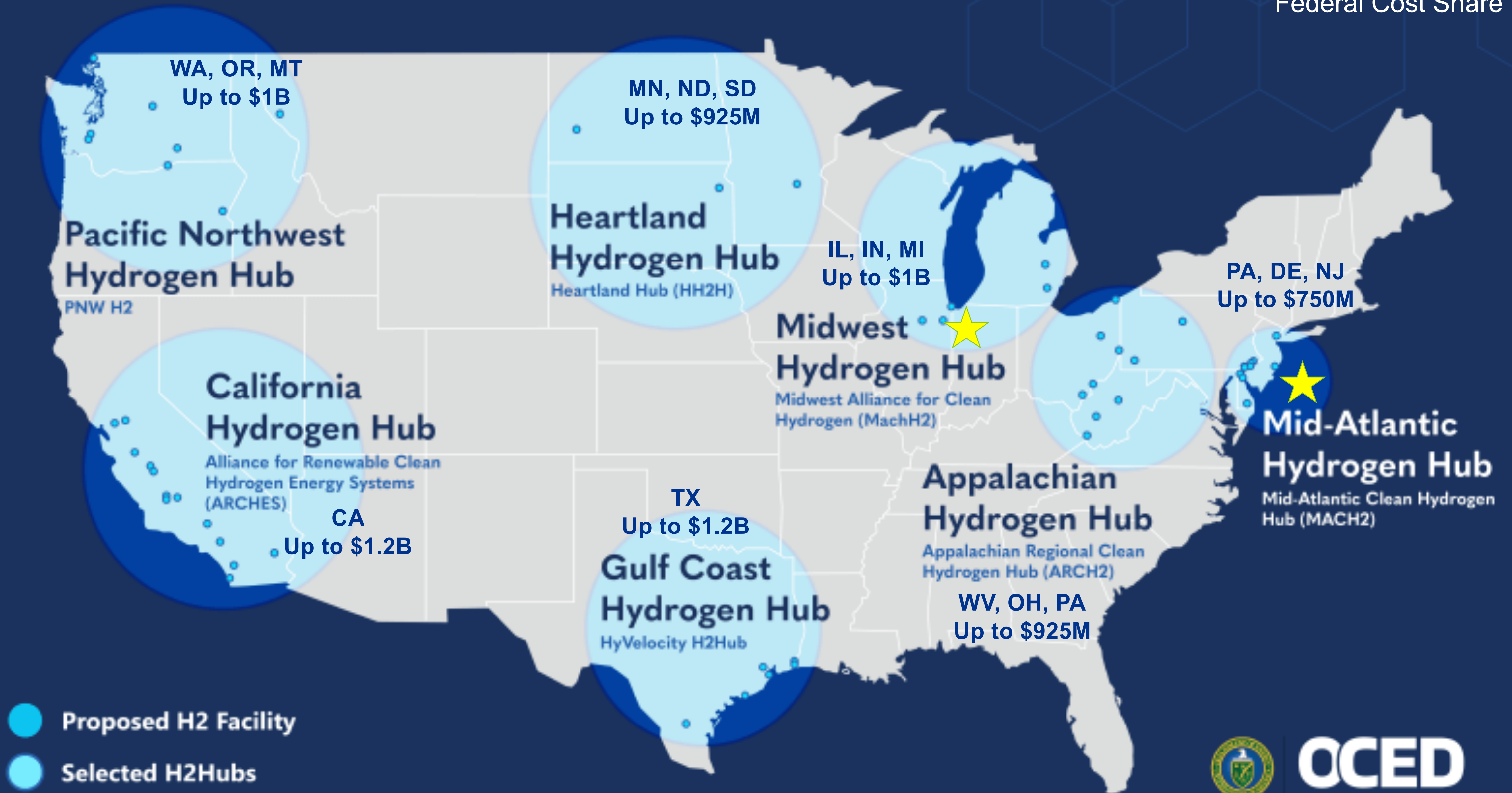
Constellation Nine Mile Point Nuclear Plant Hydrogen Production

- March 7, 2023, started clean hydrogen production facility at Constellation's Nine Mile Point Nuclear Plant in Oswego, New York
- The project leverages DOE grant of $5.8 million to demonstrate hydrogen production and end use for the plant's own consumption of hydrogen
- The PEM electrolyzer uses 1.25 MWe of power behind the meter to produce 560 kg/day of clean hydrogen, more than enough to meet the plant's hydrogen use.
- The additional hydrogen production is being explored as a long duration energy storage system in a separate grant project supported by NYSERDA.
- Constellation has committed to invest $900 million through 2025 for commercial clean hydrogen production using nuclear energy. This includes participation in the Midwest Alliance for Clean Hydrogen (MachH2).

