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Integrated Energy Systems: The Role of Nuclear Energy in Supporting Economy-wide Net-zero Solutions

October 2022

Changing the World's Energy Future

Shannon M Bragg-Sitton

Idaho National Laboratory

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IES
Integrated Energy Systems

Integrated Energy Systems: The Role of Nuclear Energy in Supporting Economy-wide Net-zero Solutions

Need for Heat & Hydrogen: The Role of Low-Carbon Nuclear
Ministry of Industry & Trade of the Czech Republic

11 October 2022

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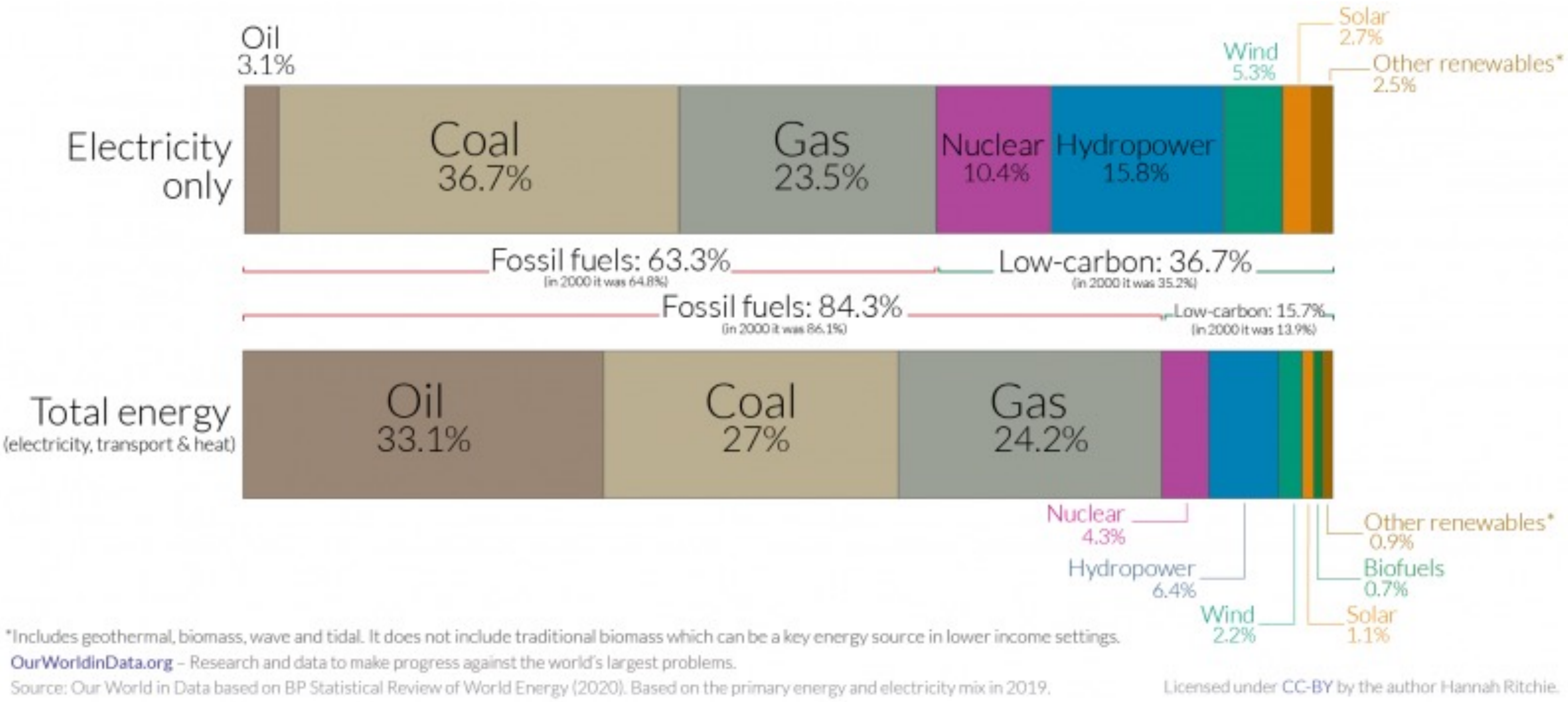
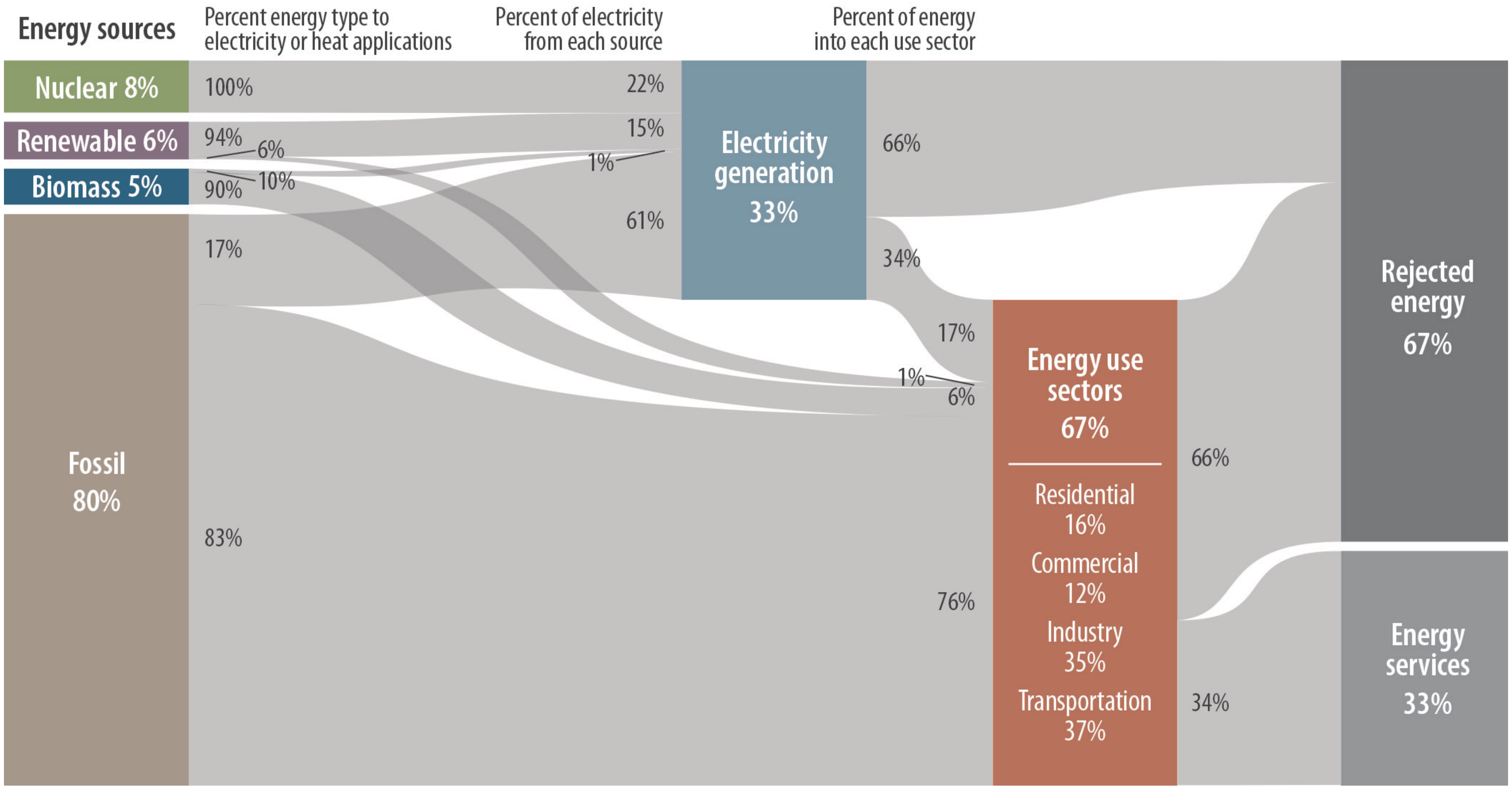
Idaho National Laboratory

