



Developing and Demonstrating Nuclear- based Integrated Energy Systems

October 2022

Changing the World's Energy Future

Shannon M Bragg-Sitton



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IES

Integrated Energy Systems

Developing and Demonstrating Nuclear-based Integrated Energy Systems

MARVEL Technology Review

20 October 2022

Shannon Bragg-Sitton, Ph.D.

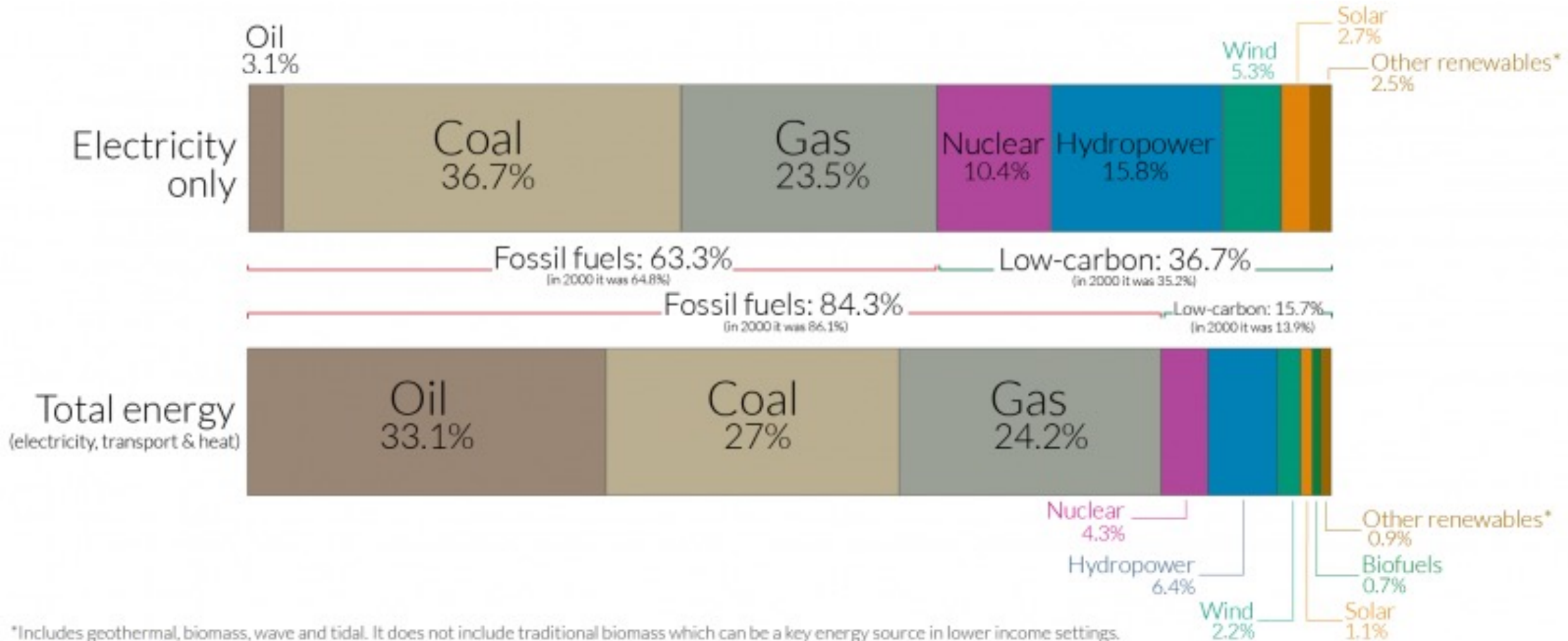
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The global challenge: Decarbonizing electricity and total energy sources (2019)

