Integrated Energy Systems

Integrated Nuclear-Renewable Energy Systems to Maximize Clean Energy Utilization

Sustainable Nuclear Energy Technology Platform (SNETP) FORUM 2021

virtual platform

4 February 2021

Shannon Bragg-Sitton, Ph.D.

National Technical Director, DOE-NE Integrated Energy Systems

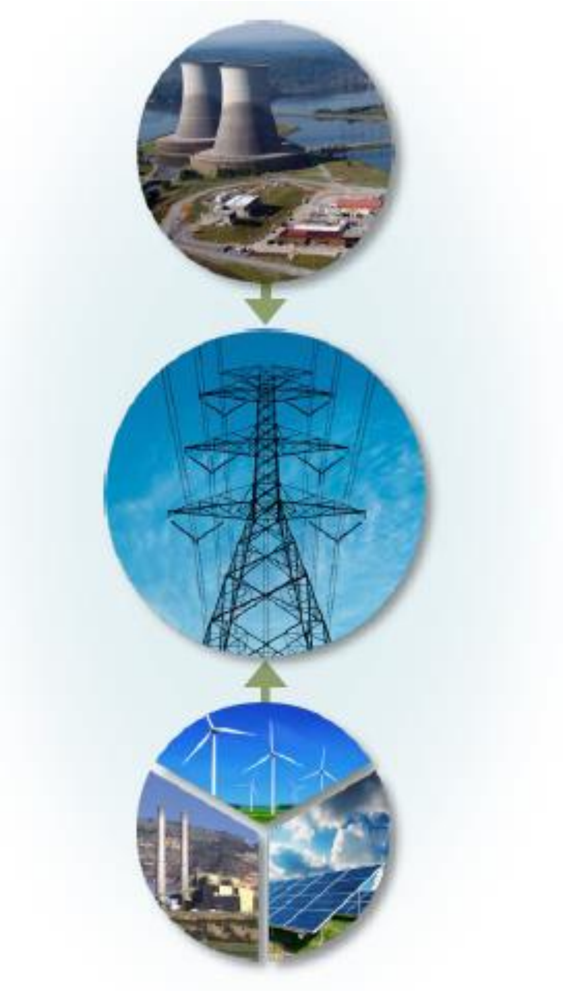
Lead, Integrated Energy Systems

Nuclear Science & Technology

shannon.bragg-sitton@inl.gov

Idaho National Laboratory

Today's Grid



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

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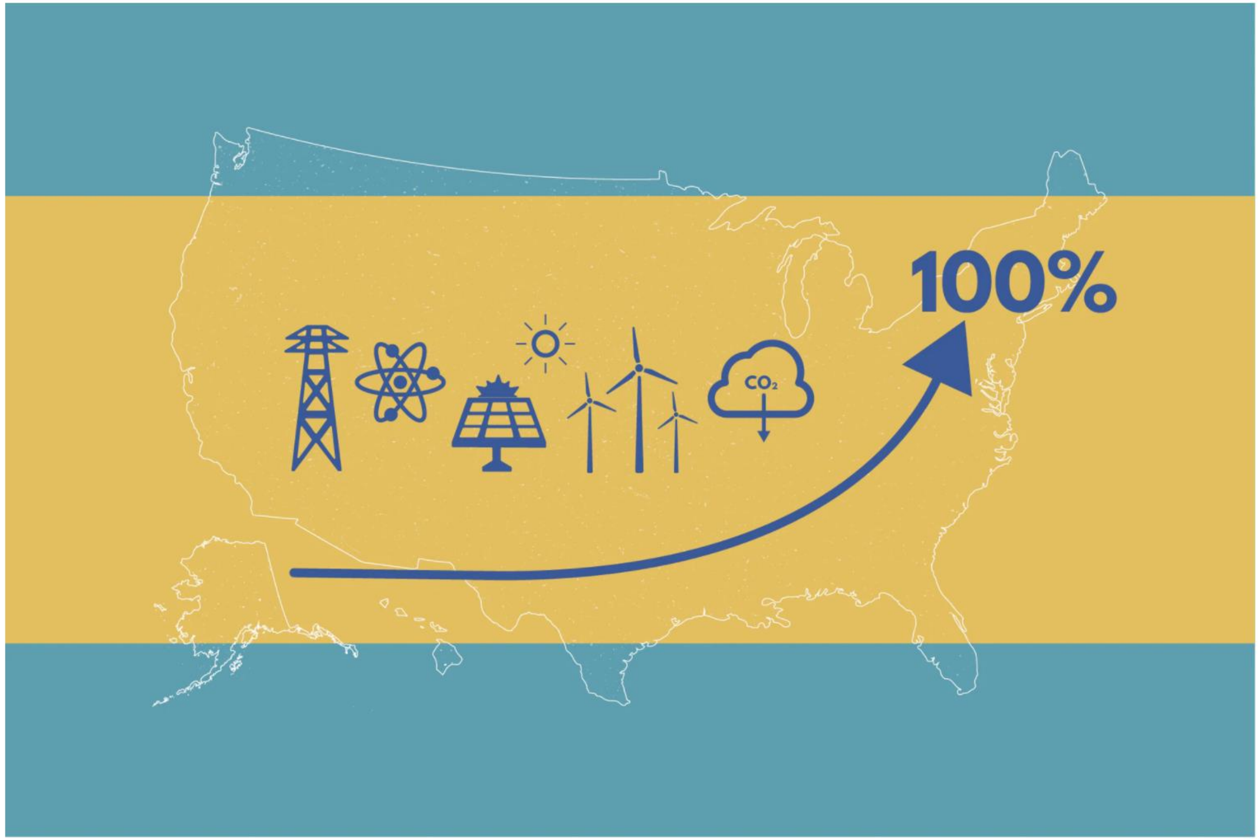
Technology-Inclusive Clean Energy Standards Offer Opportunities

GRAPHIC *Published December 11, 2019 · Updated November 19, 2020 · 15 minute read*

Clean Energy Targets Are Trending



Two essential themes:

Clean energy commitments are rapidly gaining popularity. Our research identified a total of 153 portfolio standards and other commitments to clean energy since 1983. But a whopping 67% of them were adopted just since 2016.

Climate leaders want more technology options to choose from. Prior to 2016, 90% of commitments were exclusive to renewable energy. That trend has almost completely reversed since then, with 73% of states, utilities, and major cities now embracing “technology-inclusive” commitments like clean energy standards that take advantage of nuclear power, carbon capture, and other carbon-free options.

[Go to the article](#)

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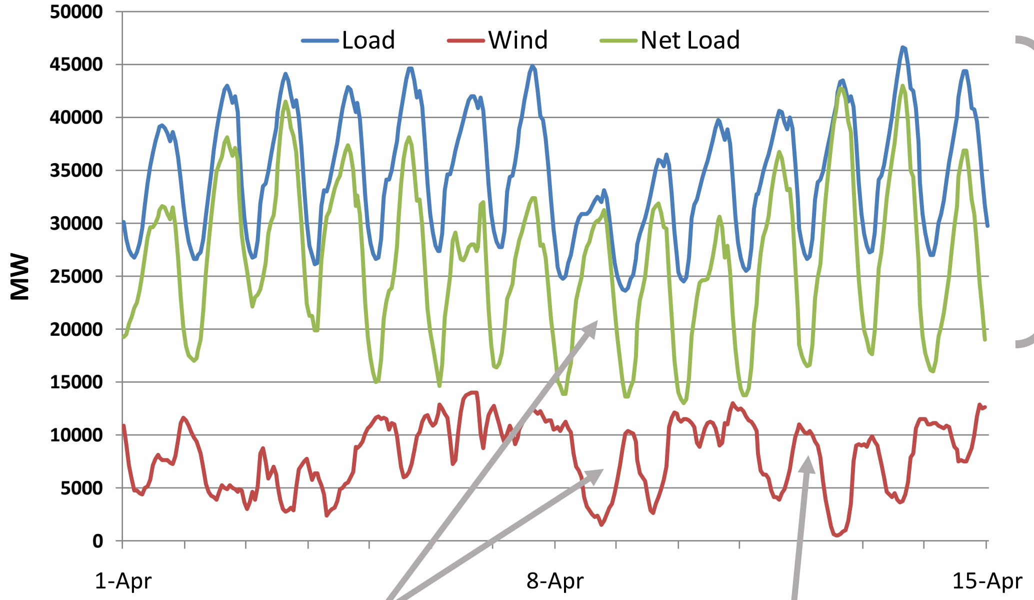
Consequences of Increasing Variable Renewable Power Generation



