IES

Integrated Energy Systems

Advancing Nonelectric Applications of Nuclear Energy for Economy-wide Net Zero Solutions

NRC Regulatory Information Conference

Reimagining Nuclear's Role in Energy and the Electric Grid

(virtual)

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INL

Idaho National Laboratory

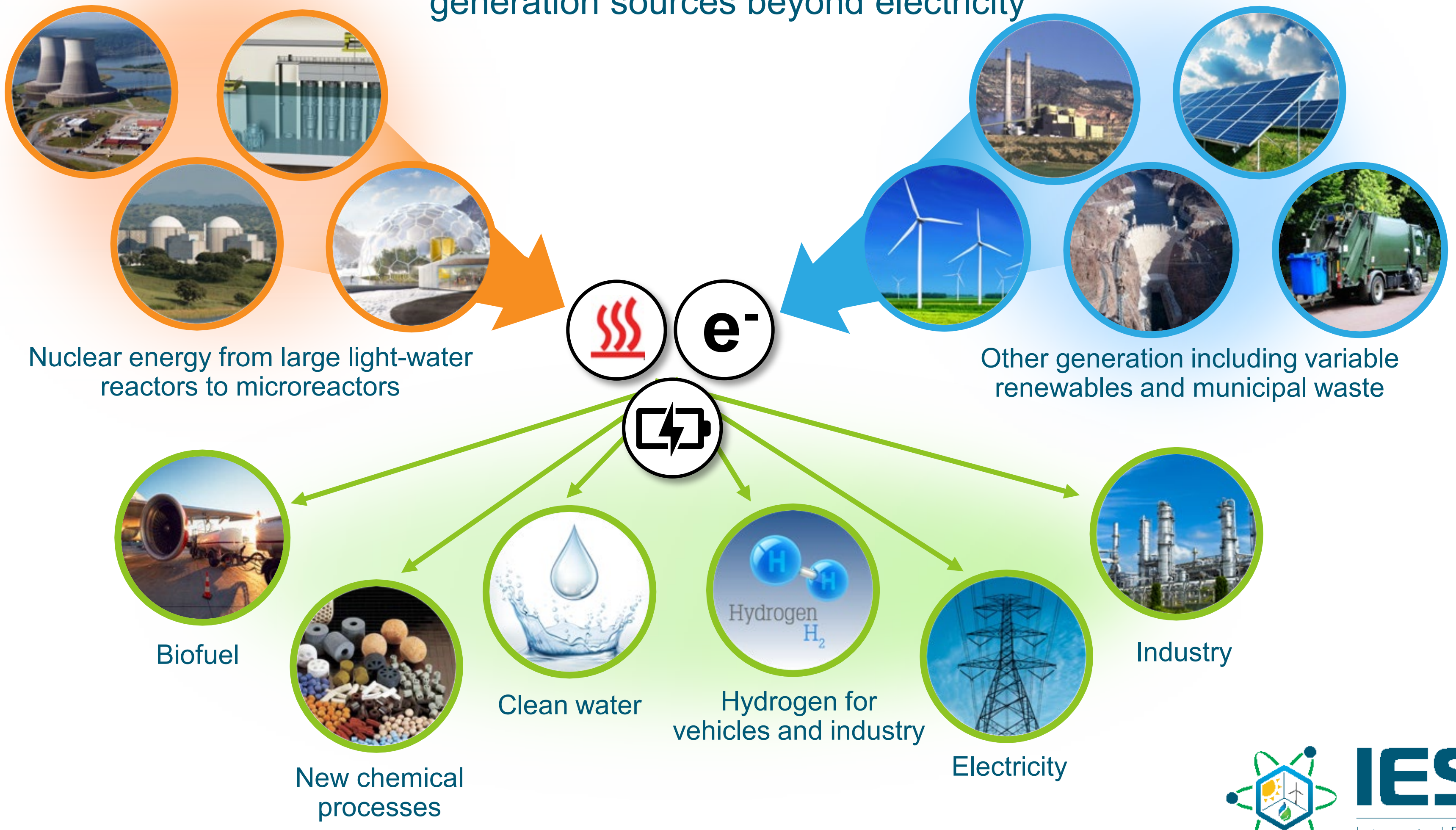
Cross-sectoral energy solutions provide opportunities to achieve net-zero while maintaining grid stability and affordability