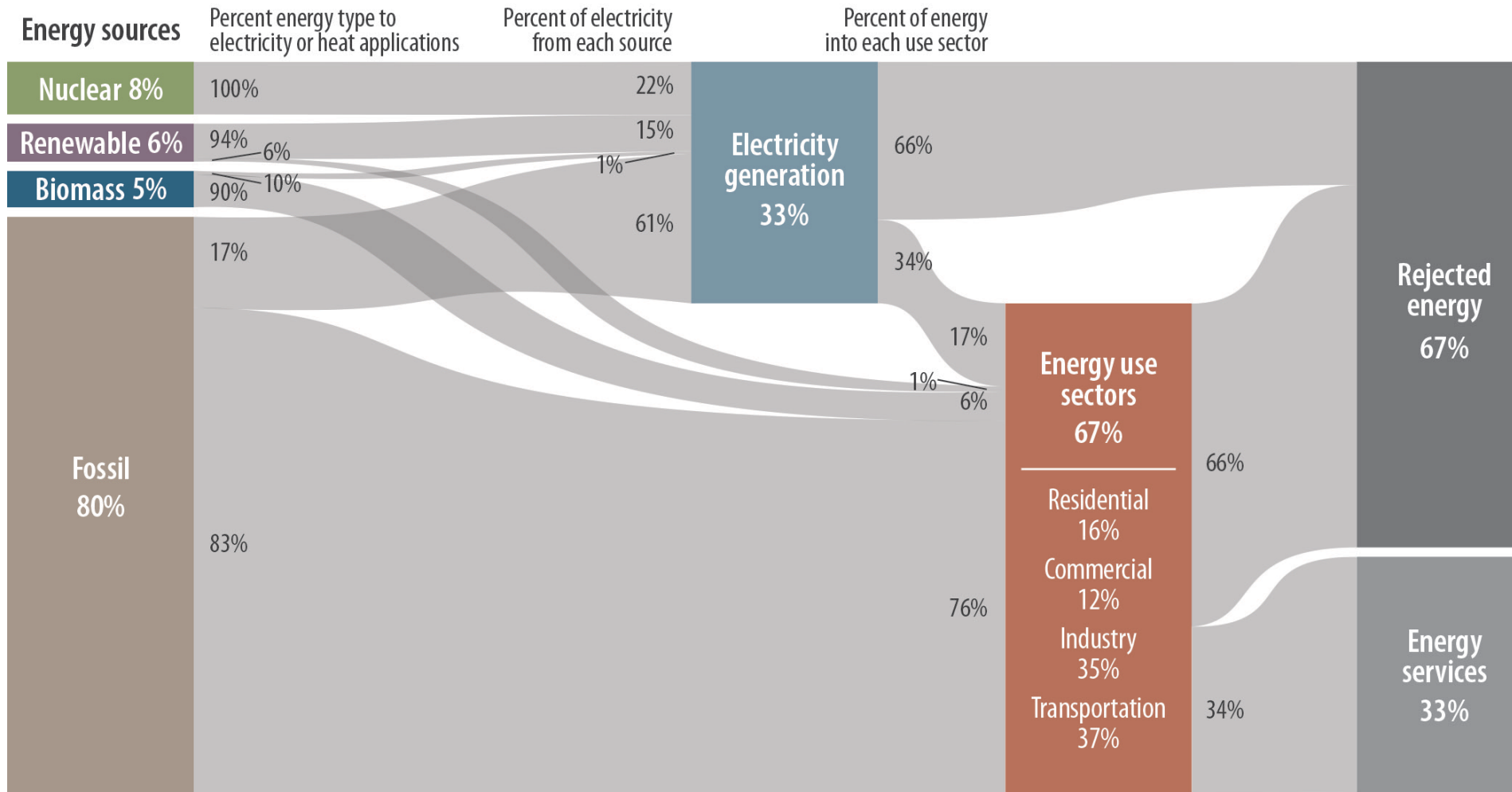


OurWorldInData.org – Research and data to make progress against the world's largest problems.

Source: Our World in Data based on BP Statistical Review of World Energy (2020). Based on the primary energy and electricity mix in 2019.

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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>)

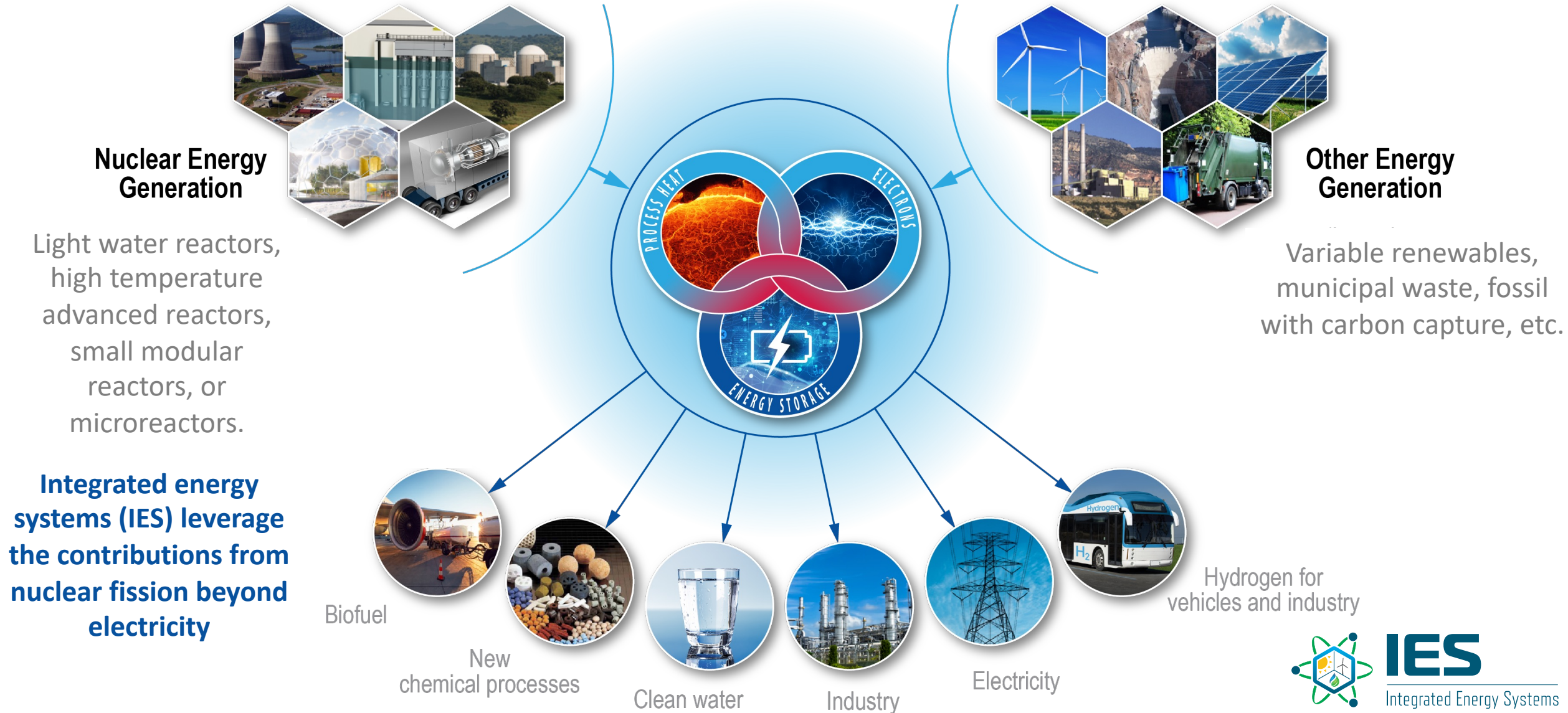
Hydrogen Shot ←
Long Duration Storage Shot
Carbon Negative Shot
Enhanced Geothermal Shot
Floating Offshore Wind Shot
Industrial Heat Shot

