INL/MIS-22-69533-Revision-0

Integrated Energy Systems: Advancing Economy-wide Net-Zero Solutions

October 2022

Shannon M Bragg-Sitton

Changing the World's Energy Future

Idaho National Laboratory

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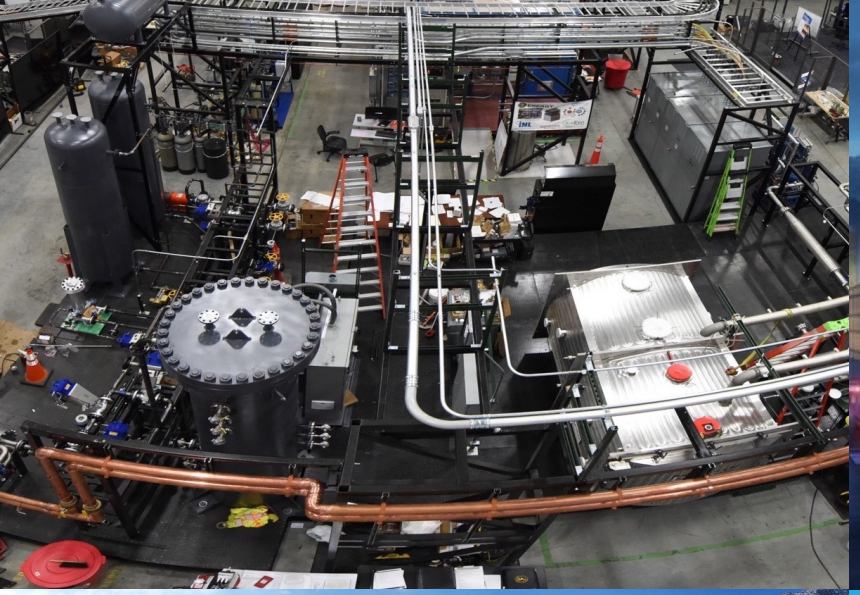

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5 October 2022

From INL/MIS-22-69533

Ambitious goals to mitigate climate change: Achieving “net-zero”

- President Biden has set a goal of achieving net-zero greenhouse gas emissions by no later than 2050 and limiting global warming to 1.5 degrees Celsius
- Steps in reaching this goal require the U.S. to achieve
  - 100 percent carbon pollution-free electricity by 2035
  - Net-zero economy wide by 2050
- Must be achieved while…
  - Investing in infrastructure
  - Fueling an economic recovery – job creation
  - Advancing environmental justice
  - Bolstering domestic supply chains

What is “net-zero”?

“Net-zero” refers to a target of completely negating the amount of greenhouse gases produced by human activity, to be achieved by reducing emissions and implementing methods of absorbing carbon dioxide from the atmosphere

The “Net-Zero” goal aligns perfectly with the INL vision, mission, and values

INL Values

Excellence, Inclusivity, Integrity, Ownership, Teamwork, and Safety

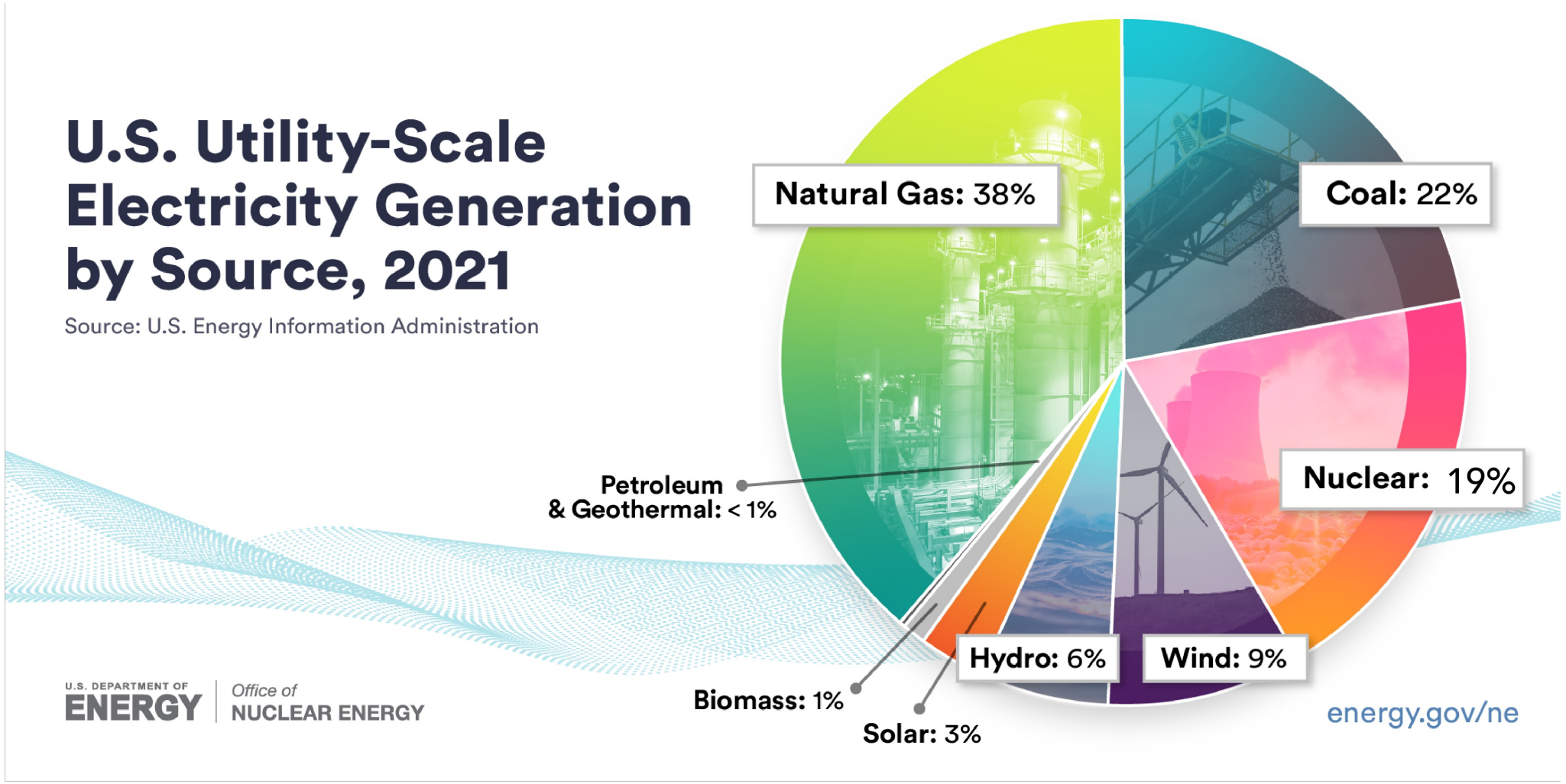
INL Vision

INL will change the world’s energy future and secure our critical infrastructure.