Ramp Range (increases in this two-week period from 19.3 GW/day to 26.2 GW/day)

Variation in wind output increases net load ramp rate (Increases in this period from 4,052 MW/hour to 4,560 MW/hour)

Uncertainty in wind output increases uncertainty in net load to be met with conventional generators

Figure courtesy NREL

Energy storage is needed to shift excess generation to evening hours

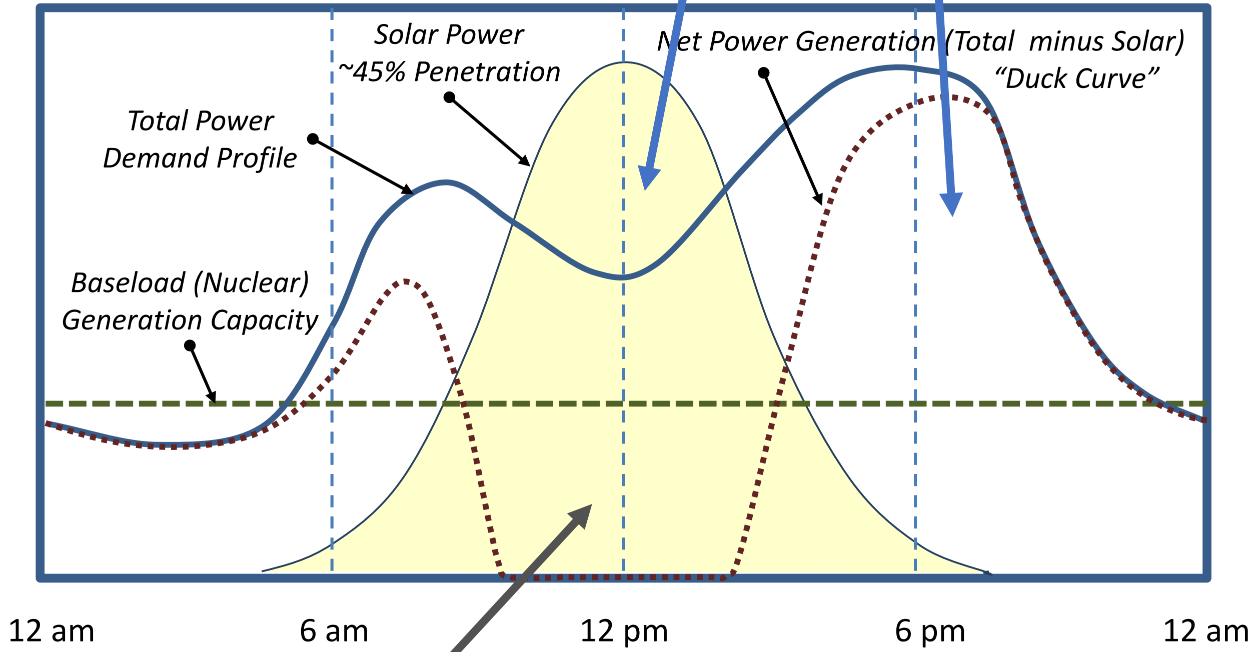


Figure developed by INL

Thermal power plants will be curtailed unless the energy can be used for non-electricity production

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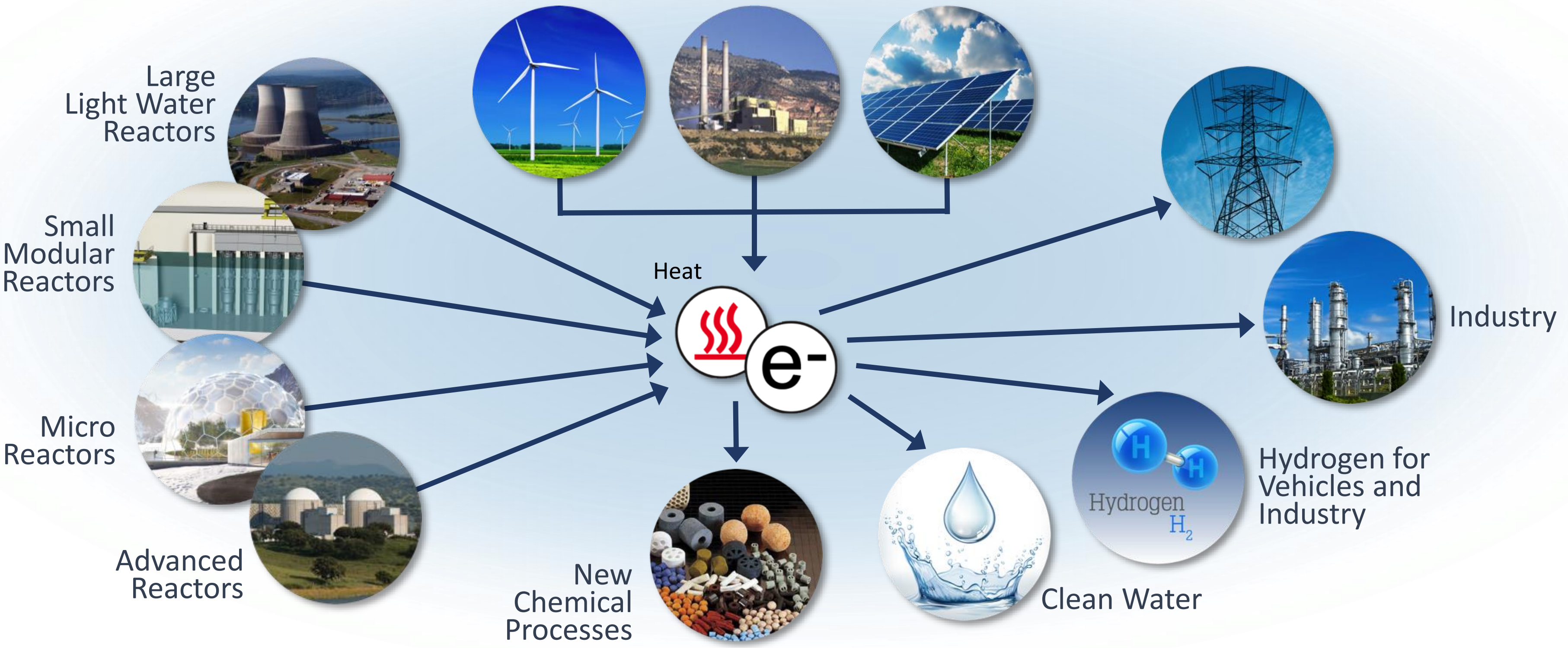
Potential solution: Multi-input, multi-output systems

- Maximizing energy utilization and generator profitability
- Minimizing environmental impacts
- Maintaining affordability, grid reliability and resilience

Potential Future Energy System

Enhanced energy system leverages contributions from low emission energy generation for electricity, industry, and transportation



Flexible Generators ❖ Advanced Processes ❖ Revolutionary Design

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Integrated Energy System Needs: Technology Advancement for Energy Transport, Conversion & Storage