The global challenge:
Decarbonizing electricity and total energy sources (2019)



2018 energy sources and consumers, U.S.



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/

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.

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)*

Hydrogen Shot ← **Goal: Achieve $1/kg-$H_2$ within a decade, emissions free**

Long Duration Storage Shot

Carbon Negative Shot

Enhanced Geothermal Shot

Floating Offshore Wind Shot

Industrial Heat Shot

ENERGY earthshots U.S. DEPARTMENT OF ENERGY

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What does next generation nuclear energy offer?

Advanced reactor design concepts

Key Benefits

- Enhanced inherent/passive safety
- Deployment flexibility
- Versatile applications
- Long fuel cycles
- Reduced waste
- Advanced manufacturing and factory manufacturing to reduce costs

60+ private sector projects under development

SIZES

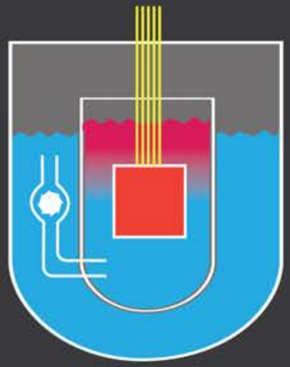
SMALL
1 MW to 20 MW
Micro-reactors
Can fit on a flatbed truck. Mobile. Deployable.

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

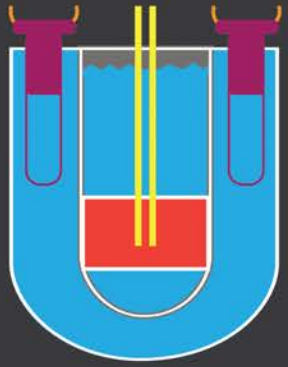
LARGE
300 MW to 1,000 + MW
Full-size Reactors
Can provide reliable, emissions-free baseload power

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

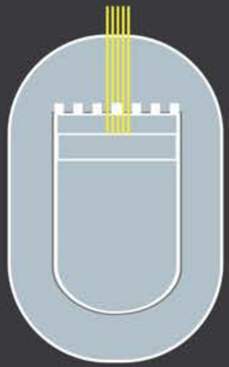
TYPES



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.