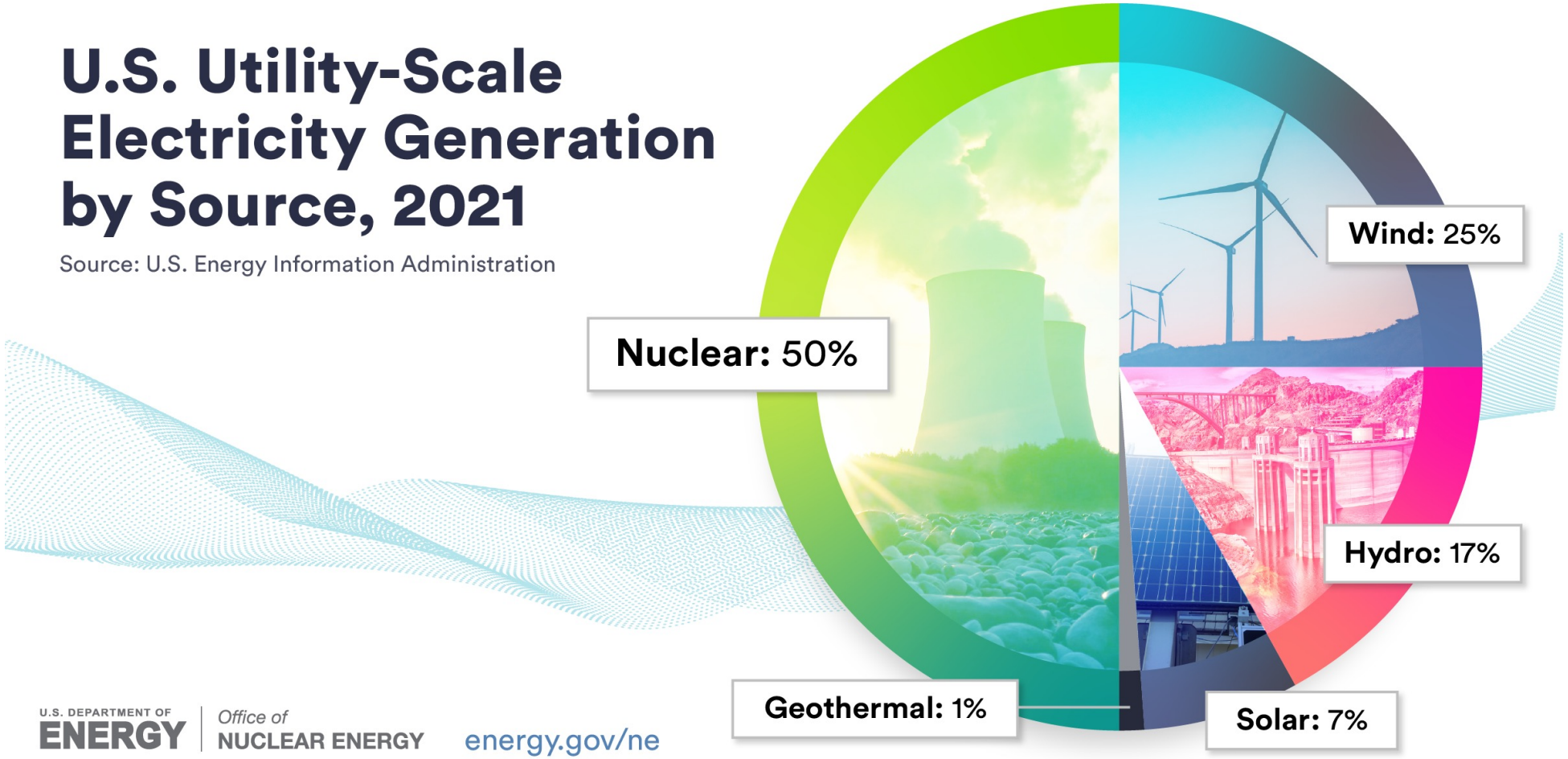
INL Mission

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

The U.S. Energy Mix (2021)



The U.S. Clean Energy Mix (2021)

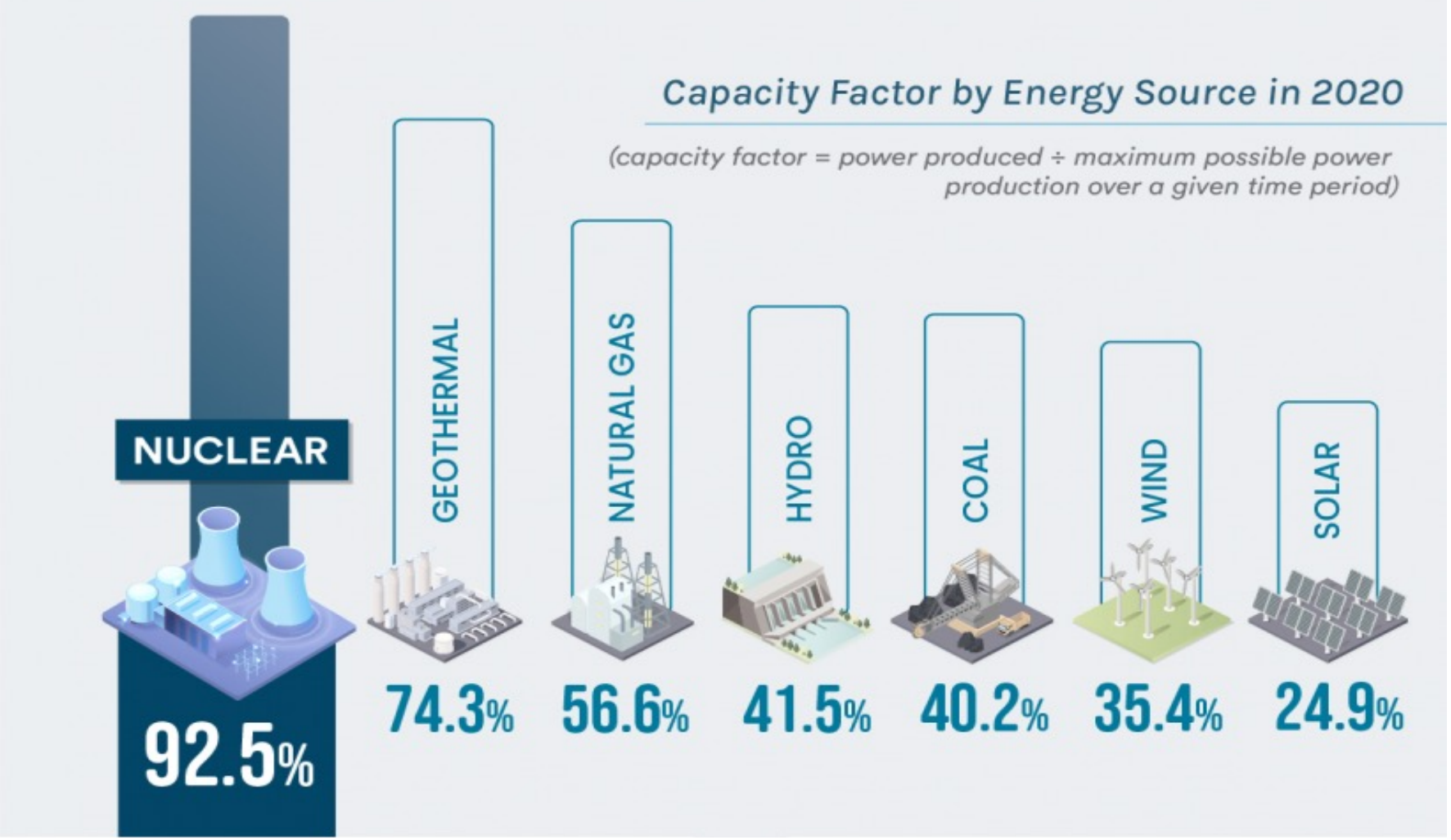


Today's energy systems

- Individual generators contribute to meeting grid demand, managed by an independent grid operator
- Individual thermal energy resources typically support industrial demand
- Transportation mostly relies on fossil fuels (with growing, yet limited, electrification)