Goal: Achieve \$1/kg-H₂ within a decade, emissions free

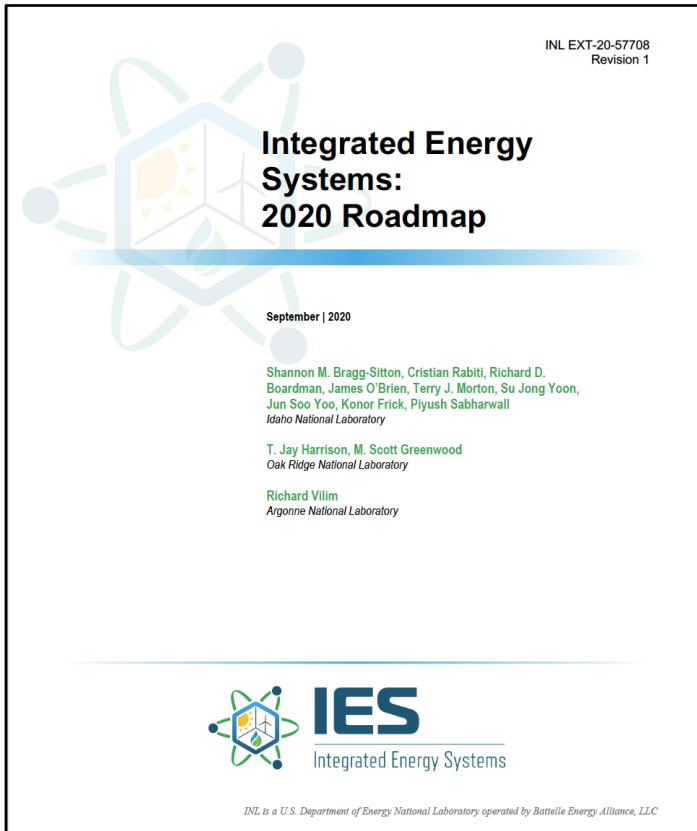


Thinking outside the box: Clean nuclear energy for non-grid applications

Future clean energy systems – transforming the energy paradigm



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



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

Experimental demonstration
for technology development
and model validation

Greenfield system design and
advanced reactor applications

Reduce risk for commercial
LWR-IES deployment

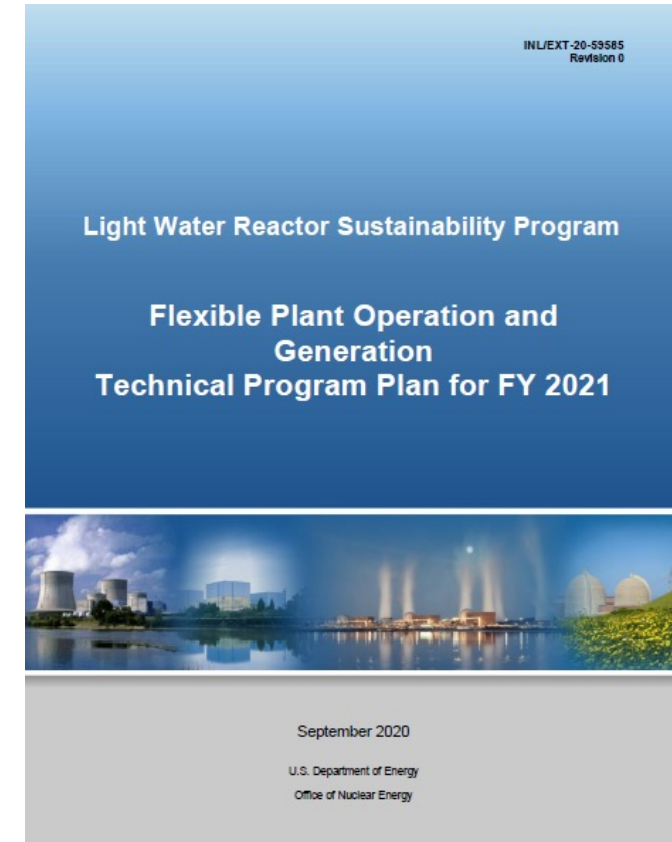
Energy dispatch design and
implementation

Technical and economic
analysis, near-term markets

Safety assessment and
licensing considerations

Timeline for Nuclear IES Deployment

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

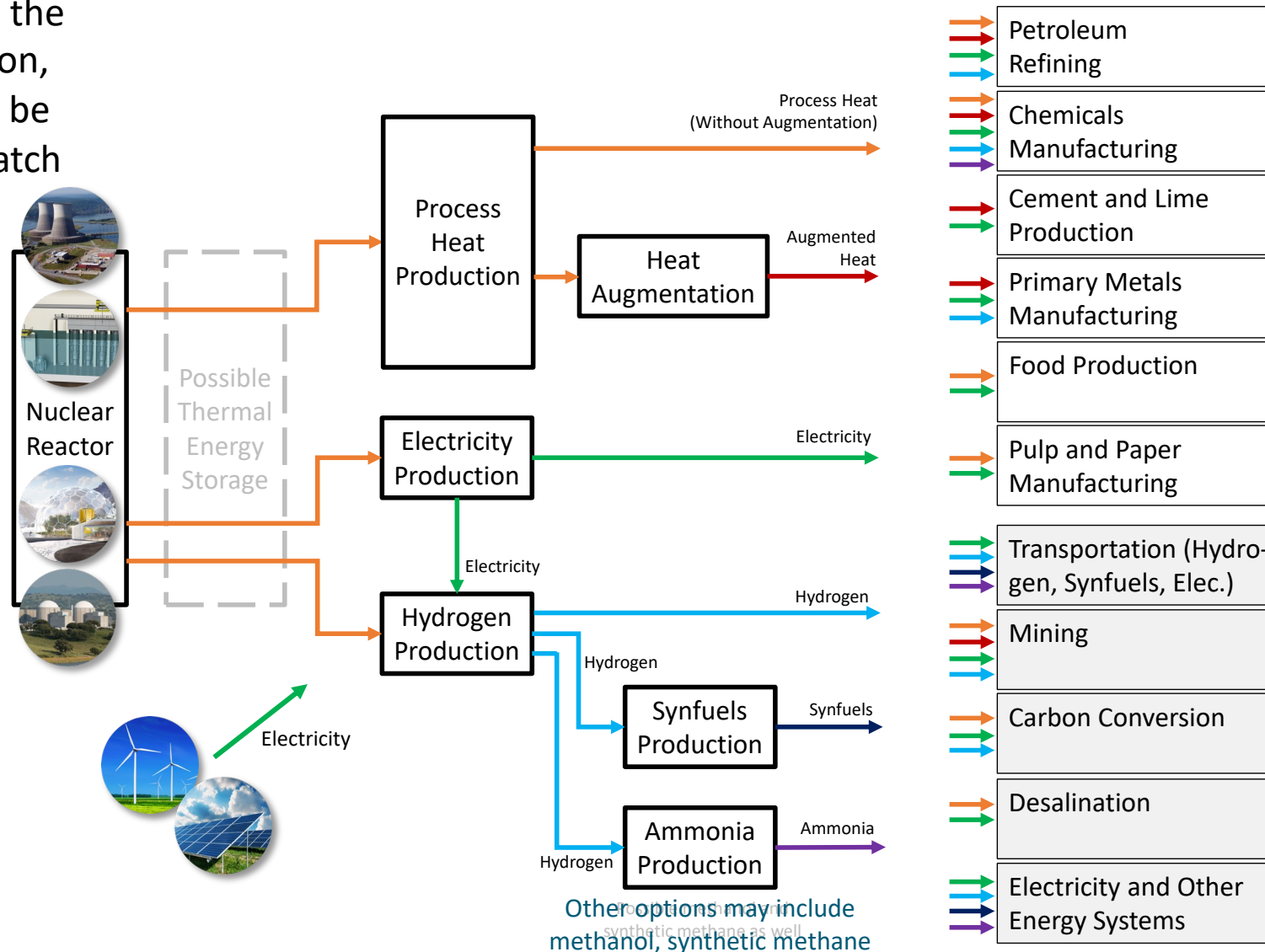


Flexible Plant Operations &
Generation Pathway



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 through IES production coupling?
- What are the **optimal coupling strategies** between IES technologies and nuclear plants?