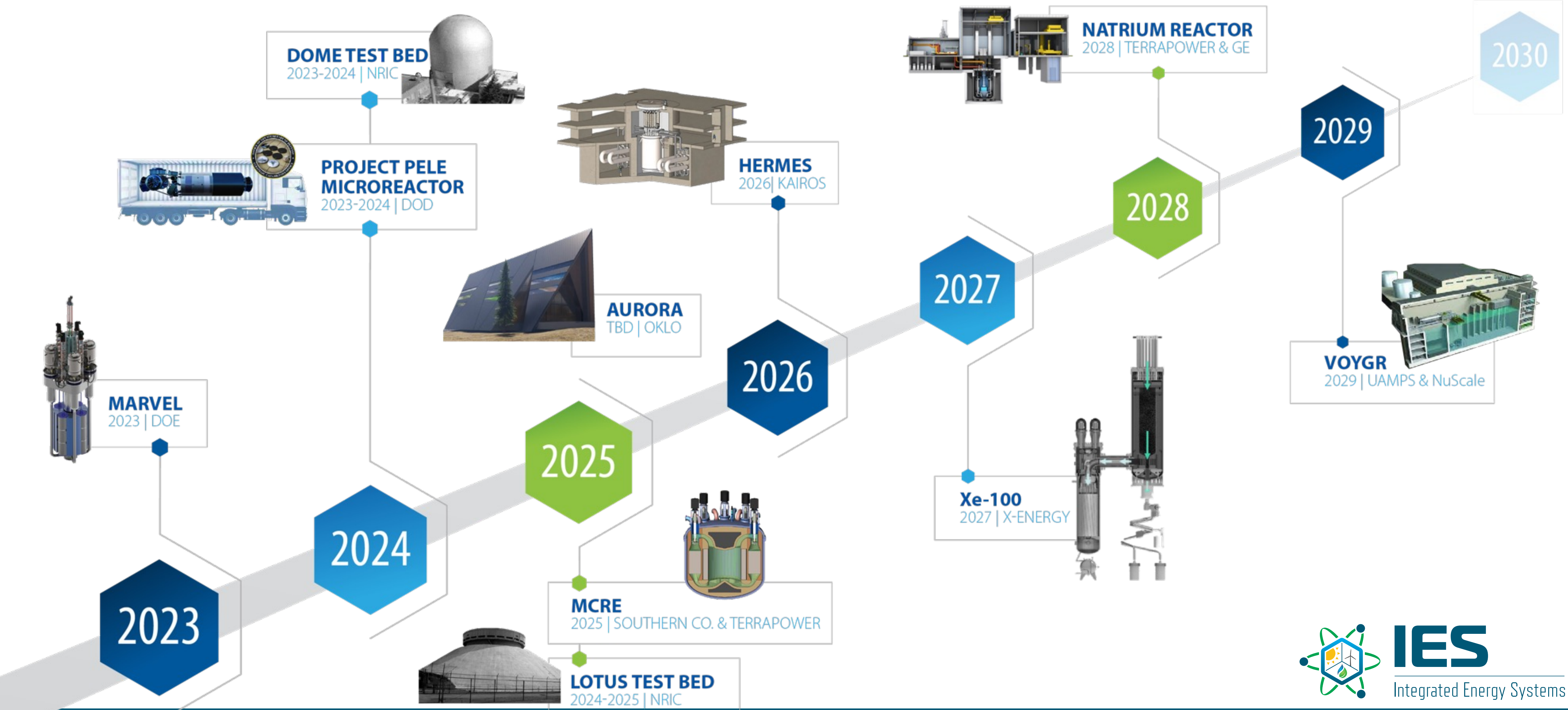


LIQUID METAL FAST REACTORS - Use liquid metal (sodium or lead) as a coolant. Operate at higher temperatures and lower pressures. Can re-use and consume spent fuel from other reactors.



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



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Thinking outside the box: Clean nuclear energy for non-grid applications

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Future clean energy systems – transforming the energy paradigm

Nuclear Energy Generation

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

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

Other Energy Generation

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

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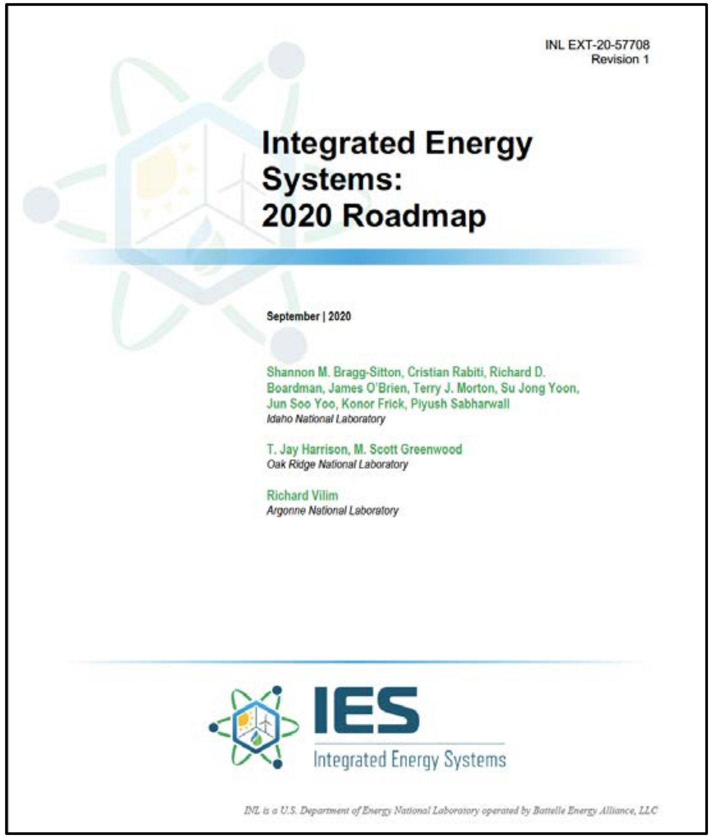
DOE-NE R&D Programs for Multi-Output Integrated Energy Systems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Revision 1