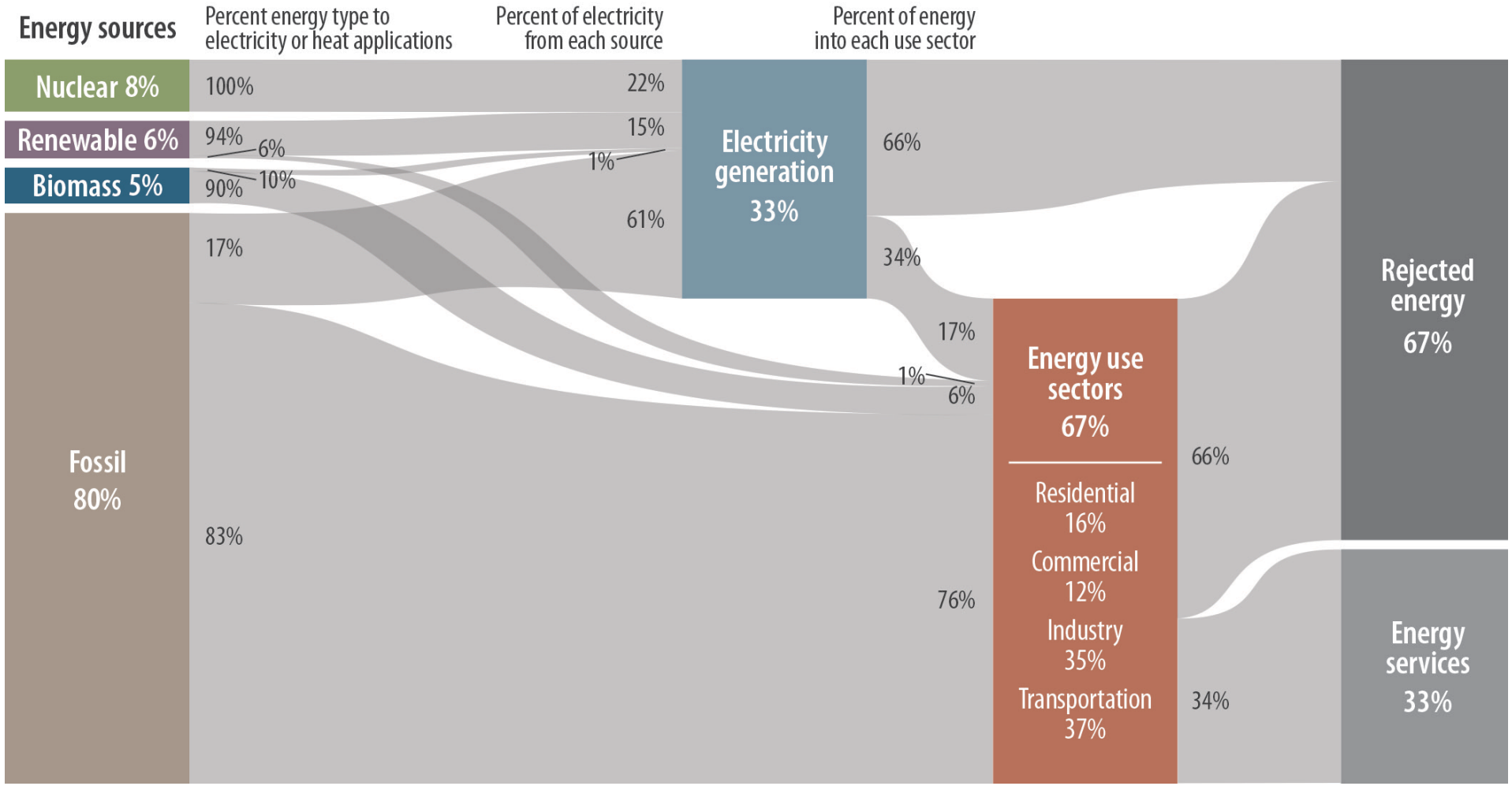
Achieving net-zero emissions will require us to consider the role(s) of <u>all</u> clean energy generation options— and we must look to non-emitting sources of <u>heat</u> in addition to electricity.

Net-zero needs reliable, dispatchable energy



Source: NEI

2018 energy sources and consumers, U.S.



Forsberg and Bragg-Sitton, Maximizing Clean Energy Use: Integrating Nuclear and Renewable Technologies to Support Variable Electricity, Heat and Hydrogen Demand, *The Bridge*, National Academy of Engineering, 50(3), p. 24-31, 2020. Available at https://www.nae.edu/239120/Fall-Issue-of-The-Bridge-on-Nuclear-Energy-Revisited.

Decarbonizing electricity is only part of the challenge

Electricity accounts for only 17% of total energy use in the U.S. across all "Energy use sectors," with the remaining 83% used in the form of heat.

Adapted from LLNL (2020), https://flowcharts.llnl.gov/

The Department of Energy is doubling down on their commitment to clean energy

- *Energy EarthshotsTM 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)

Hydrogen Shot

Long Duration Storage Shot

Carbon Negative Shot

Enhanced Geothermal Shot

Floating Offshore Wind Shot

Industrial Heat Shot

ENERGY earthshots
U.S. DEPARTMENT OF ENERGY

Why Net-Zero at INL?

- INL's site characteristics and operations make it a highly relevant demonstration site; representative of a city or county
- INL will lead by example; lessons learned can inform best-practices for others
- Net-zero aligns with DOE priorities