THE POTENTIAL

Hydrogen is an **economic commodity** and an element for moving energy into fuels and chemicals in the industrial, agricultural, and transportation sectors.

THE PROBLEM

About **95%** of the hydrogen produced in the U.S. comes from **natural gas**, resulting in emissions.

Why focus on hydrogen?

THE IMPACT

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

Oil Refining



Fertilizer Production



Steel Production



Synthetic Fuels



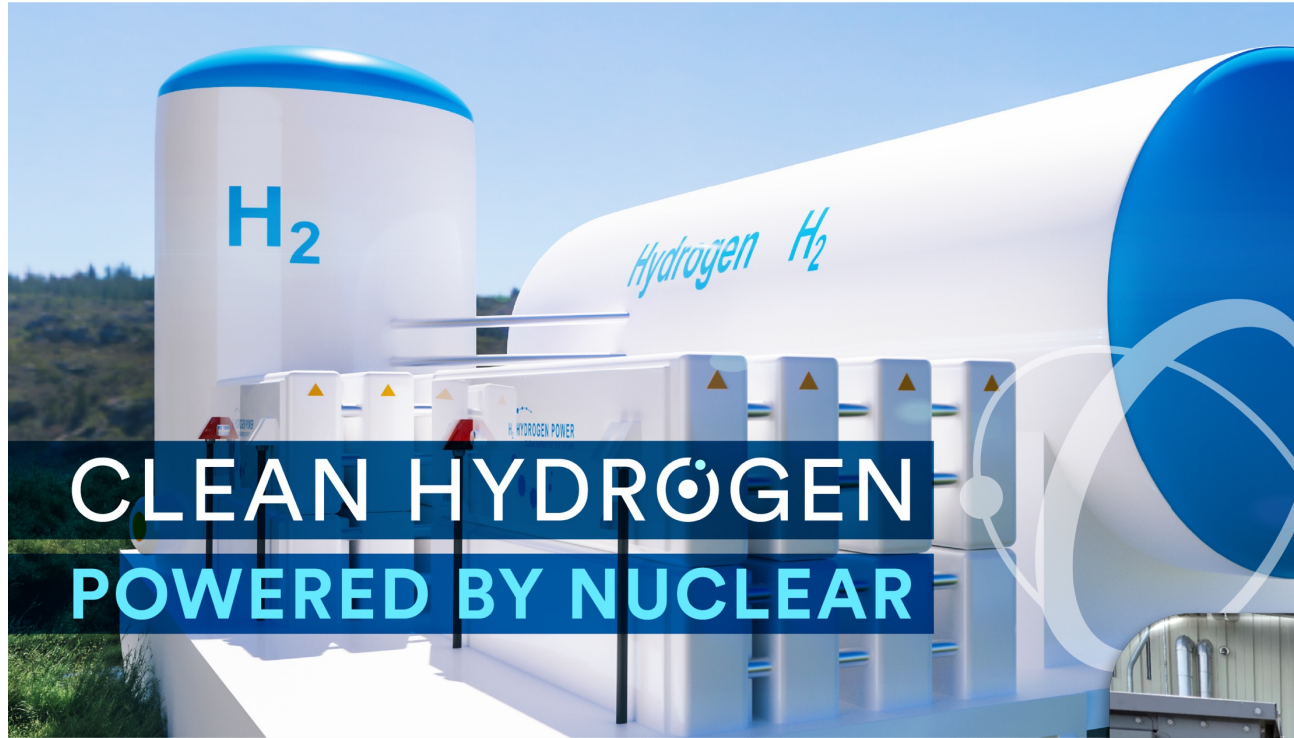
Grid Storage



Transport Fuels



Research and development in nuclear-based IES will enable a clean hydrogen future