Integrated Energy Systems: 2020 Roadmap

September | 2020

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Crosscutting Technology Development
Integrated Energy Systems

VISION

A robust and economically viable fleet of light-water and advanced nuclear reactors available to support US clean baseload electricity needs, while also operating flexibly to support a broad range of non-electric products and grid services.

Flexible simulation ecosystem for system design, analysis, technical and economic optimization
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Experimental demonstration for technology development and model validation
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Greenfield system design and advanced reactor applications

Reduce risk for commercial LWR-IES deployment

Energy dispatch design and implementation

Technical and economic analysis, near-term markets

Safety assessment and licensing considerations


INL/EXT-20-59585
Revision 0

Light Water Reactor Sustainability Program

Flexible Plant Operation and Generation
Technical Program Plan for FY 2021

September 2020

U.S. Department of Energy
Office of Nuclear Energy

Flexible Plant Operations & Generation Pathway

Timeline for Deployment

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Current fleet **NOW**—Advanced Reactors **5-15 years**

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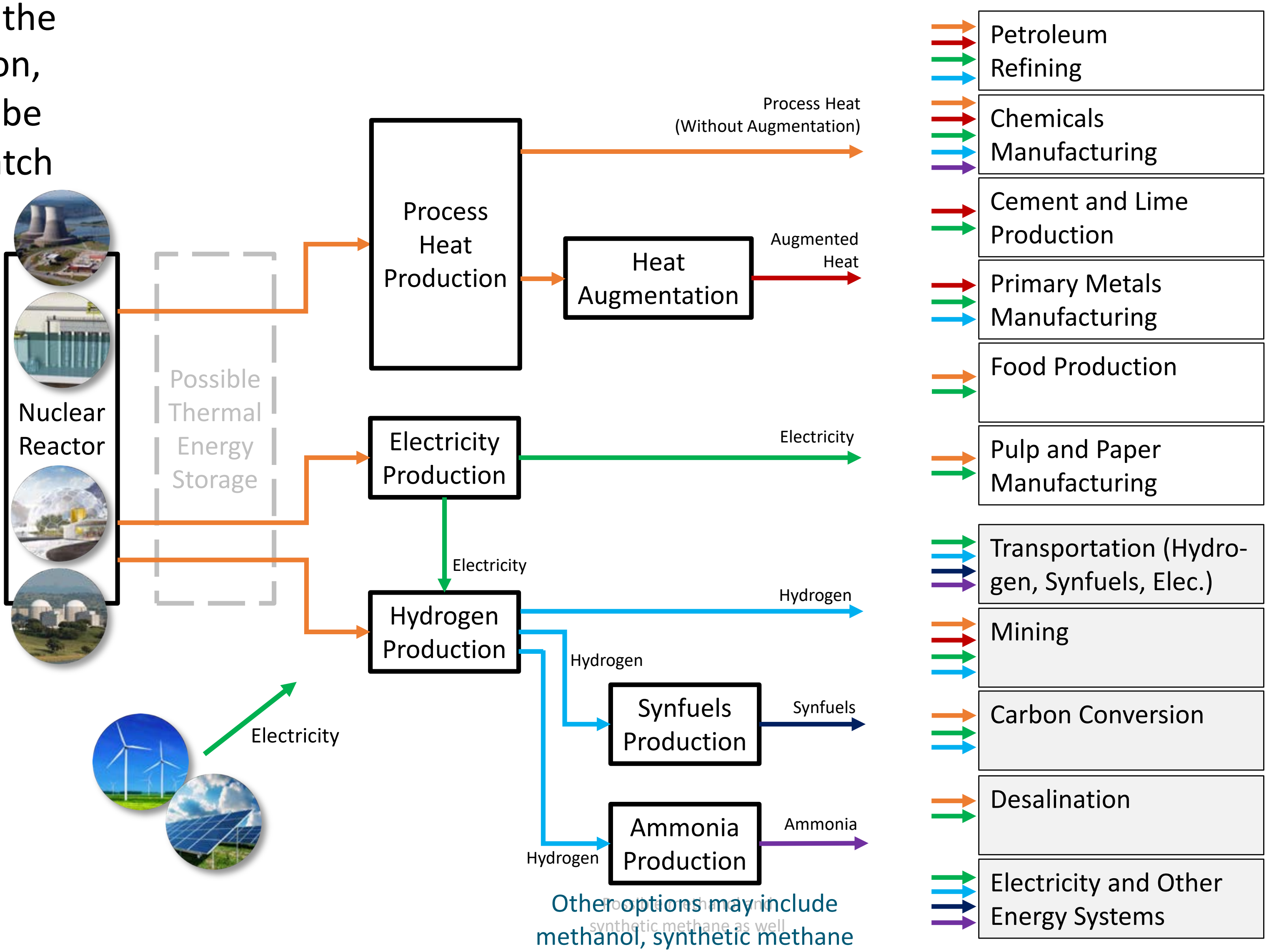
LWRS LIGHT WATER REACTOR SUSTAINABILITY