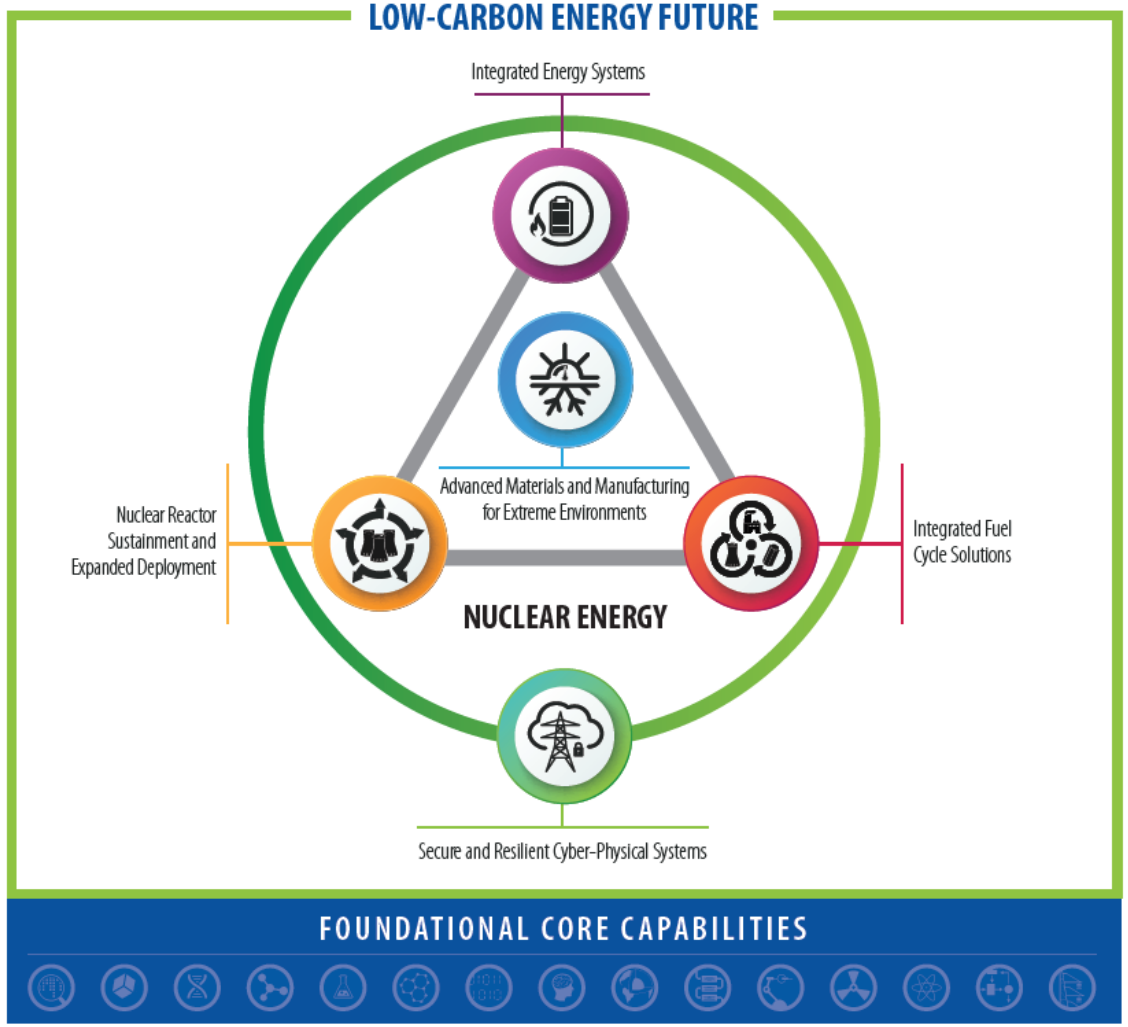
600+
Total vehicles

5,400+
Employees

300+
DOE-owned buildings & trailers

~50
MW purchased in FY20

INL's Strategic Initiatives support the Administration's goals



Strategic INL research initiatives advance energy and security goals for the nation

Future clean energy systems – transforming the energy paradigm

Nuclear Energy Generation

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

Other Energy Generation

Variable renewables, municipal waste, fossil with carbon capture, etc.

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

Biofuel

New chemical processes

Clean water

Industry

Electricity

Hydrogen for vehicles and industry

Potential nuclear-driven IES opportunities

Examples not exhaustive




Nuclear Reactor

Possible Thermal Energy Storage

Process Heat Production

Process Heat (Without Augmentation)

Heat Augmentation

Augmented Heat

Electricity Production

Electricity

Electricity

Hydrogen Production

Hydrogen

Hydrogen

Synfuels Production

Synfuels

Hydrogen

Ammonia Production

Ammonia

Electricity

Possible methanol and

Other options may include methanol, synthetic methane

- Petroleum Refining
- Chemicals Manufacturing
- Cement and Lime Production
- Primary Metals Manufacturing
- Food Production
- Pulp and Paper Manufacturing
- Transportation (Hydrogen, Synfuels, Elec.)
- Mining
- Carbon Conversion
- Desalination
- Electricity and Other Energy Systems

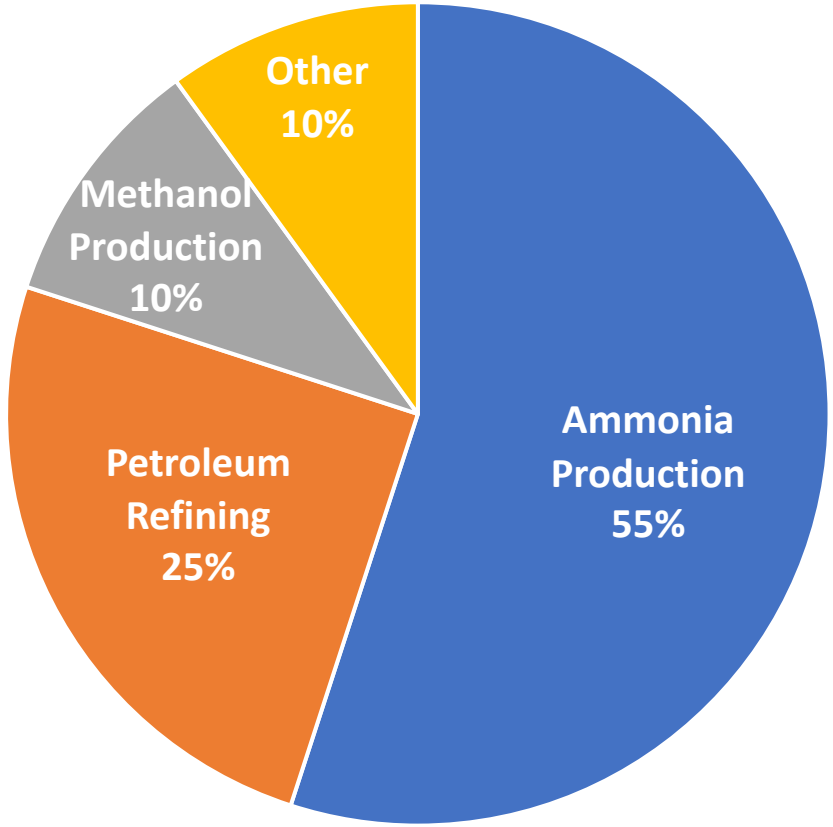
Source: INL, *National Reactor Innovation Center (NRIC) Integrated Energy Systems Demonstration Pre-Conceptual Designs*, April 2021

Why all the hype about hydrogen?