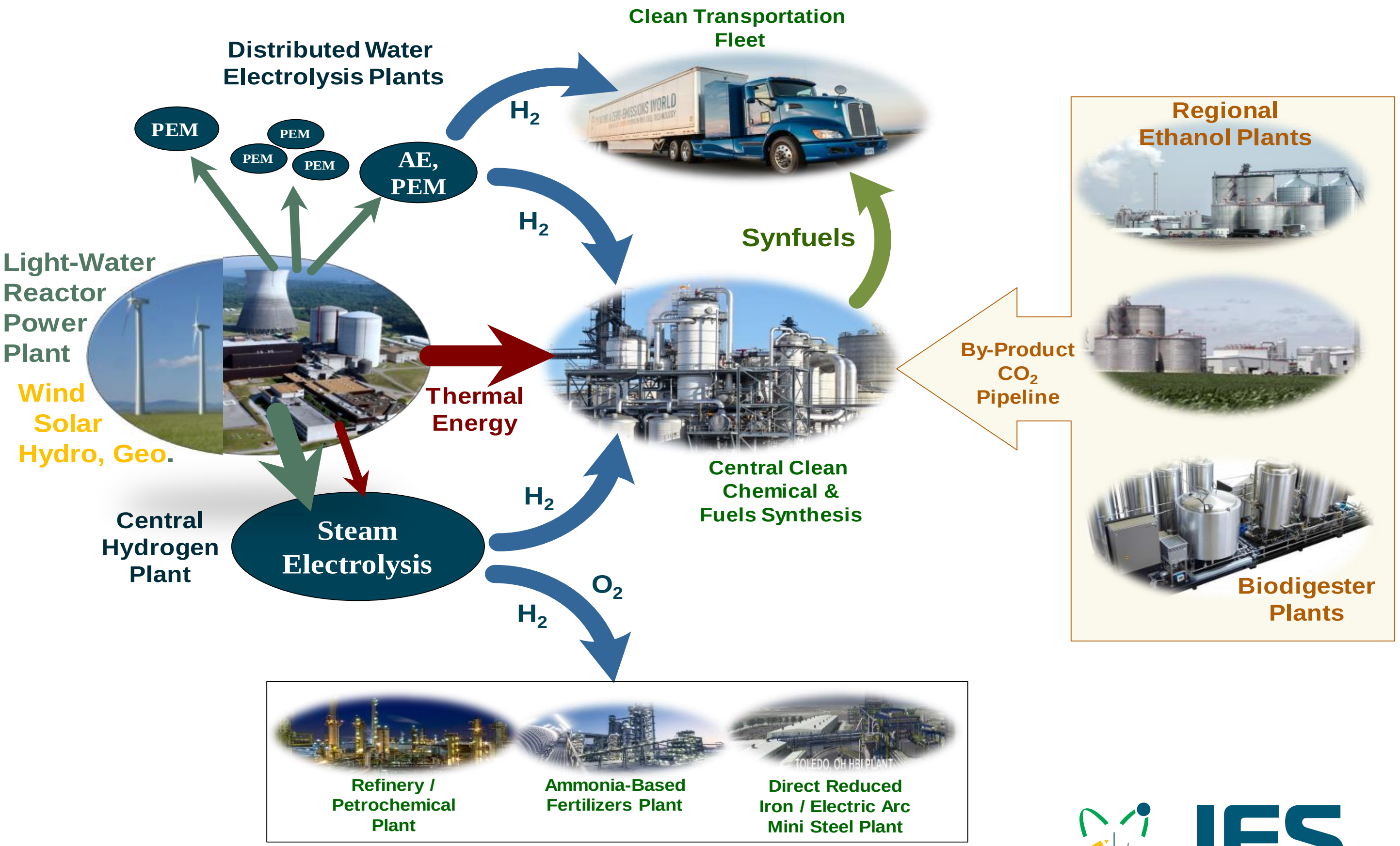
Integrated Energy Systems Involve

- Thermal, electrical, and process intermediates integration
- More complex systems than co-generation, poly-generation, or combined heat and power
- May exploit the economics of coordinated energy systems
- May provide grid services through demand response (import or export)

Technology Development Needs & Opportunities

- New energy storage technologies (thermal, chemical, and electrical)
- Thermo-Electrical chemical conversion processes
- Modern advanced informatics and decision systems for massive data
- Embedded sensors for health monitoring
- Cyber security approaches

Example: Nuclear-driven IES in the U.S. Midwest
(notional)



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Priority Application: Conceptual H_2@Scale Energy System*

Can hydrogen effectively be a new energy currency for nuclear energy?

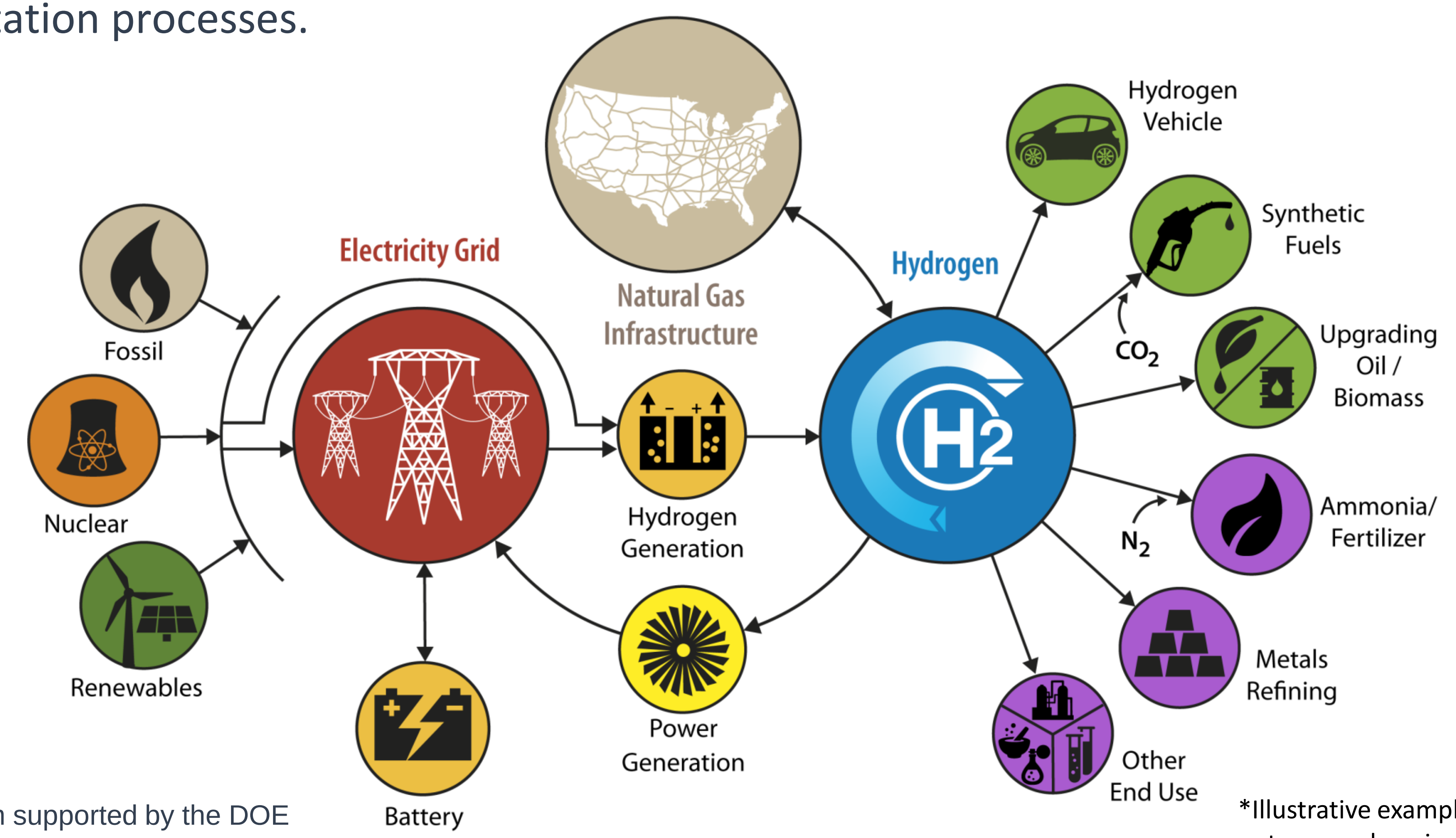
Vision: Leverage hydrogen's unique ability to address cross-energy sector issues and to enable clean, efficient industrial and transportation processes.

Hydrogen Attributes:

- Clean and convenient energy carrier
- Scalable energy storage
- Vital to fuels and chemicals production
- Used to upgrade coal to higher value products

Other key H2@Scale Benefits:

- Provides grid resiliency
- Deeply reduces air pollutant emissions



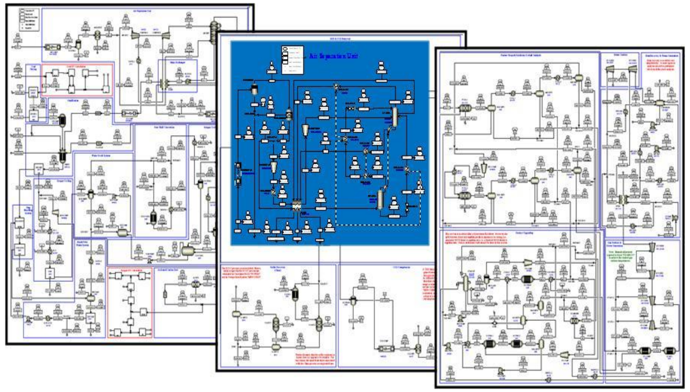
*H2@Scale is a complementary, collaborating program supported by the DOE Energy Efficiency & Renewable Energy Hydrogen & Fuel Cell Technologies Office.