Summary of potential nuclear-driven IES opportunities

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



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

Guiding questions in evaluating integrated energy systems

- What are **economically and technically viable** options for integrated energy system (IES) coupling to nuclear power plants in specific grid energy systems?
- What is the **statistically ideal** mix for Nuclear-IES within various markets?
- What are **driving economic factors** that existing and future nuclear technologies can leverage though IES production coupling?
- What are the **optimal coupling strategies** between IES technologies and nuclear plants?

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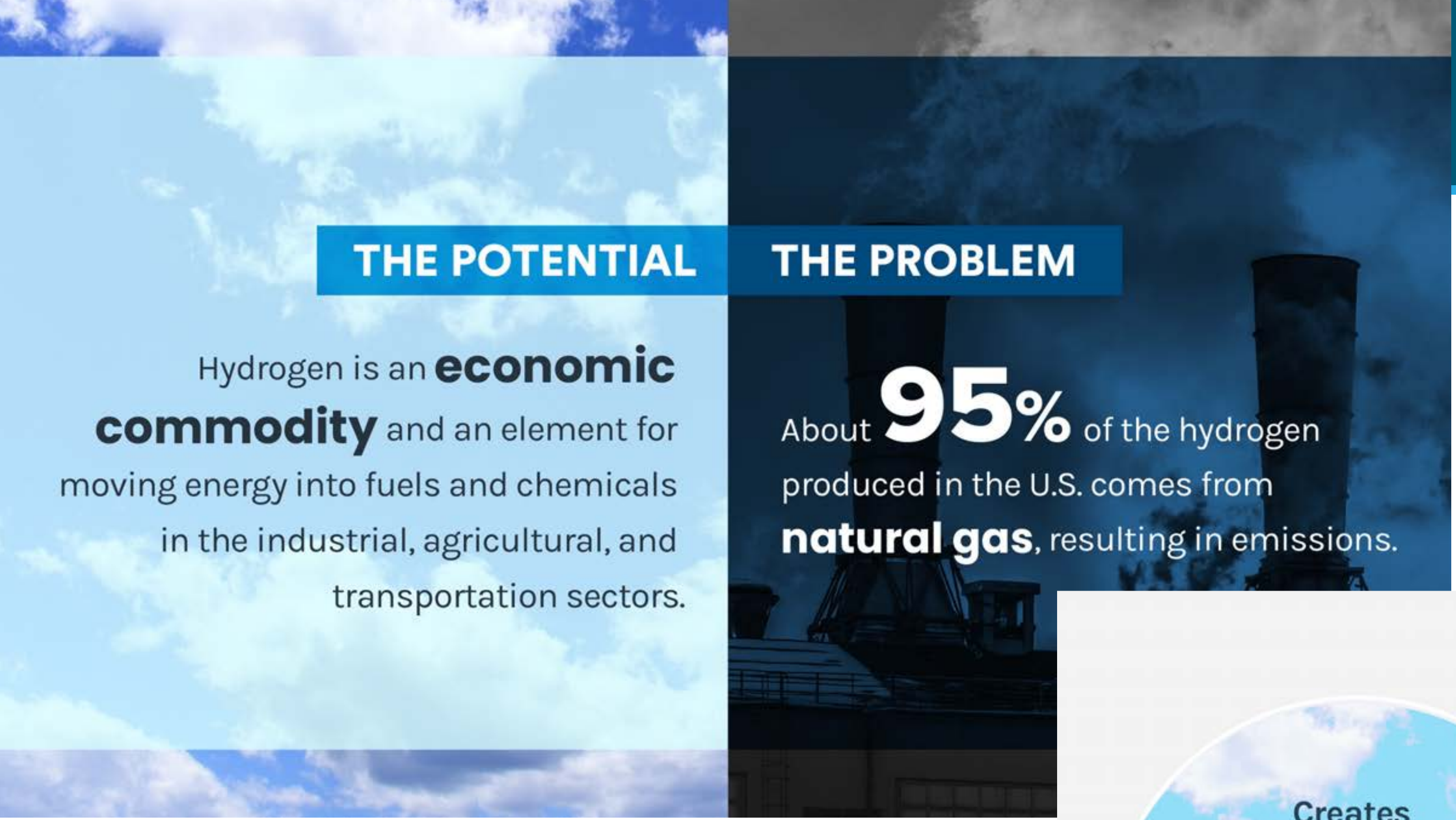
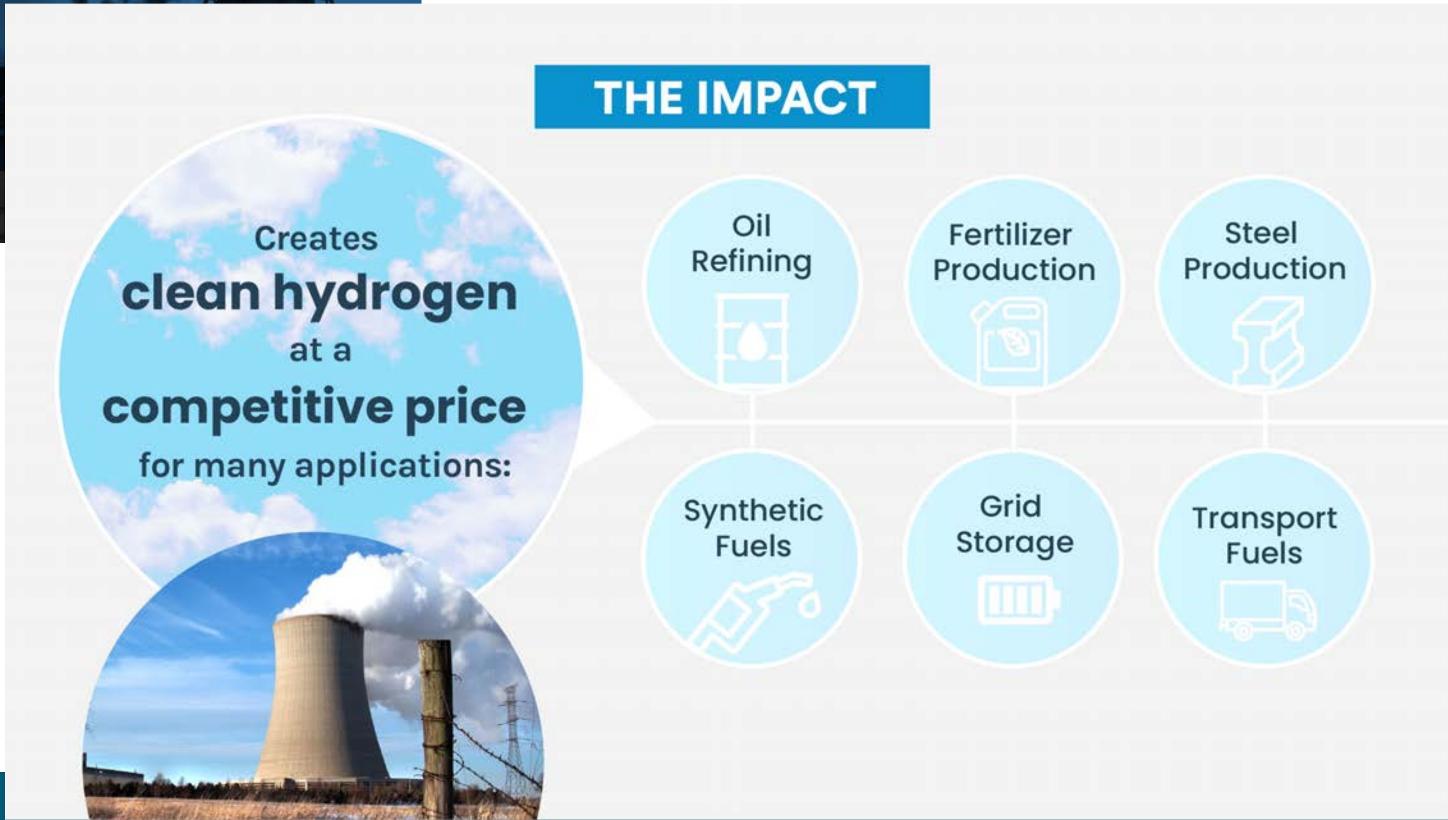
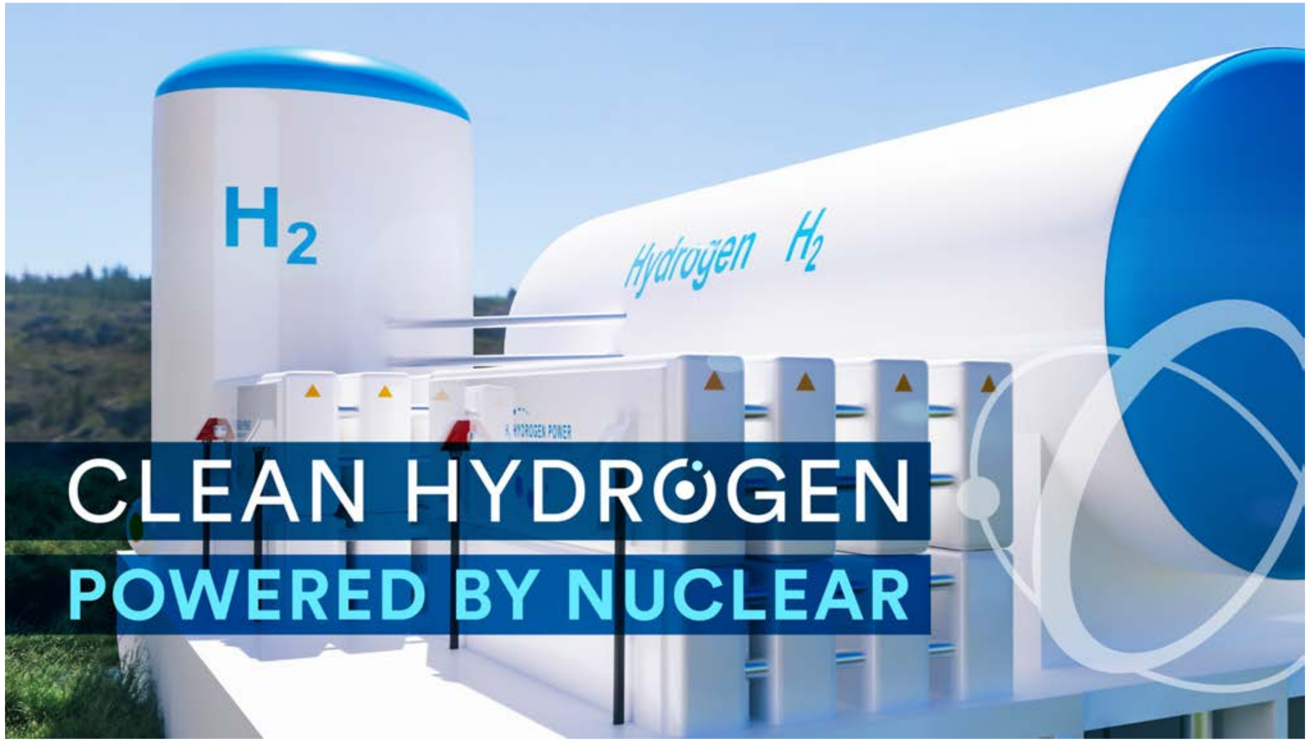
Why focus on hydrogen?