Hydrogen applications in industry

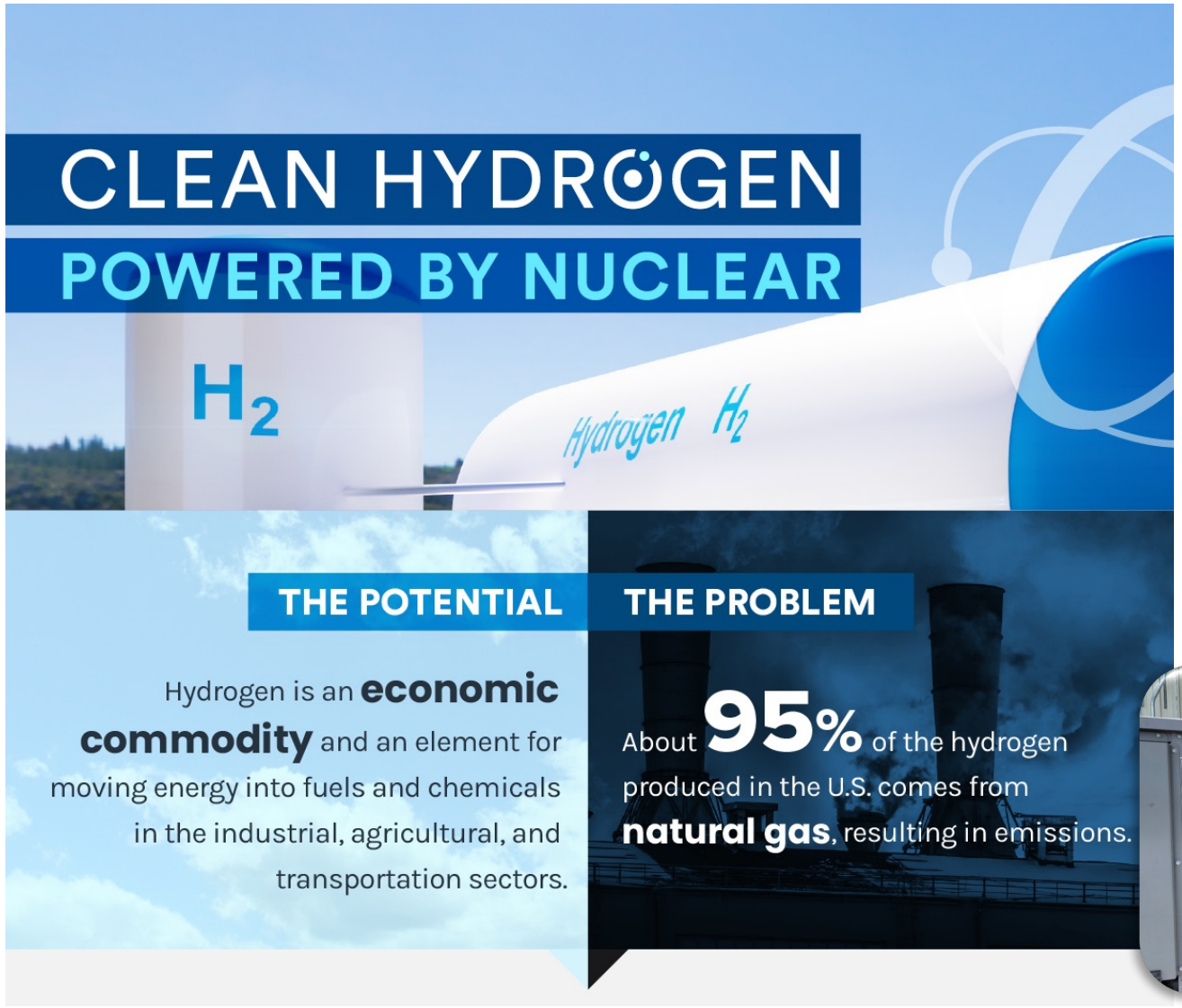
- Agriculture/chemical industry: ammonia, ammonia-based fertilizers
- Petroleum refining: hydrocracking to produce gasoline, diesel
- Methanol production
- Other:
  - Food (e.g., hydrogenated oils)
  - Metalworking
  - Welding
  - Flat glass production
  - Electronics manufacturing
  - Medical applications

Fraction of Global Hydrogen Use by Industry



Data source: Hydrogen Europe
hydrogeneurope.eu/hydrogen-applications

INL research and development will enable—and lead the way— to a clean hydrogen future



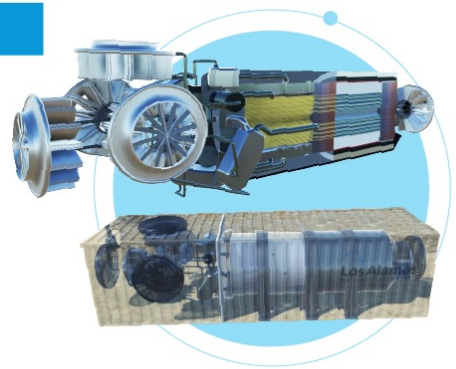
- INL is the nation's lead nuclear laboratory

  AND

- The lead laboratory for high temperature steam electrolysis (breaking water—steam—into its constituent parts)

BUT HOW?

Current and advanced reactors can utilize the constant heat and electricity they generate to split water into pure hydrogen and oxygen through **low- and high-temperature electrolysis**.



THE IMPACT

Creates **clean hydrogen** at a **competitive price** for many applications:

- Oil Refining
- Fertilizer Production
- Steel Production
- Synthetic Fuels
- Grid Storage
- Transport Fuels

THE RESULT

- ✓ Reduces air emissions
- ✓ Deploys hydrogen at scale
- ✓ Expands the use of carbon-free nuclear energy into the transportation and industrial sectors
- ✓ Supports the Hydrogen Shot goal of reducing the cost of clean hydrogen by **80%** *to $1 per kilogram within a decade*

LEARN MORE: energy.gov/ne

U.S. DEPARTMENT OF ENERGY | Office of NUCLEAR ENERGY

Nuclear-H_2 demonstration projects

Four projects have been selected for demonstration of hydrogen production at U.S. nuclear power plants (NPP)

- H_2 production using direct electrical power offtake
- Develop monitoring and controls procedures for scaleup to large commercial-scale H_2 plants
- Evaluate power offtake dynamics on NPP power transmission stations to avoid NPP flexible operations
- Produce H_2 for captive use by NPPs and clean hydrogen markets

Projects

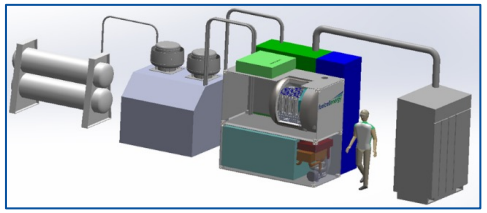
- Constellation: Nine-Mile Point NPP (~1 MWe LTE/PEM)
- Energy Harbor: Davis-Besse NPP (~1-2MWe LTE/PEM)
- Xcel Energy: Prairie Island NPP (~150 kWe HTSE)
- FuelCell Energy: Demonstration at INL (250 kWe)

Nine Mile Point NPP LTE/PEM

Davis-Besse NPP LTE-PEM

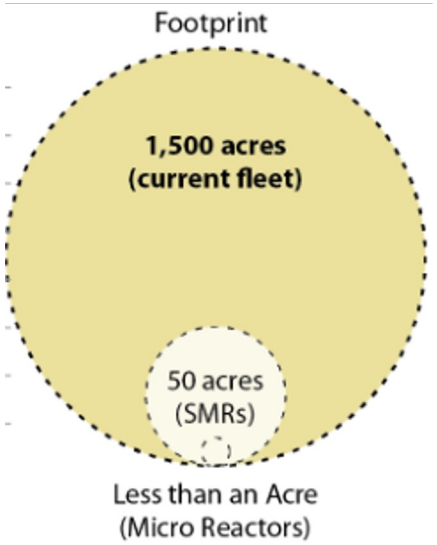
Thermal & Electrical Integration at Prairie Island NPP HTSE/SOEC