THE RESULT

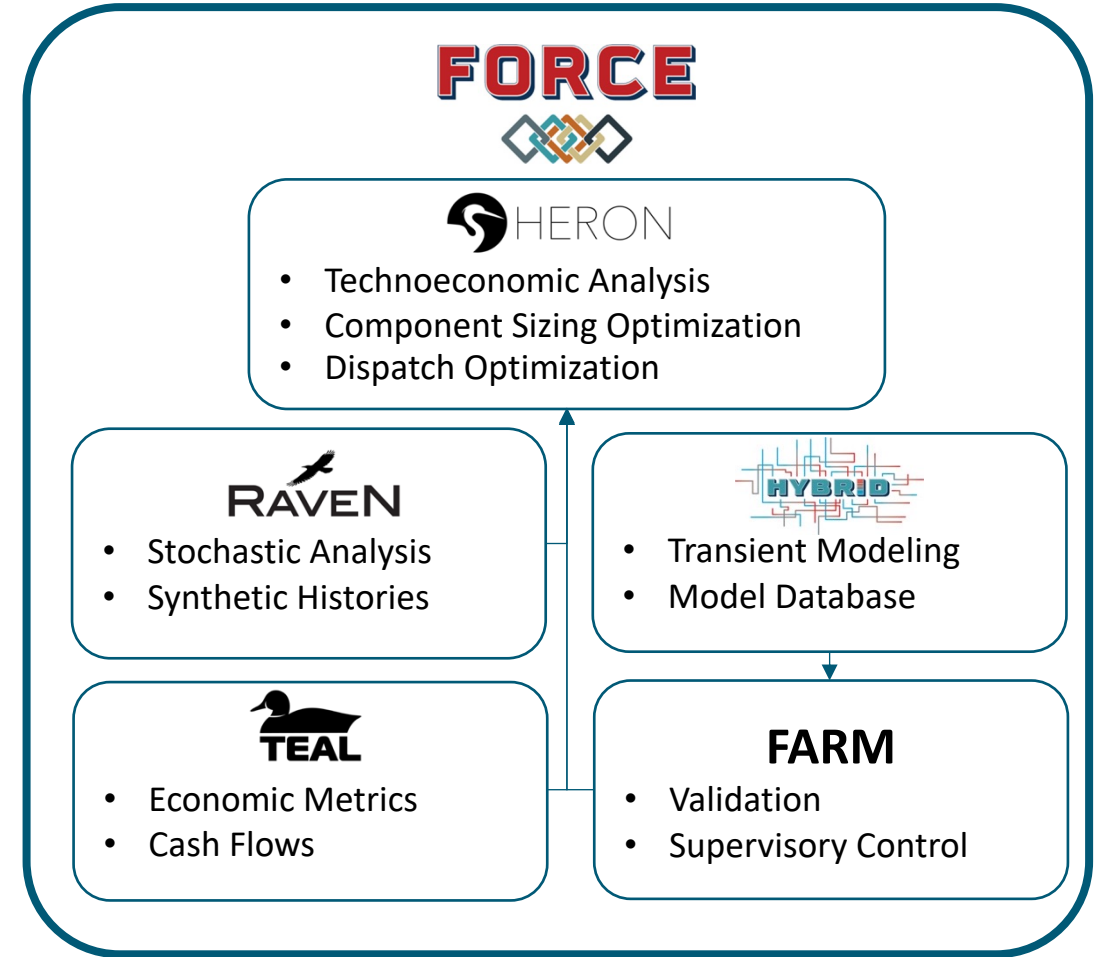
- ✓ Reduces air emissions
- ✓ Deploys hydrogen at scale
- ✓ Expands the use of carbon-free nuclear energy into the transportation and industrial sectors
- ✓ Supports the Hydrogen Shot goal of reducing the cost of clean hydrogen by

80% *to \$1 per kilogram within a decade*



IES analysis and optimization tool suite

- Technoeconomic Assessment for IES: Framework for Optimization of Resources and Economics (FORCE)
 - Optimization
 - Portfolio
 - Dispatch
 - Analysis
 - Economic
 - Stochastic
 - Physical
 - Supervisory Control
 - Workflow Automation

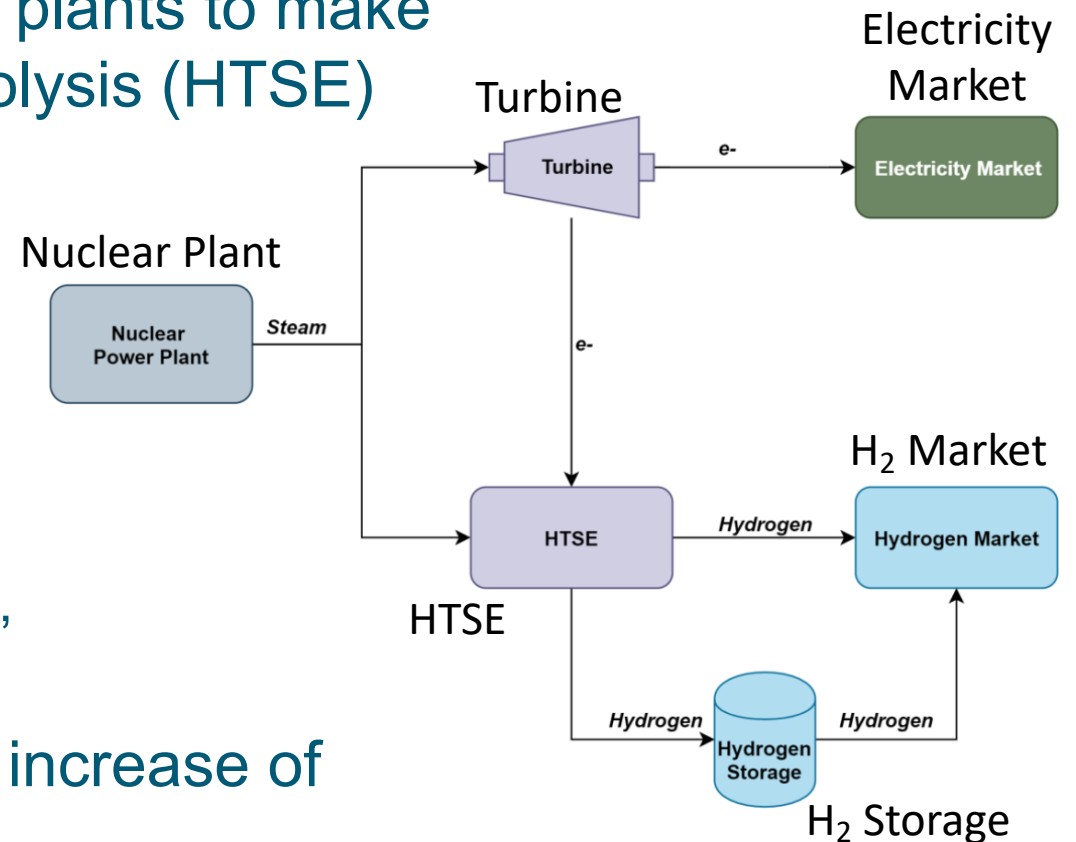


For more information and to access opensource tools, see https://ies.inl.gov/SitePages/System_Simulation.aspx.

Recorded training modules can be viewed at https://ies.inl.gov/SitePages/FORCE_2022.aspx.