INL research and development in integrated energy systems will enable a clean hydrogen future



- INL is the U.S. lead nuclear energy laboratory **AND**
- The lead laboratory for high temperature steam electrolysis (i.e., breaking water—steam—into its constituent parts)

Integrated Energy Systems

Dynamic Energy Transport and Integration Laboratory (DETAIL) for electrically heated testing of integrated systems

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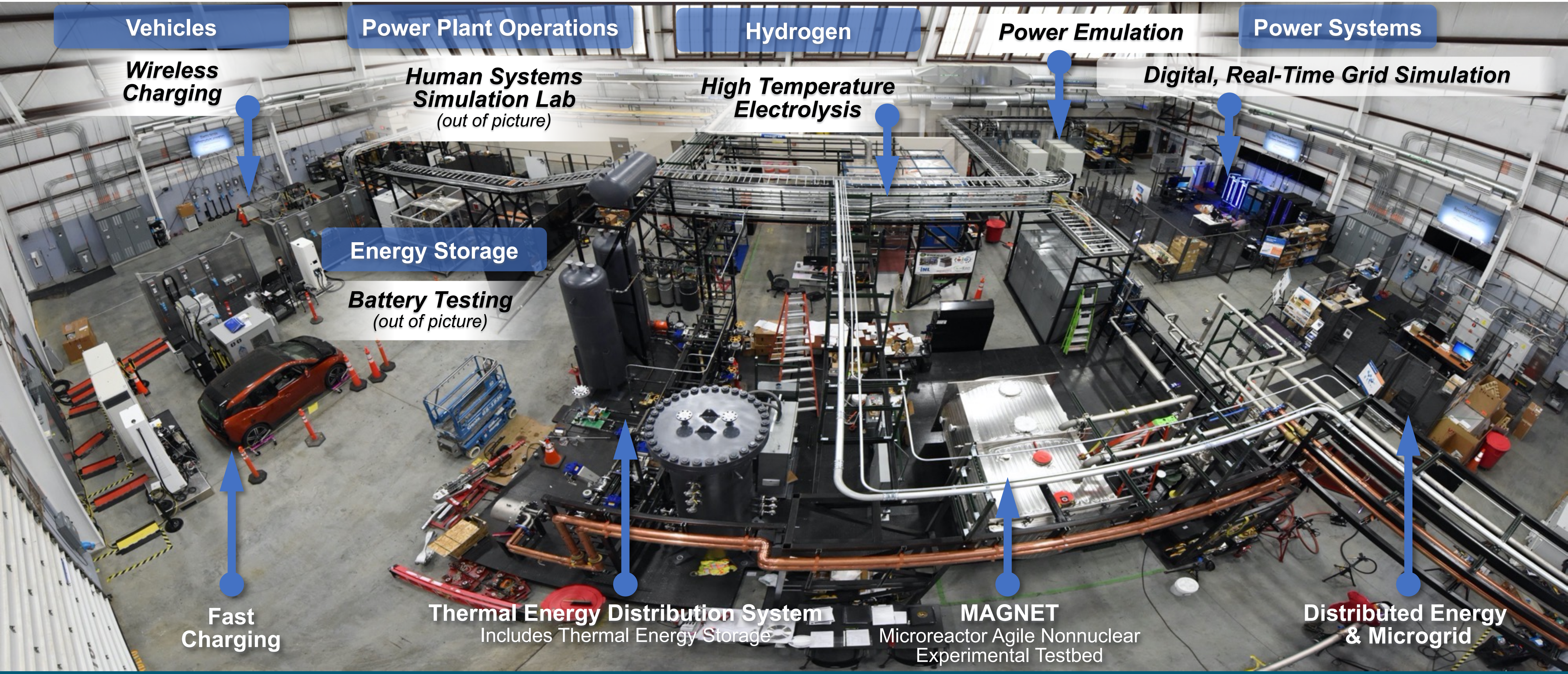