Constellation

SELECTED REGIONAL CLEAN HYDROGEN HUBS

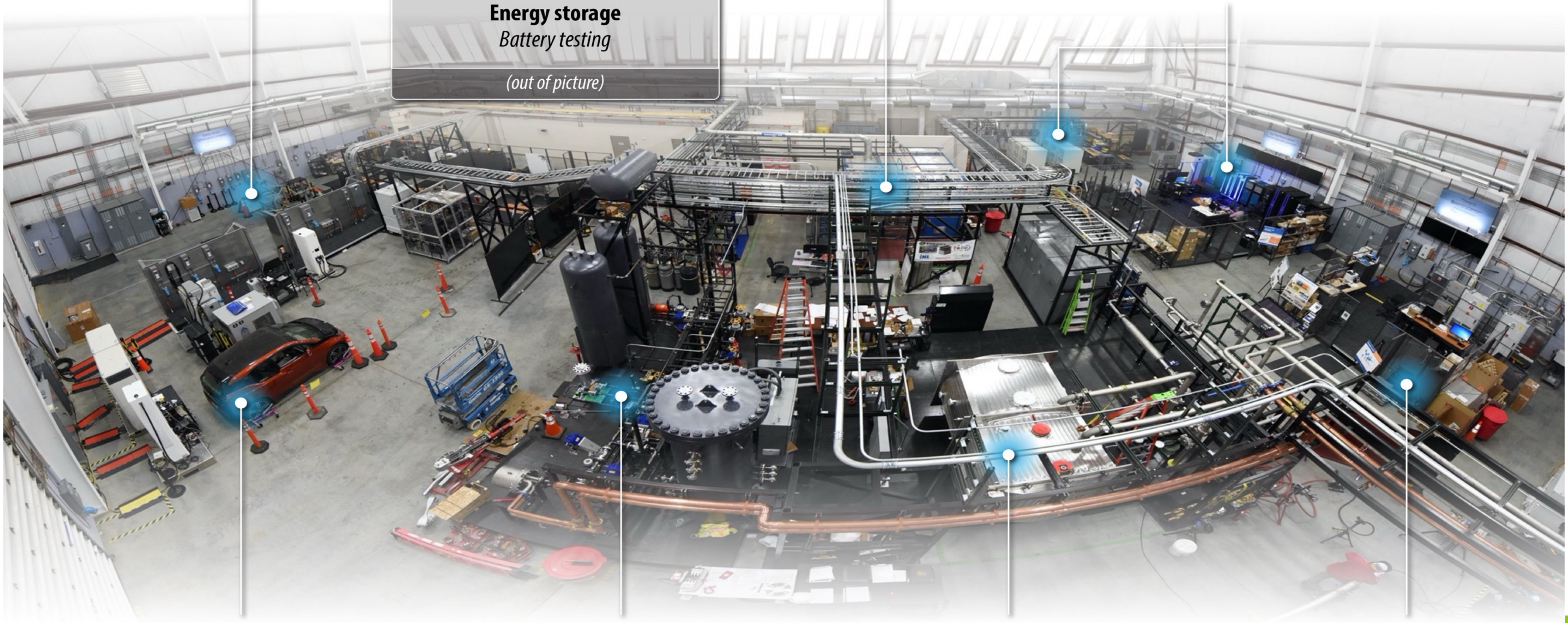
Location
Federal Cost Share



OCED

https://www.energy.gov/oced/regional-clean-hydrogen-hubs-selections-award-negotiations

Dynamic Energy Transport and Integration Laboratory (DETAIL)

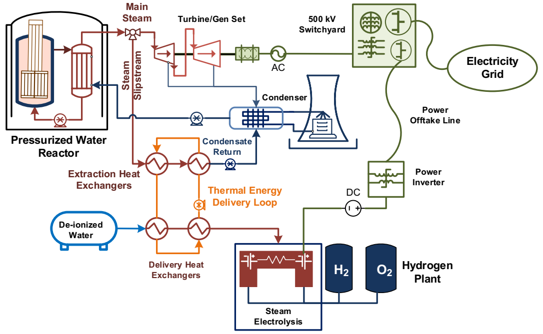


Hydrogen technology development and commercialization

Cell Fabrication and Stack Manufacturing

Modular Systems / Balance of Plant

Pilot Plant and Commercial Scale Demonstration

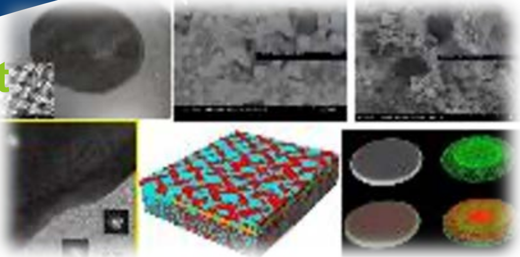


Commercial Demonstrations

High Throughput Materials Testing

5-20 kWe stack assembly and performance testing

3-10 cell short stack testing



Electrode Engineering & Diagnosis

Commercial Stack Testing

Targeting high performance, durability, and cost efficiency

Materials Development and Testing

Materials Preparation

Energy Technology Proving Ground (ETPG)

**Artist rendition of the ETPG.*

A demonstration and testbed complex that:

- *Validates industrial technologies*
- *Designs and controls integrated energy systems*
- *Leverages contributions from nuclear energy beyond electricity*
- *Integrates and leverages testbeds across the DOE laboratory complex, e.g. NREL-ARIES*

Idaho National Laboratory

Additional references

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