FuelCell Energy at INL, SOEC at increasing scale



~2024

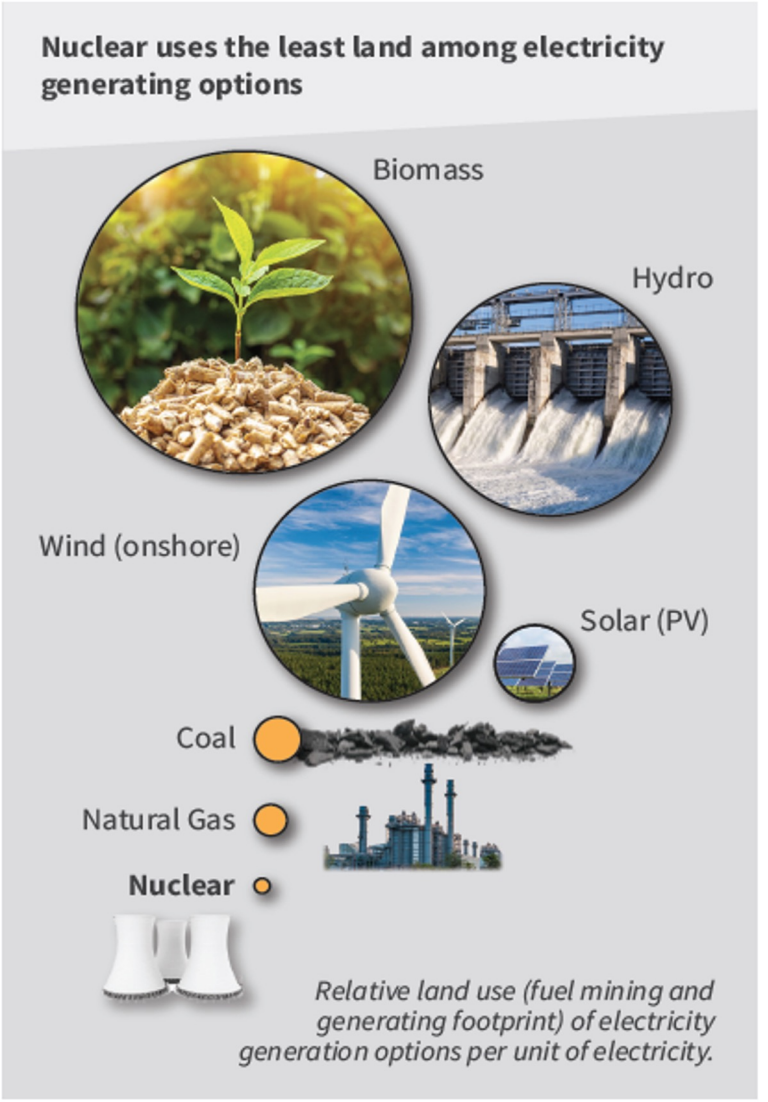
Nuclear energy and deployment flexibility



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

Microreactors and small modular reactors can be deployed to provide reliable energy where it is needed with a small footprint that allows for siting very near to the intended use.

IES
Integrated Energy Systems



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

Advanced Reactor Design Concepts

Key Benefits

- Inherent/passive safety
- Deployment flexibility
- Versatile applications
- Long fuel cycles
- Reduced waste
- Advanced manufacturing to reduce cost

60+ private sector projects under development

SIZES

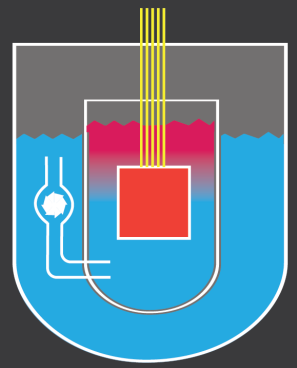
SMALL
1 MW to 20 MW
Micro-reactors
Can fit on a flatbed truck. Mobile. Deployable.

MEDIUM
20 MW to 300 MW
Small Modular Reactors
Factory-built. Can be scaled up by adding more units.

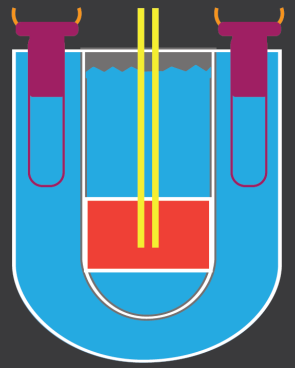
LARGE
300 MW to 1,000 + MW
Full-size Reactors
Can provide reliable, emissions-free baseload power

Advanced Reactors Supported by the U.S. Department of Energy

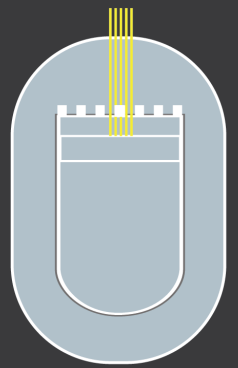
TYPES



MOLTEN SALT REACTORS – Use molten fluoride or chloride salts as a coolant. Online fuel processing. Can re-use and consume spent fuel from other reactors.