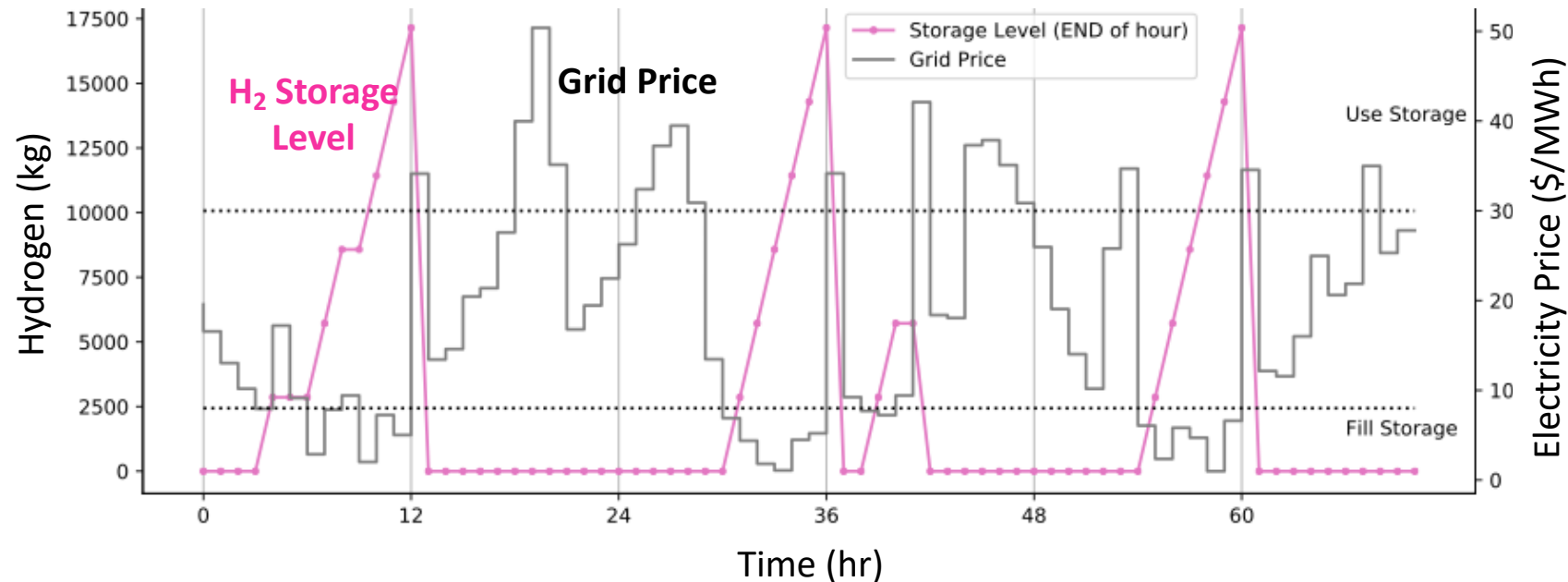
Example: Disruptive potential of nuclear produced hydrogen

- Collaboration between INL, ANL, NREL, Constellation (Exelon), and Fuel Cell Energy
- Evaluated potential of using existing nuclear plants to make hydrogen via high temperature steam electrolysis (HTSE) in parallel to grid electricity
 - Low grid pricing → hydrogen is more profitable
 - High grid pricing → grid is more profitable
 - H₂ storage provides flexibility in plant operations, ensures that all demands are met
 - H₂ off-take satisfies demand across steel manufacturing, ammonia and fertilizer production, and fuel cells for transportation
- Analysis results suggest a possible revenue increase of **\$1.2 billion (\$2019)** over a 17-year span



Flexible Hydrogen production

- Outcome: Award from the DOE EERE Hydrogen & Fuel Cell Technologies Office with joint Nuclear Energy funding for follow-on work and demonstration at Constellation Nine-Mile Point plant.
- Full report: [Evaluation of Hydrogen Production Feasibility for a Light Water Reactor in the Midwest \(INL/EXT-19-55395\)](#)



Nuclear-H₂ demonstration projects

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

- H₂ production using direct electrical power offtake
- Develop monitoring and controls procedures for scaleup to large commercial-scale H₂ plants
- Evaluate power offtake dynamics on NPP power transmission stations to avoid NPP flexible operations
- Produce H₂ 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*



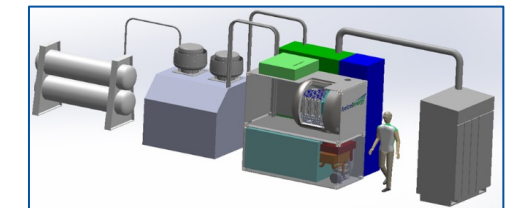
*Davis-Besse NPP
LTE-PEM*



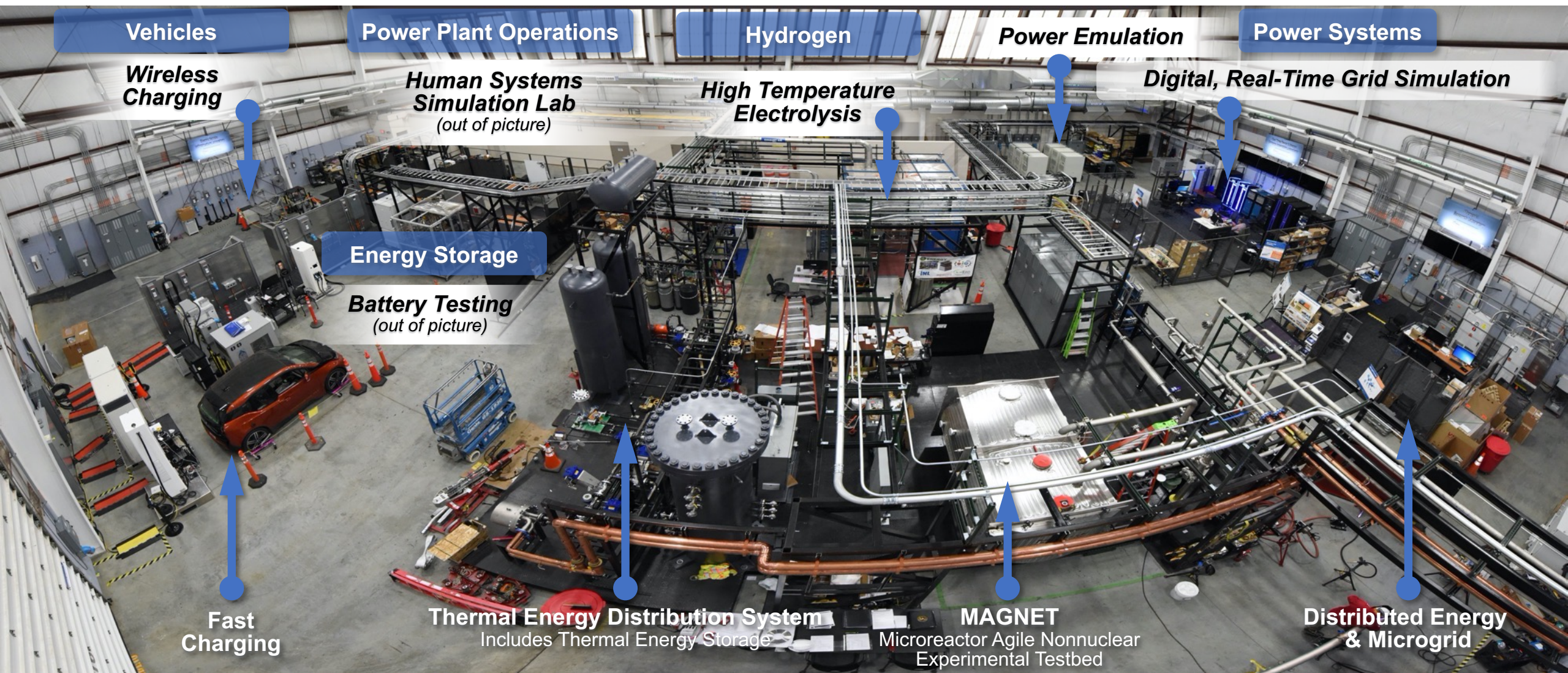
*Thermal & Electrical
Integration at Prairie
Island NPP
HTSE/SOEC*