*Illustrative example, not comprehensive

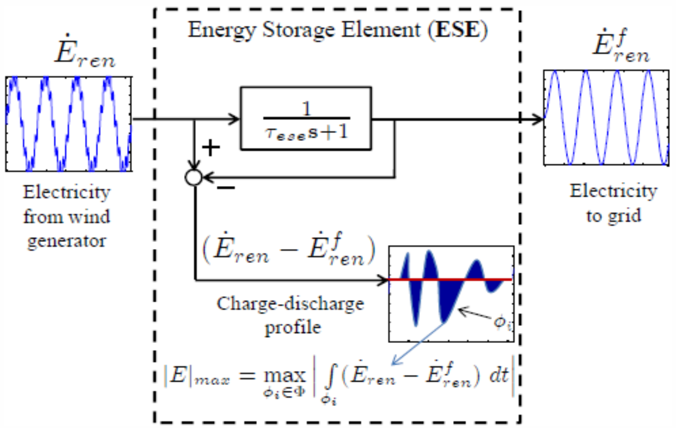
Modeling, Analysis, and Evaluation for Optimal Energy System Design and Realtime Dispatch

Graded approach to identify design options and evaluate integrated system architectures

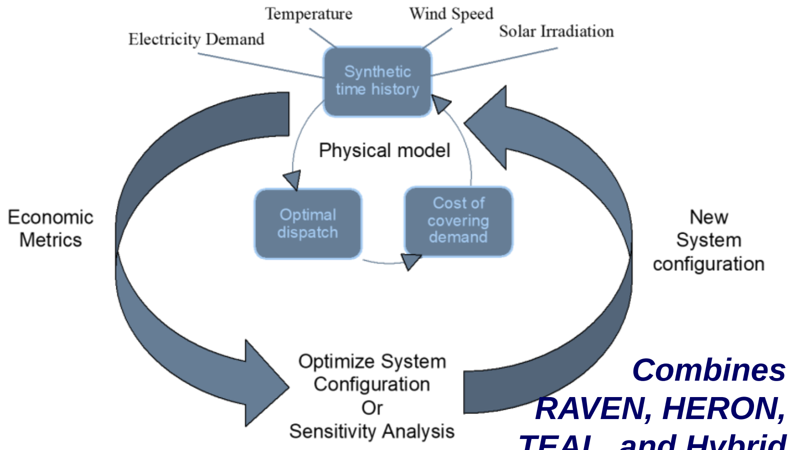
Aspen Plus® and HYSYS® Process Models



Modelica®, Aspen Dynamics®



Framework for Optimization of ResourCes and Economics (FORCE) (System-level Optimization)



Combines RAVEN, HERON, TEAL, and Hybrid

Process Modeling technical and economic value proposition

Dynamic Modeling technical and control feasibility

High Fidelity Optimization energy system design and realtime dispatch

Leveraging commercial and specially-designed simulation tools.

Consideration of Resource—Technology—Economic—Market Potential

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Tri-laboratory initiative collaboration for IES

- The U.S. DOE Applied Energy Tri-Laboratory Consortium published a foundational article on modeling, simulation, and analysis approaches for novel hybrid energy systems
- The consortium includes INL (nuclear energy), the National Renewable Energy Laboratory, and the National Energy Technology Laboratory (fossil energy)
- The intelligent design of increasingly complex, multidimensional energy systems is a significant challenge, requiring innovations in the approaches to formulate and optimize the complex, dynamic, multiscale interactions among energy sources, electricity generation and distribution, energy services, energy-intense processes and products, and markets

Joule

Volume 5, Issue 1, 20 January 2021, Pages 47-58

CellPress

Perspective

Multi-input, Multi-output Hybrid Energy Systems

Douglas J. Arent [1], Shannon M. Bragg-Sitton [2], David C. Miller [3], Thomas J. Tarka [3], Jill A. Engel-Cox [1, 4], Richard D. Boardman [2], Peter C. Balash [3], Mark F. Ruth [1], Jordan Cox [1], David J. Garfield [1]

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https://doi.org/10.1016/j.joule.2020.11.004   Get rights and content

- The Tri-Lab team is working to develop a framework for modeling, analysis, and optimization of these systems and identifies key capabilities that are needed to adequately represent tightly coupled HES
- Successful implementation of this new paradigm requires interdisciplinary RD&D via cross-sector research programs

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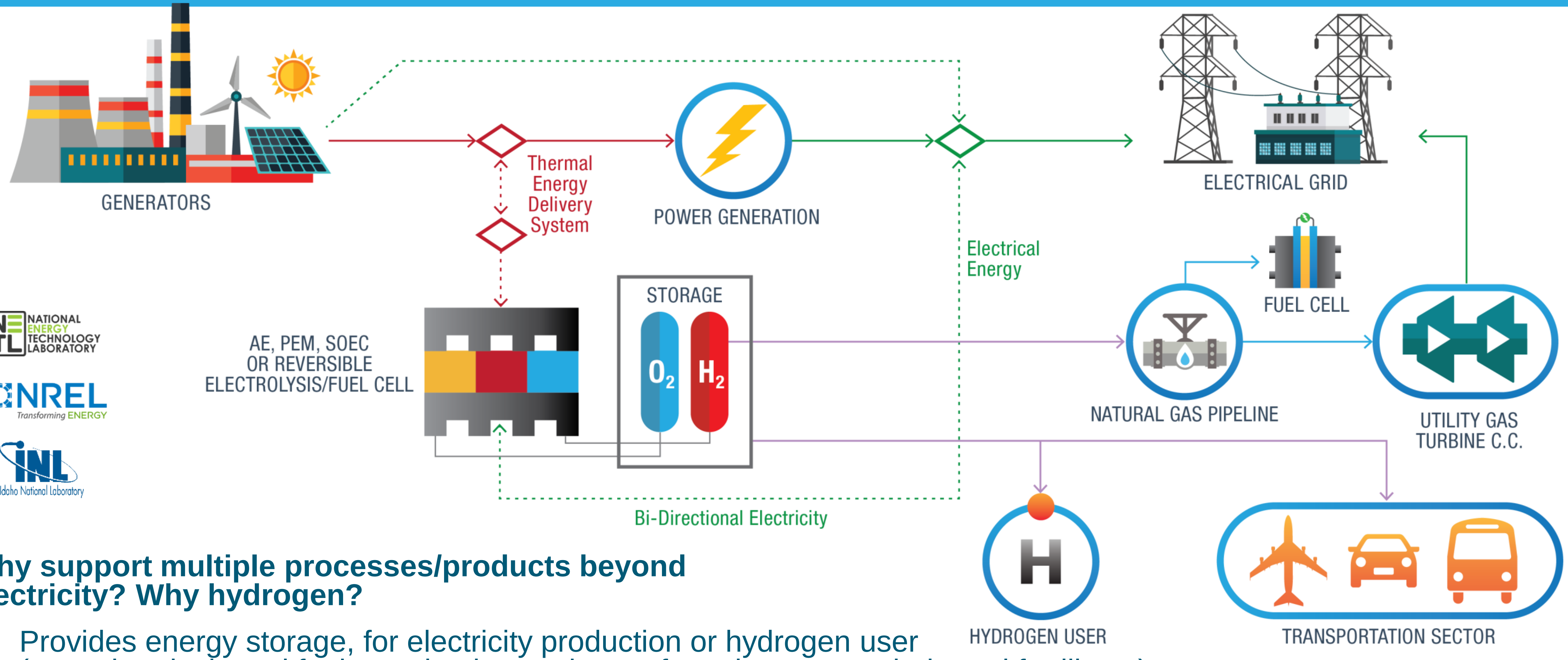
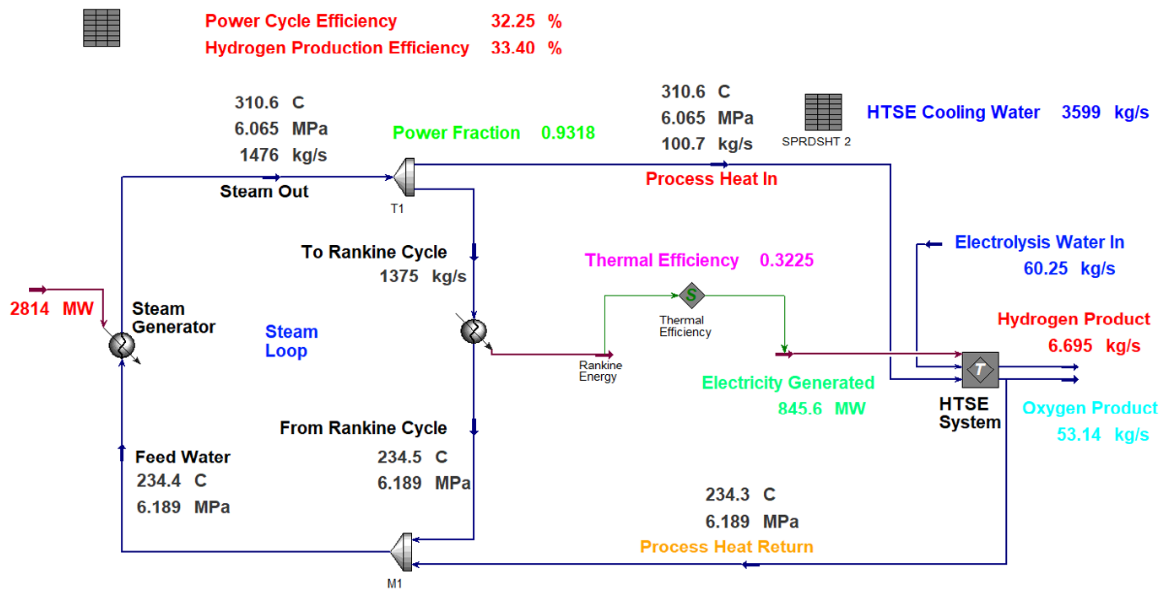
Example: Multiple Generators for Hydrogen Production