Nuclear-H_2 demonstration projects

Multiple 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

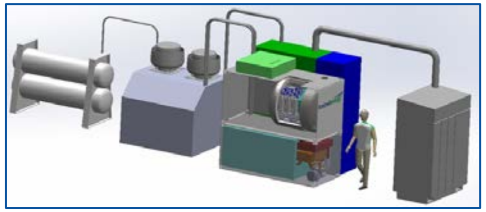
- Constellation: Nine-Mile Point NPP (~1 MWe LTE/PEM)
- Energy Harbor: Davis-Besse NPP (~1-2 MWe LTE/PEM)
- Xcel Energy: Prairie Island NPP (~150 kWe HTSE)
- FuelCell Energy: Demonstration at INL (250 kWe)

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

H2@Scale U.S. Department of Energy

LWRS LIGHT WATER REACTOR SUSTAINABILITY

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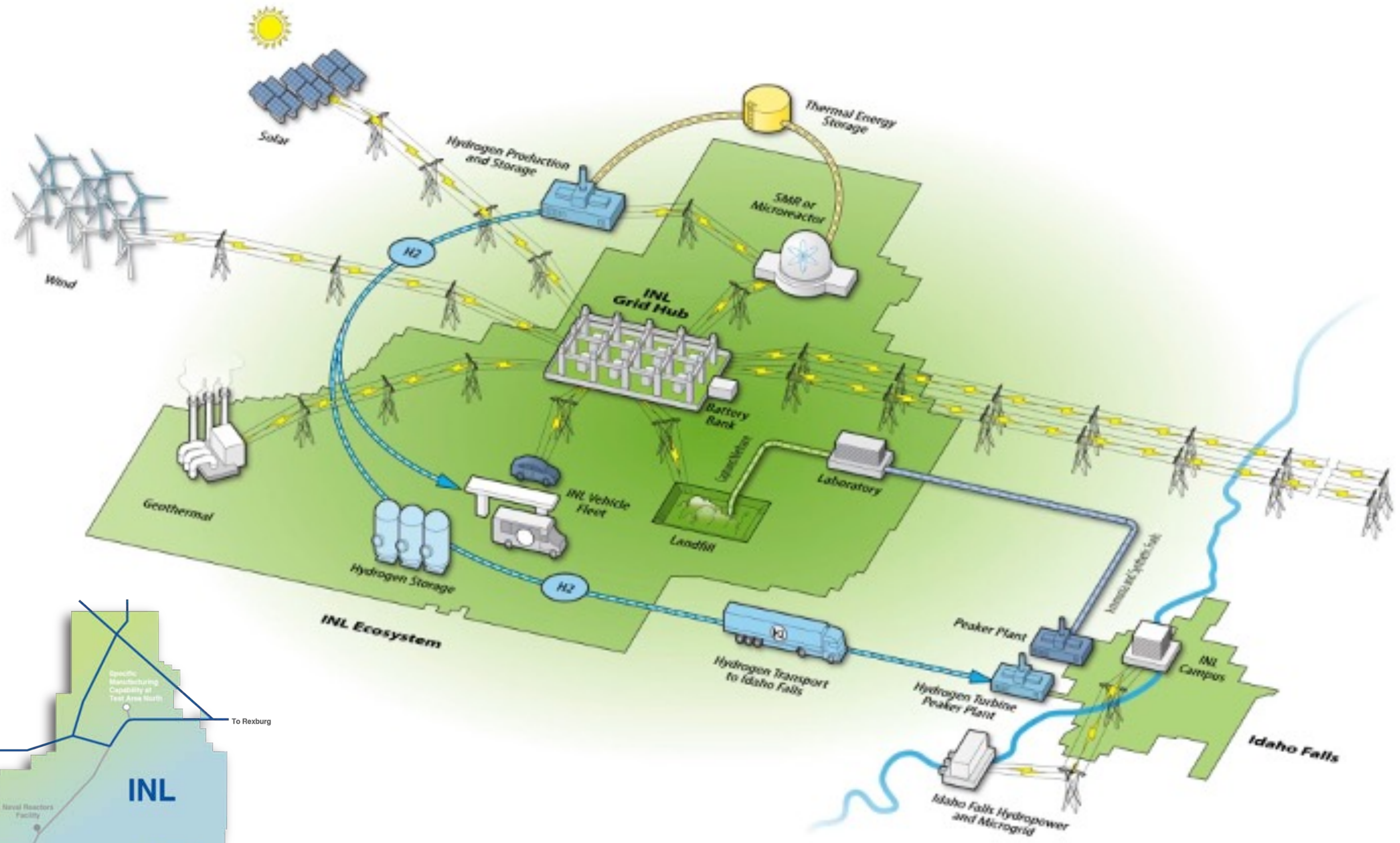
INL’s commitment to net-zero will be a leading demonstration ushering in a secure, resilient net-zero energy future



- INL has committed to becoming a net-zero campus by 2031
- Attributes of a small city or county
- 890 sq mi
- >5400 employees
- >50 MWe purchased in FY2020
- >300 DOE-owned buildings
- Existing microgrid
- 3 fire stations, 1 museum, medical facilities, …
- >40 miles primary roads

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WWW.INL.GOV