*FuelCell Energy at
INL, SOEC at
increasing scale*



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

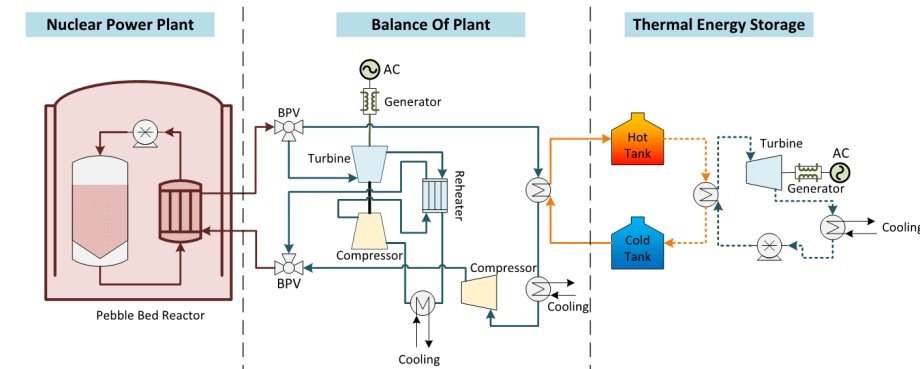


National Reactor Innovation Center (NRIC) advanced reactor testing infrastructure

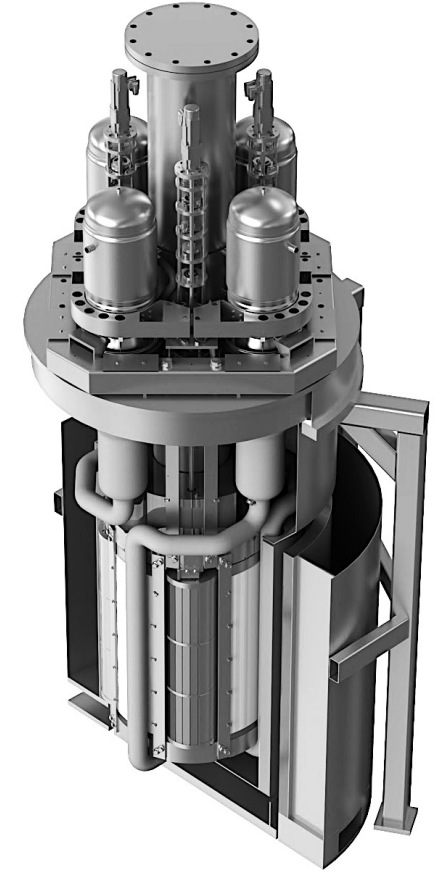
- NRIC Goal: Demonstrate two advanced reactors by 2025
- NRIC Strategy
 - Repurpose two facilities at INL and establish two test beds to provide confinement for reactors to go critical for the first time
 - Build/establish testing infrastructure for fuels and components
- NRIC DOME (Demonstration of Microreactor Experiments)
 - Advanced Microreactors up to 20 MWth
 - High-Assay Low-Enriched Uranium (HALEU) fuels < 20%
- NRIC-IES demonstration platform
 - Design and construct a highly flexible advanced reactor integrated energy system (AR-IES) demonstration platform
 - **Goal:** Demonstrate how advanced reactors can be coupled to various thermal energy users, and how thermal energy storage can enable coupled operation of various thermal loads/users.