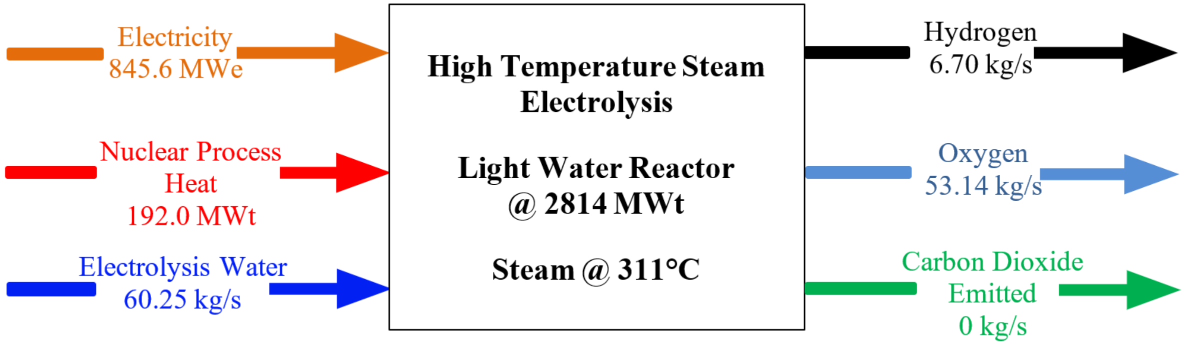


Why support multiple processes/products beyond electricity? Why hydrogen?

1) Provides energy storage, for electricity production or hydrogen user (e.g., chemicals and fuels synthesis, steel manufacturing, ammonia-based fertilizers)
2) Provides second source of revenue to the generator
3) Provides opportunity for grid services, including reserves and grid regulation

IES Technoeconomic Analysis





INL/EXT-19-55090, ***Evaluation of Non-electric Market Options for a Light-water Reactor in the Midwest***, August 2019.

- Identify potential integration points for thermal and electrical interconnections between the nuclear plant and energy user (e.g., high temperature electrolysis)
- Design and evaluate system control approaches
- Assess energy and process flows
- Evaluate and optimize process economics to determine cost to produce commodities (e.g., electricity, hydrogen)
- Assess market viability for the nuclear-IES, e.g.,
  - Determine resulting levelized cost of H_2 as a function of various assumptions (production scale, efficiency, electricity price, etc.)
  - Evaluate product costs relative to incumbent technology, i.e., steam methane reforming
- Determine optimal realtime energy dispatch to coupled energy users

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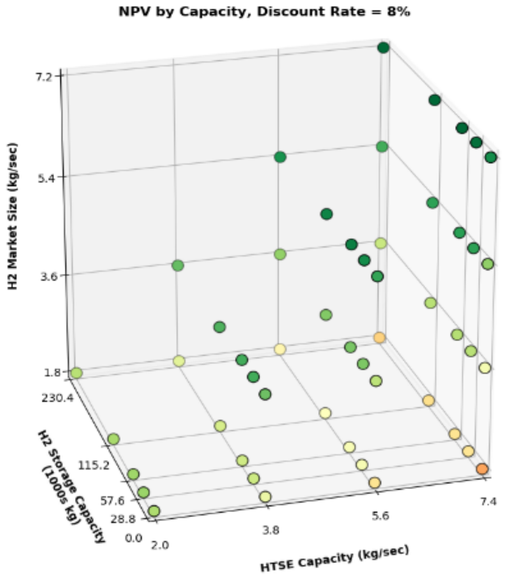
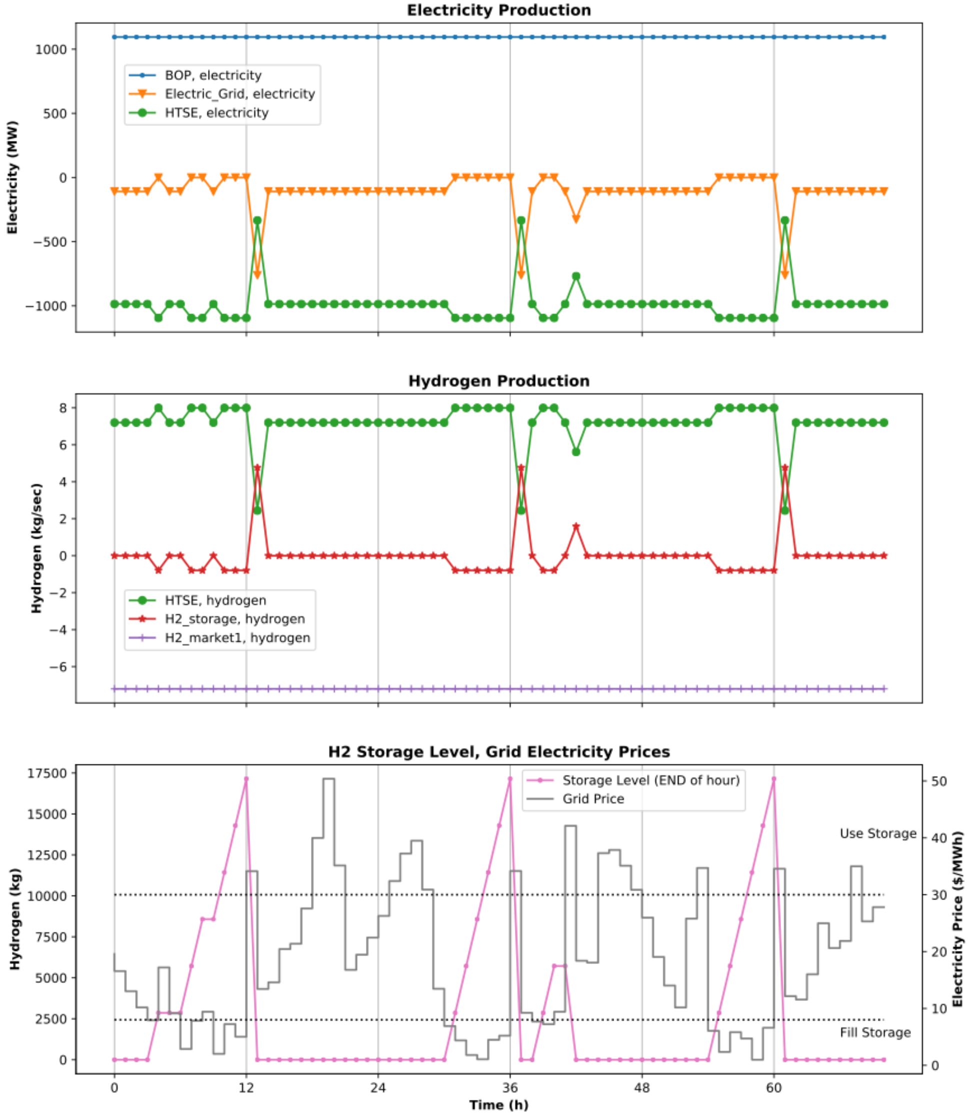
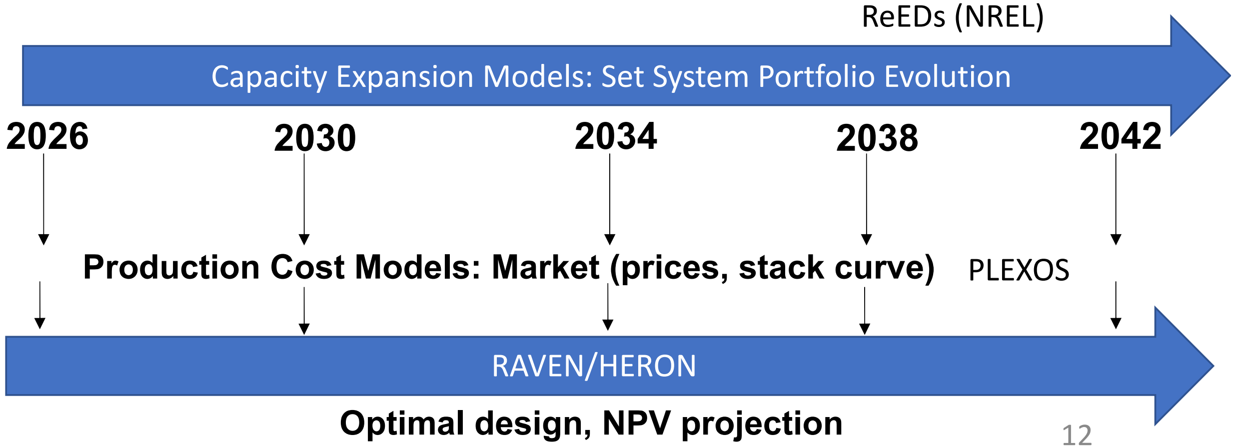
Plant- and Region-Specific Case Analyses: NPV Optimization