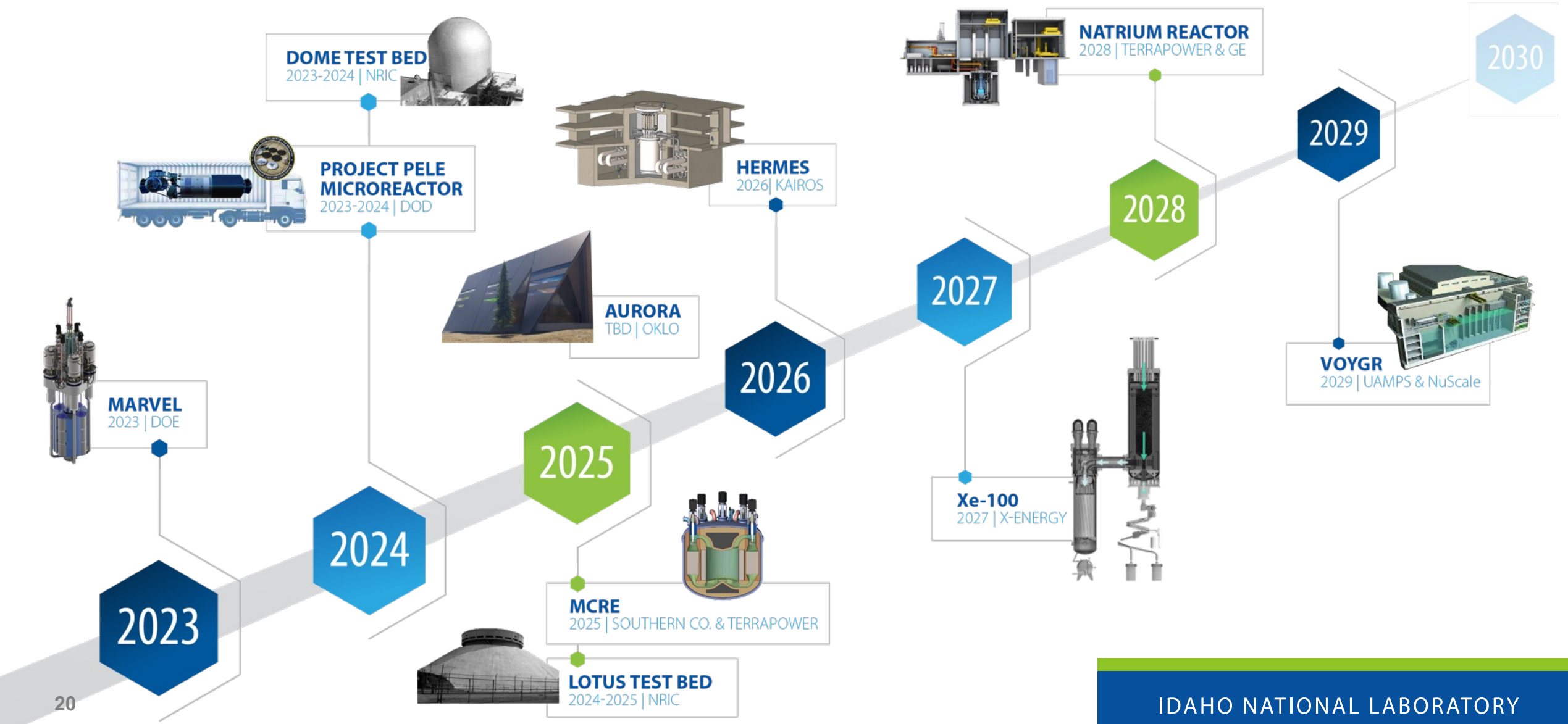


LIQUID METAL FAST REACTORS - Use liquid metal (sodium or lead) as a coolant. Operate at higher temperatures and lower pressures. Can re-use and consume spent fuel from other reactors.

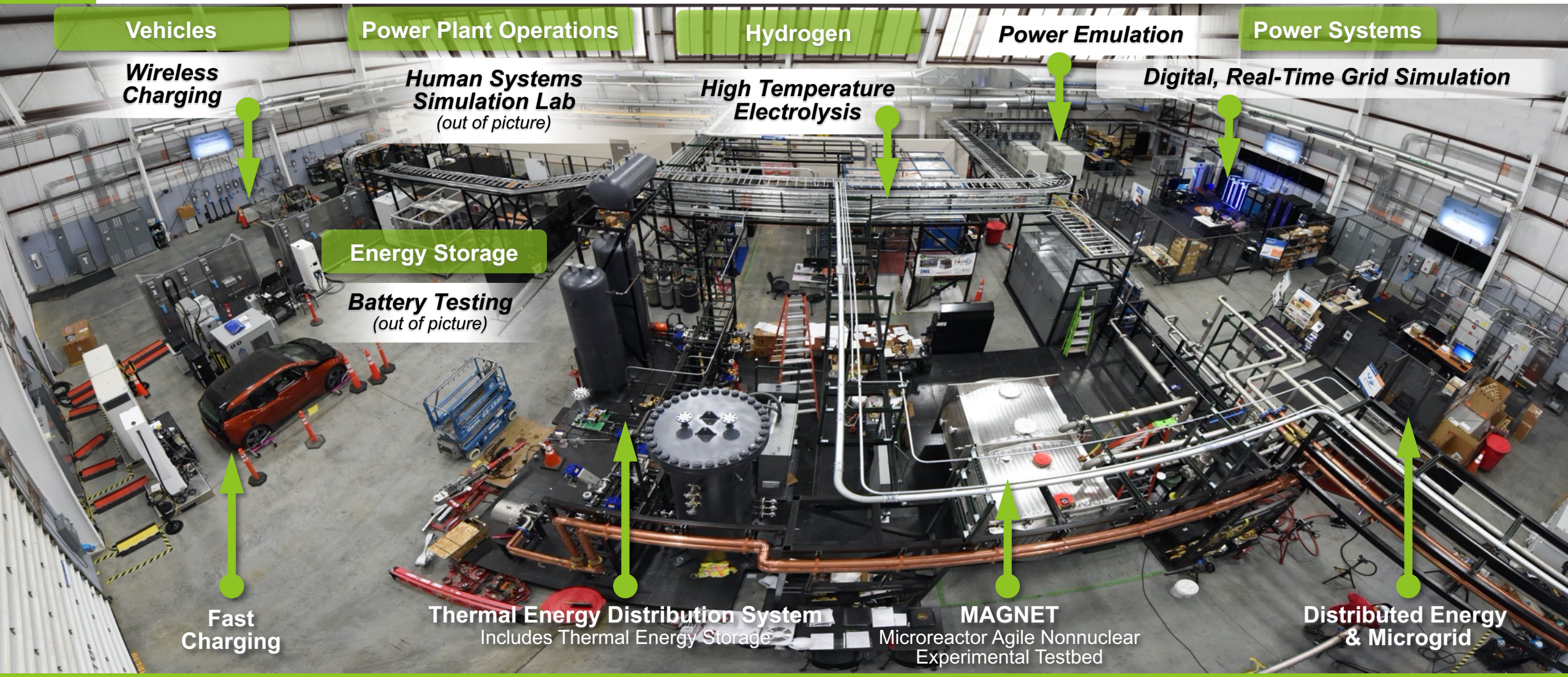


GAS-COOLED REACTORS – Use flowing gas as a coolant. Operate at high temperatures to efficiently produce heat for electric and non-electric applications.

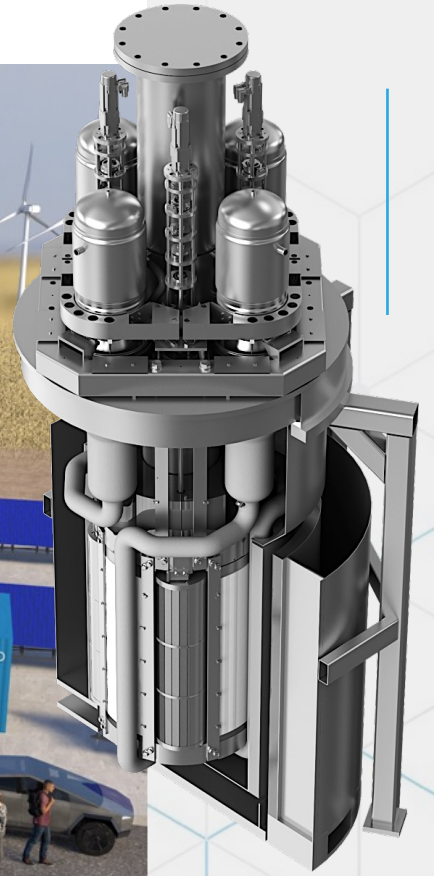
Accelerating advanced reactor demonstration & deployment



Dynamic Energy Transport and Integration Laboratory (DETAIL)