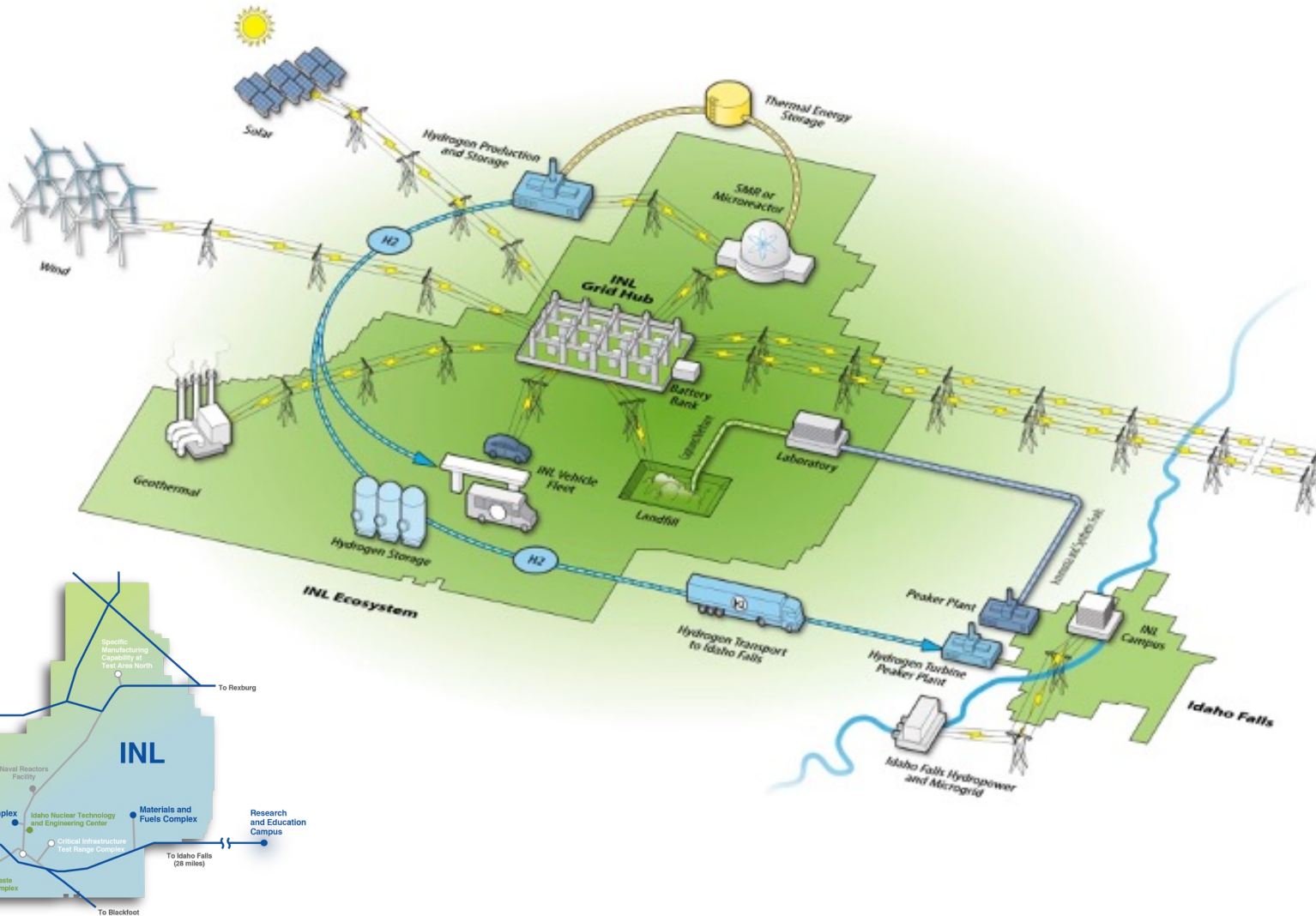
*Anticipate initial reactor testing in ~2024.
Flexible testbed to support testing of
multiple reactor concepts using the same
infrastructure ~annually.*



Demonstrating IES with the MARVEL microreactor

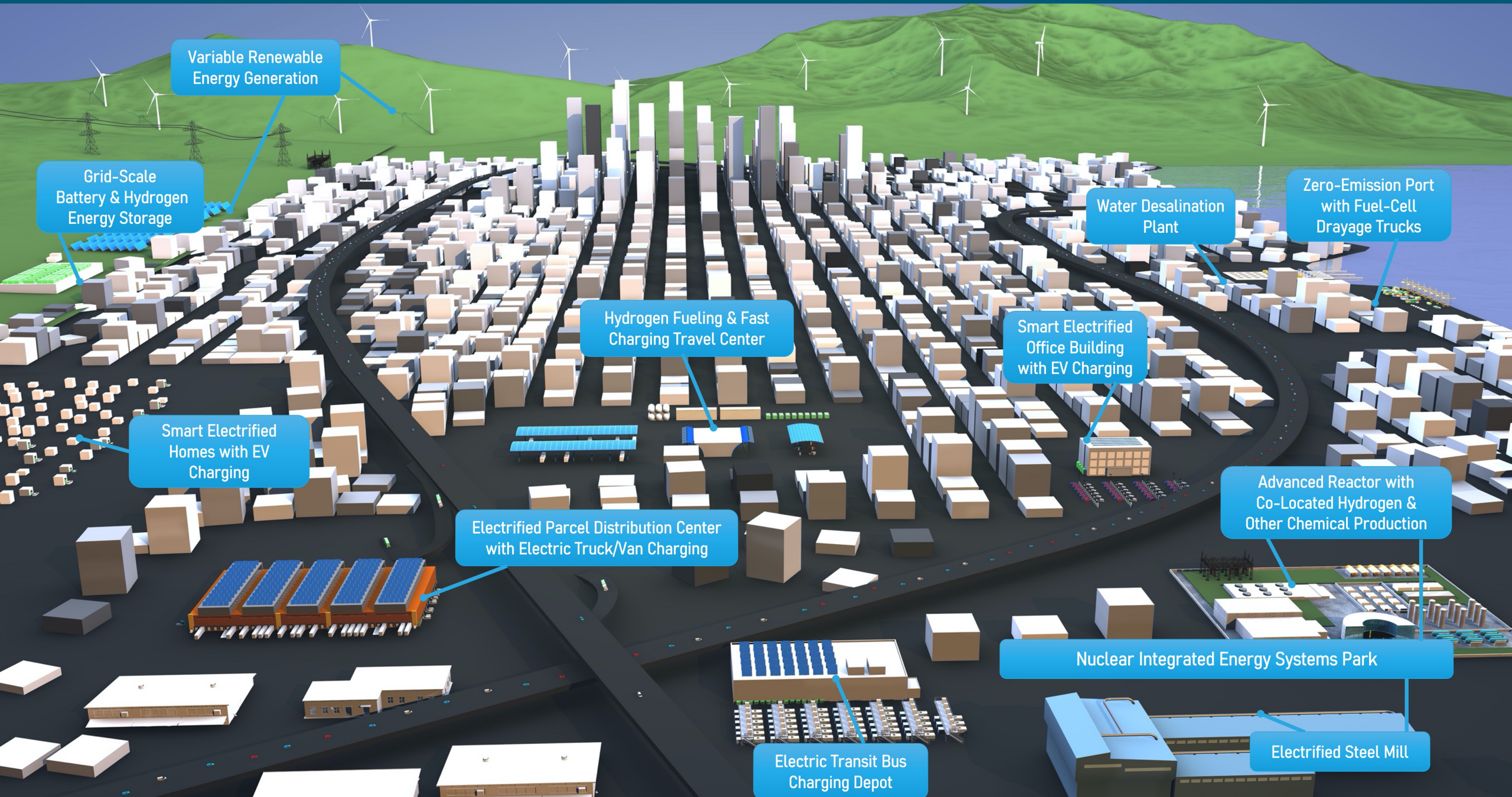


Demonstrating net-zero IES at INL



- 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

A vision for a net-zero future





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