- LWR with thermally coupled HTE
- Markets
  - Day ahead electricity
  - Hydrogen (demand curve)
- NPV optimization, parameters
  - Electricity price (buy vs. sell)
  - H_2 production capacity
  - H_2 storage capacity
- Constraints
  - Maintain hot standby for HTE
  - Ramp rates for switching (grid vs. H_2)
  - 24/7 provision of H_2 to market

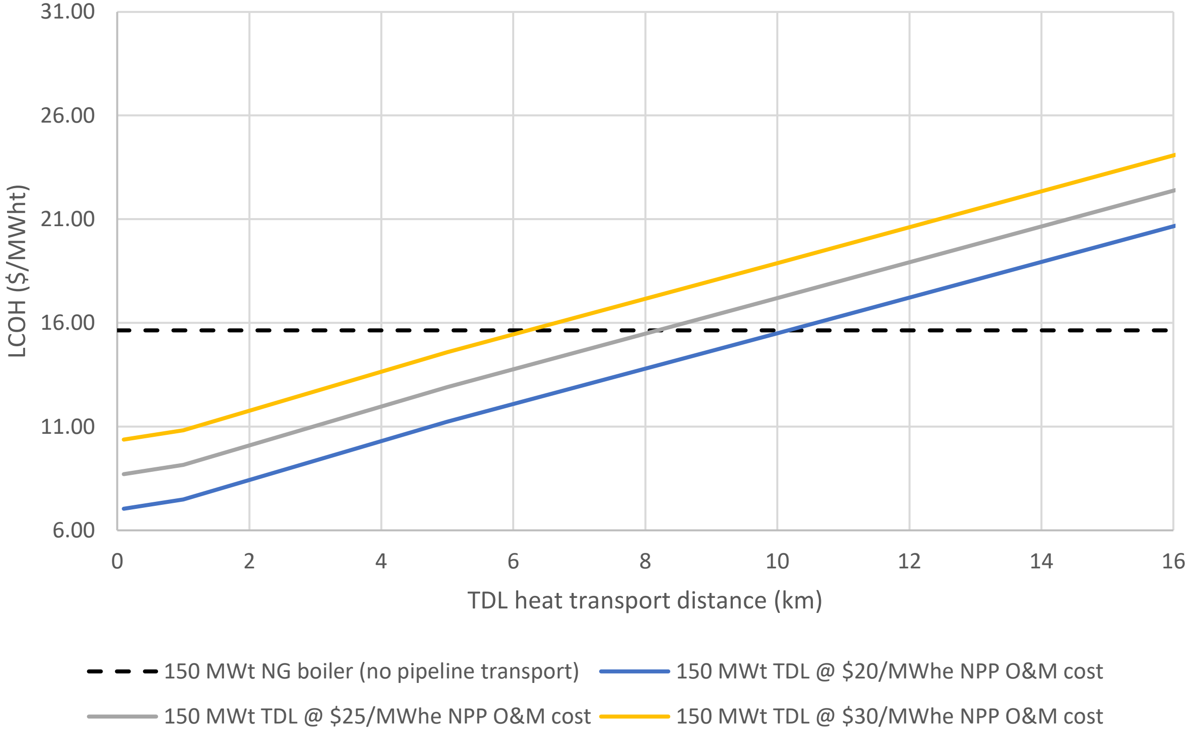
Optimize Net Present Value



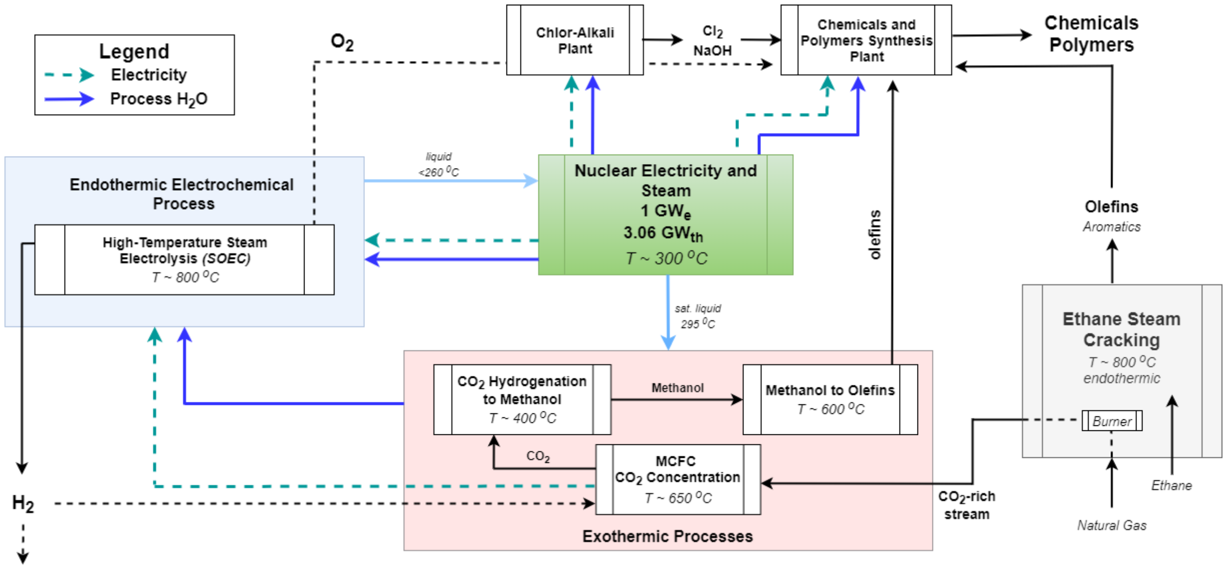




Finding cost-competitive markets for nuclear



Cost of High-Pressure Steam Delivery from a Nuclear Power Plant to Industrial Users versus Natural Gas Boiler (in 2019$)



Specific Industrial Park Concept using nuclear heat and electricity to produce chemicals and polymers with minimal CO_2 emissions

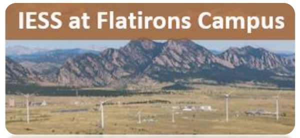
INL/EXT-20-58884: Markets and Economics for Thermal Power Extraction from Nuclear Power Plants for Industrial Processes, June 2020
https://www.osti.gov/biblio/1692372-markets-economics-thermal-power-extraction-from-nuclear-power-plants-aiding-decarbonization-industrial-processes

LWRS LIGHT WATER REACTOR SUSTAINABILITY

Dynamic Energy Transport and Integration Laboratory (DETAIL)