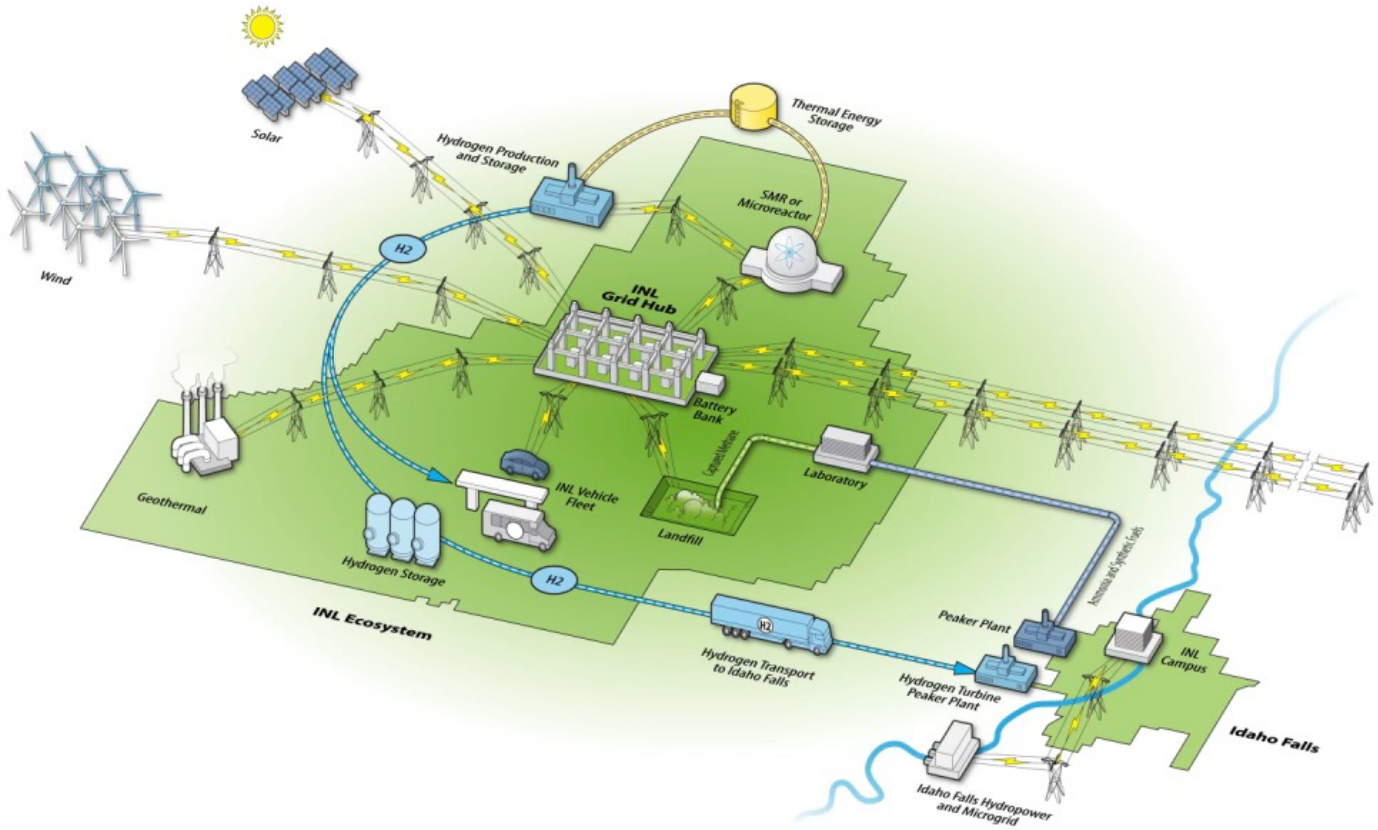


INL microgrid with MARVEL microreactor

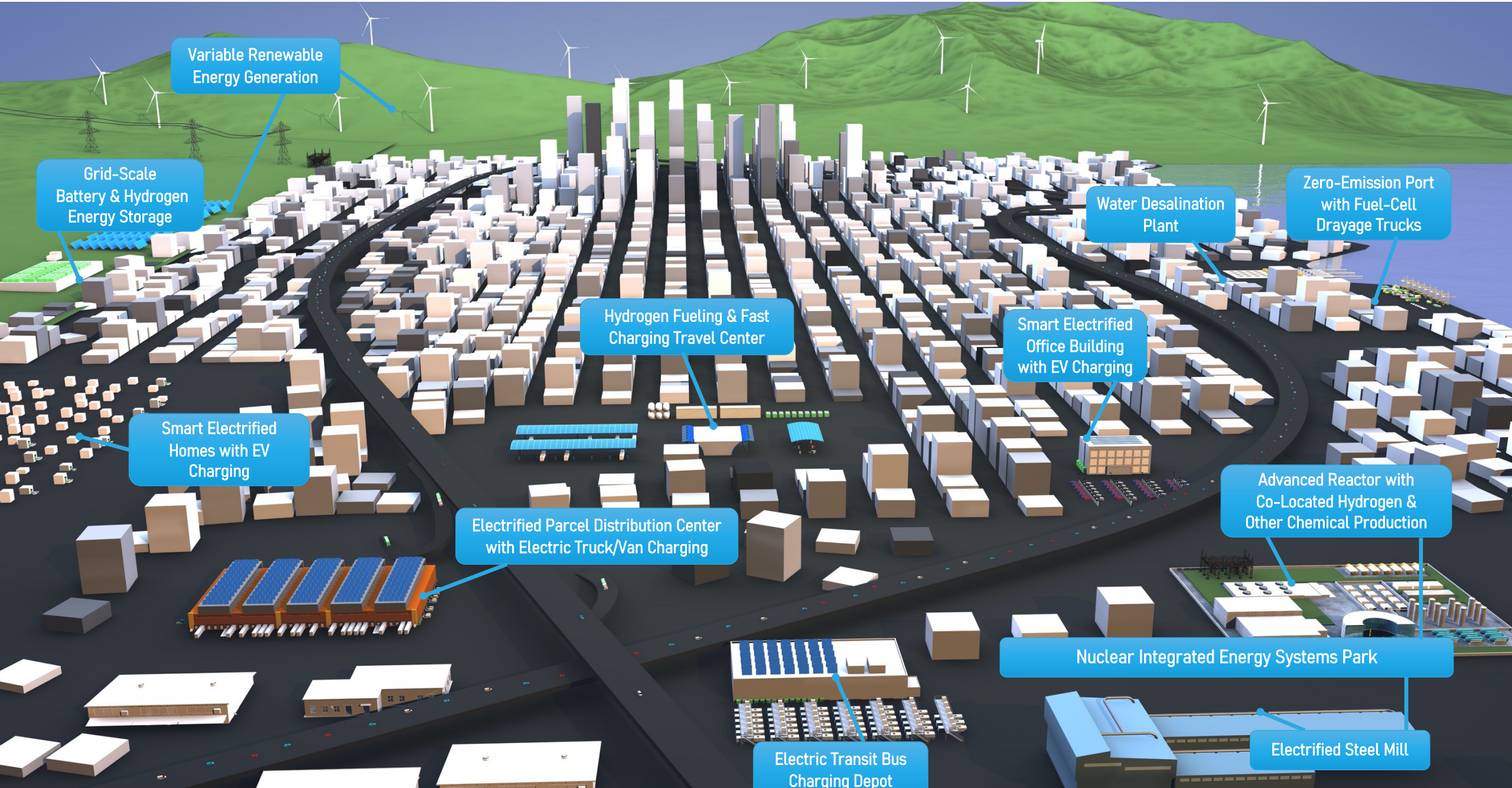


MARVEL TEAM
is innovating in every area of a microreactor

INL secure, resilient net-zero energy future.



A vision for a net-zero future



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