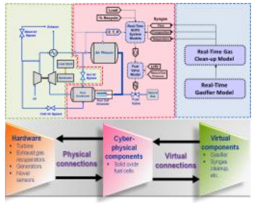
Idaho National Laboratory

ARIES



NREL
Transforming ENERGY

NATIONAL ENERGY TECHNOLOGY LABORATORY



Human-in-the-Loop

Power Hardware and Grid-in-the-Loop

Hydrogen and other Flexible Industrial Processes

Thermal Energy Generation and Transport

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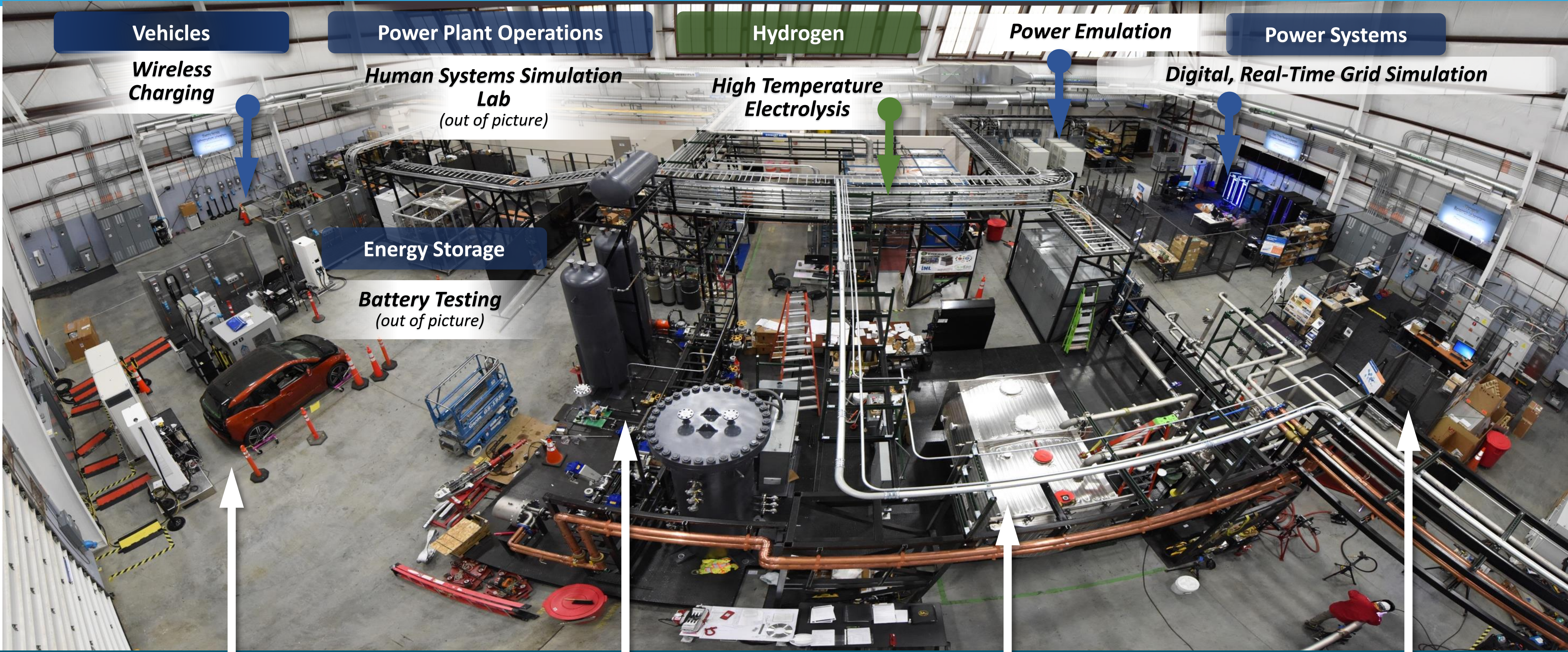
Energy Systems Laboratory



Fast Charging

Thermal Energy Distribution System (TEDS)
Includes Thermal Energy Storage

Microreactor Agile Nonnuclear Experiment Testbed (MAGNET)

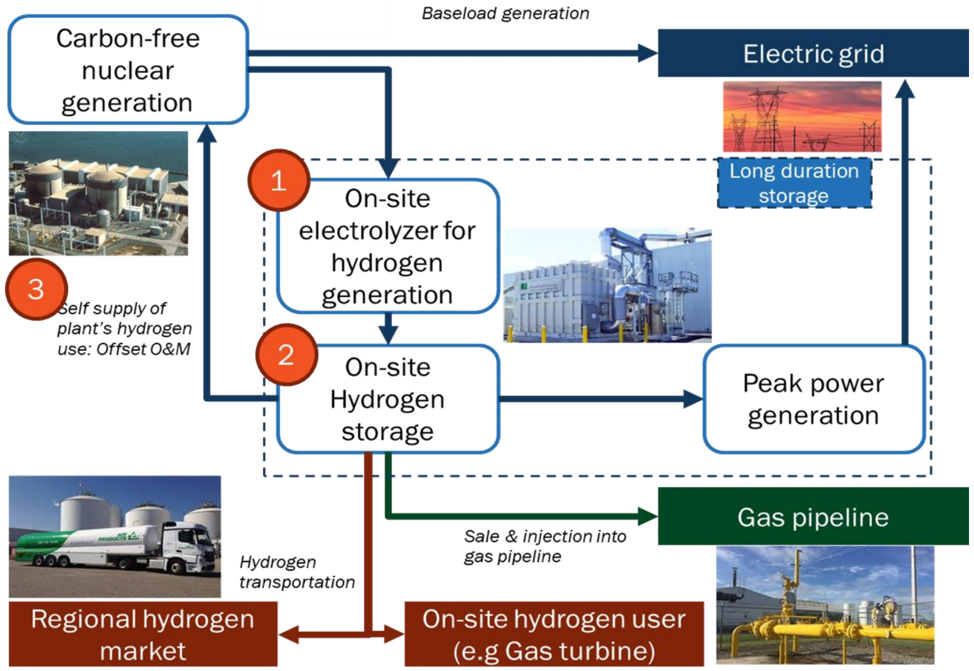
Distributed Energy & Microgrid

Advancing Private-Public Partnerships for LWR-H_2 Demonstration Projects

Exelon

Nel Hydrogen, ANL, INL, NREL (via DOE)

Purpose: Demonstrate hydrogen production using direct electrical power offtake from a nuclear power plant



Analysis Report: Evaluation of Hydrogen Production for a Light Water Reactor in the Midwest

**Exelon plans commence testing in 2021

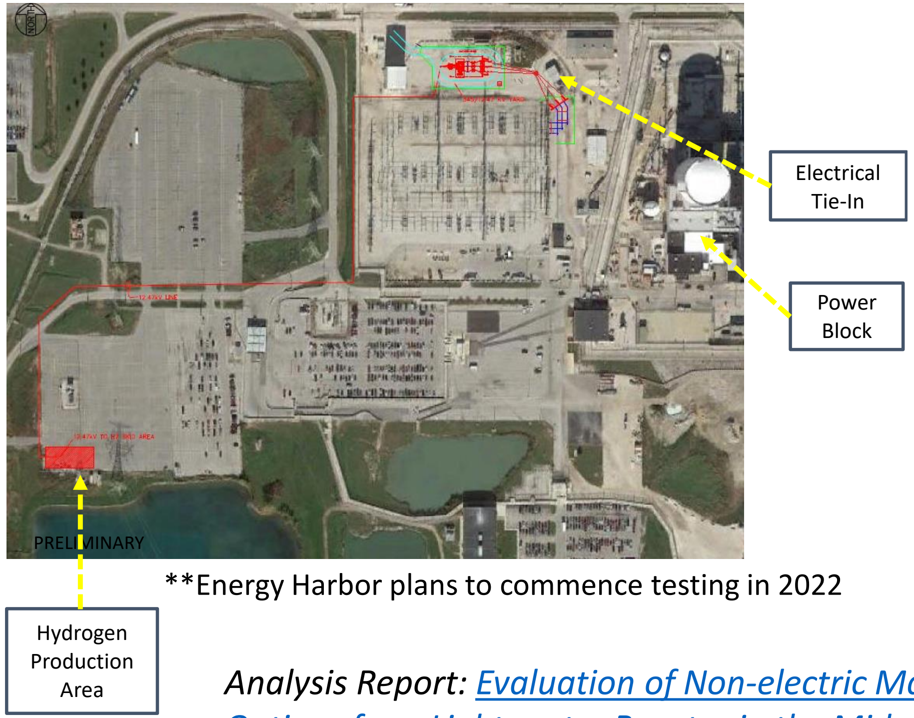
Both projects are public-private partnerships funded via collaboration among DOE-NE, DOE-EERE HFTO, and industry.

energy harbor

Xcel Energy

aps

Purpose: Produce hydrogen for first movers of clean hydrogen; fuel-cell buses, heavy-duty trucks, forklifts, and industrial users

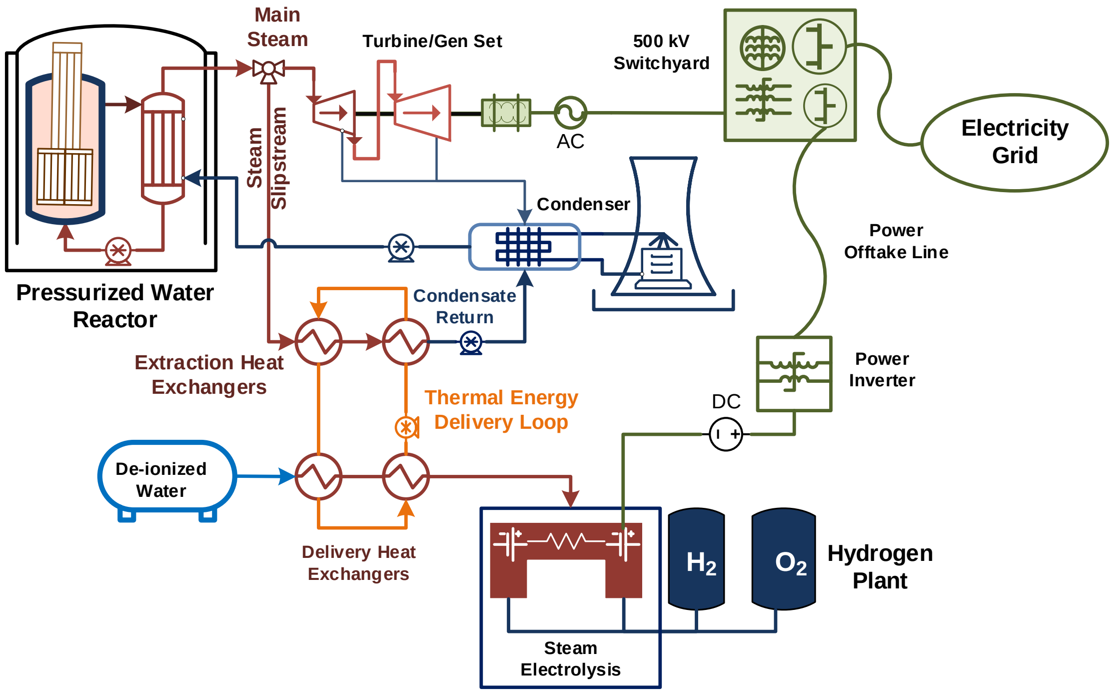


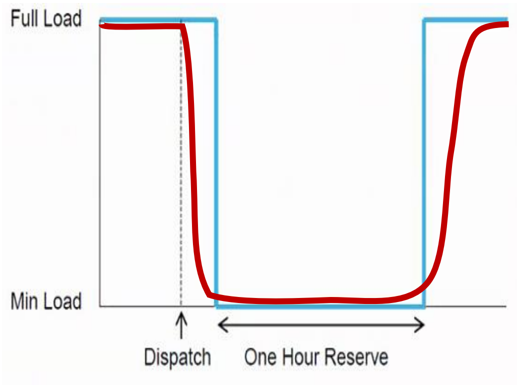
**Energy Harbor plans to commence testing in 2022

Analysis Report: Evaluation of Non-electric Market Options for a Light-water Reactor in the Midwest

Nuclear Hydrogen Production Demonstrations

- Two Low-Temperature Electrolysis (LTE, 1-3 MWe)
  - Exelon Generation
  - Energy Harbor (at Davis-Besse)
- Two High Temperature Electrolysis (HTE, 250 kWe)
  - Xcel Energy
    - Project award recently announced, under negotiation with DOE
    - Xcel and INL are meeting with top vendors to conduct due-diligence evaluations of technology options
    - HTE skid will be tested at INL before it is delivered to an Xcel plant in Minnesota





LWRS LIGHT WATER REACTOR SUSTAINABILITY

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Coordination with Advanced Reactor Demonstration

- **By 2025, the National Reactor Innovation Center (NRIC) will support demonstration of at least two advanced reactors**
  - Support privately financed, public-private partnership, and other agency opportunities
- NRIC is equipped to facilitate the construction and demonstration of advanced reactor systems through a suite of services and capabilities
  - **Integrated Energy Systems** demonstration – currently in design
  - Digital Engineering
  - Advanced Construction Technologies Initiative
  - NRC Coordination
  - Experimental infrastructure
  - Safety and environmental analysis
  - Project Planning & Coordination
  - Outreach and communications

NRIC National Reactor Innovation Center

https://inl.gov/nric

- **Advanced Reactor IES Expert Group established in 2020**
  - Provide input on advanced reactor applications, characteristics, development needs to ensure program relevance to industry
  - Establish relevant, high-priority use cases for analysis
  - Membership currently represents a broad class of advanced reactor design concepts
  - To be extended to other generator technologies and end use community

GAIN Gateway for Accelerated Innovation in Nuclear

GAIN Webinar Series: Clean Energy for Industry
Launched in April 2020

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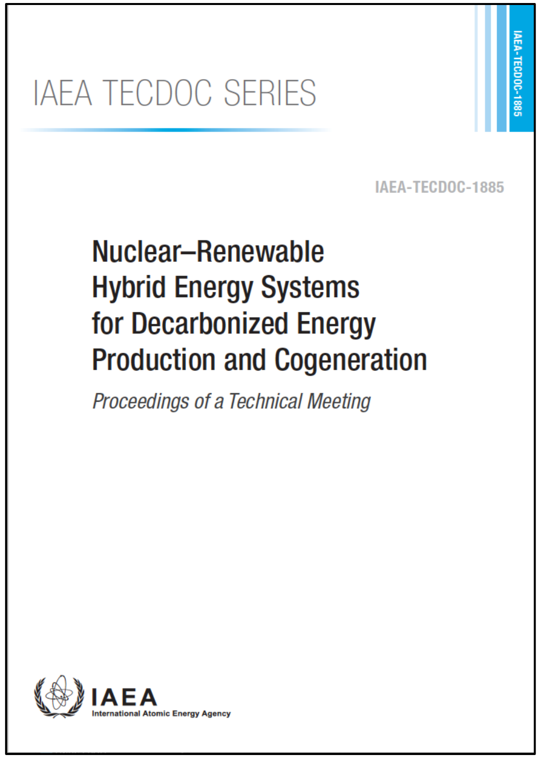
Support for International Activities: IAEA

- IAEA TECDOC-1885
  - **Nuclear–Renewable Hybrid Energy Systems for Decarbonized Energy Production and Cogeneration**
  - Proceedings of a Technical Meeting Held in Vienna, 22–25 October 2018
  - This publication consists of the proceedings of an IAEA Technical Meeting held to review and discuss concepts and innovative solutions, including the advantages and challenges associated with each option, pertaining to nuclear–renewable hybrid energy systems for decarbonized energy production and cogeneration.
- IAEA Nuclear Energy Series – to be published in 2021
  - **Nuclear–Renewable Hybrid Energy Systems**
  - This publication presents opportunities for nuclear-renewable HESs that could be pursued in various Member States as a part of their future energy mix. It describes motivation for and potential benefits of nuclear-renewable HESs relative to independent nuclear and renewable generation that produce electricity alone. Considerations for implementation are outlined, including gaps that require additional technology and regulatory development. This publication intends to equip decision makers and stakeholders with sufficient information to consider nuclear-renewable HESs as an option within regional and national energy systems.
- Additional IAEA activities expected in the near future


IAEA TECDOC SERIES

IAEA-TECDOC-1885

Nuclear–Renewable Hybrid Energy Systems for Decarbonized Energy Production and Cogeneration

Proceedings of a Technical Meeting

IAEA
International Atomic Energy Agency

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Images 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

Thank you!

Questions?

shannon.bragg-sitton@inl.gov