Goals:

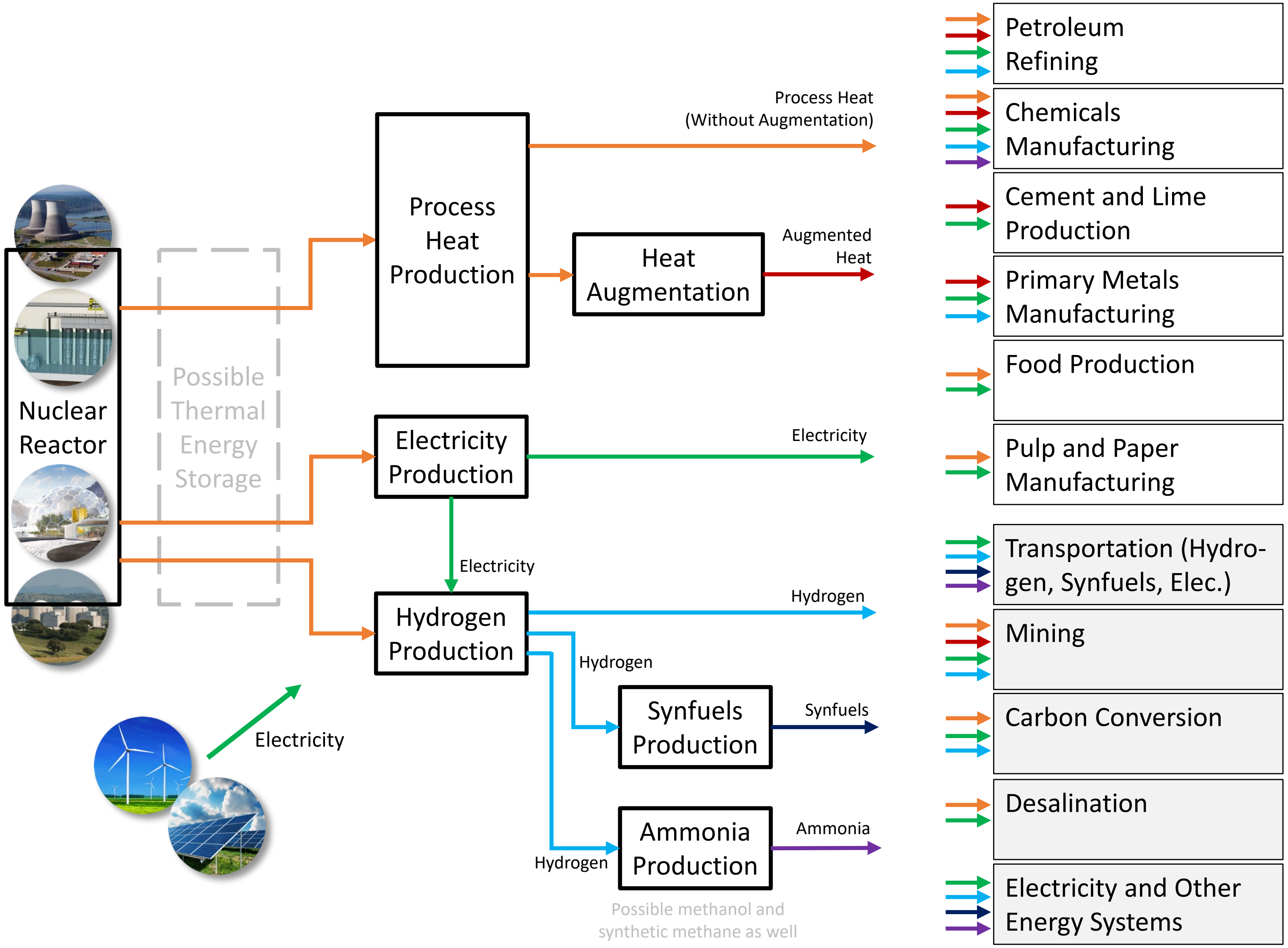
- Maximize energy utilization and generator profitability
- Minimize environmental impacts
- Maintain affordability, grid reliability and resilience

Future Energy System

Integrated grid system leverages contributions from nuclear fission and other low emission energy generation sources beyond electricity



Summary of potential nuclear-driven IES opportunities



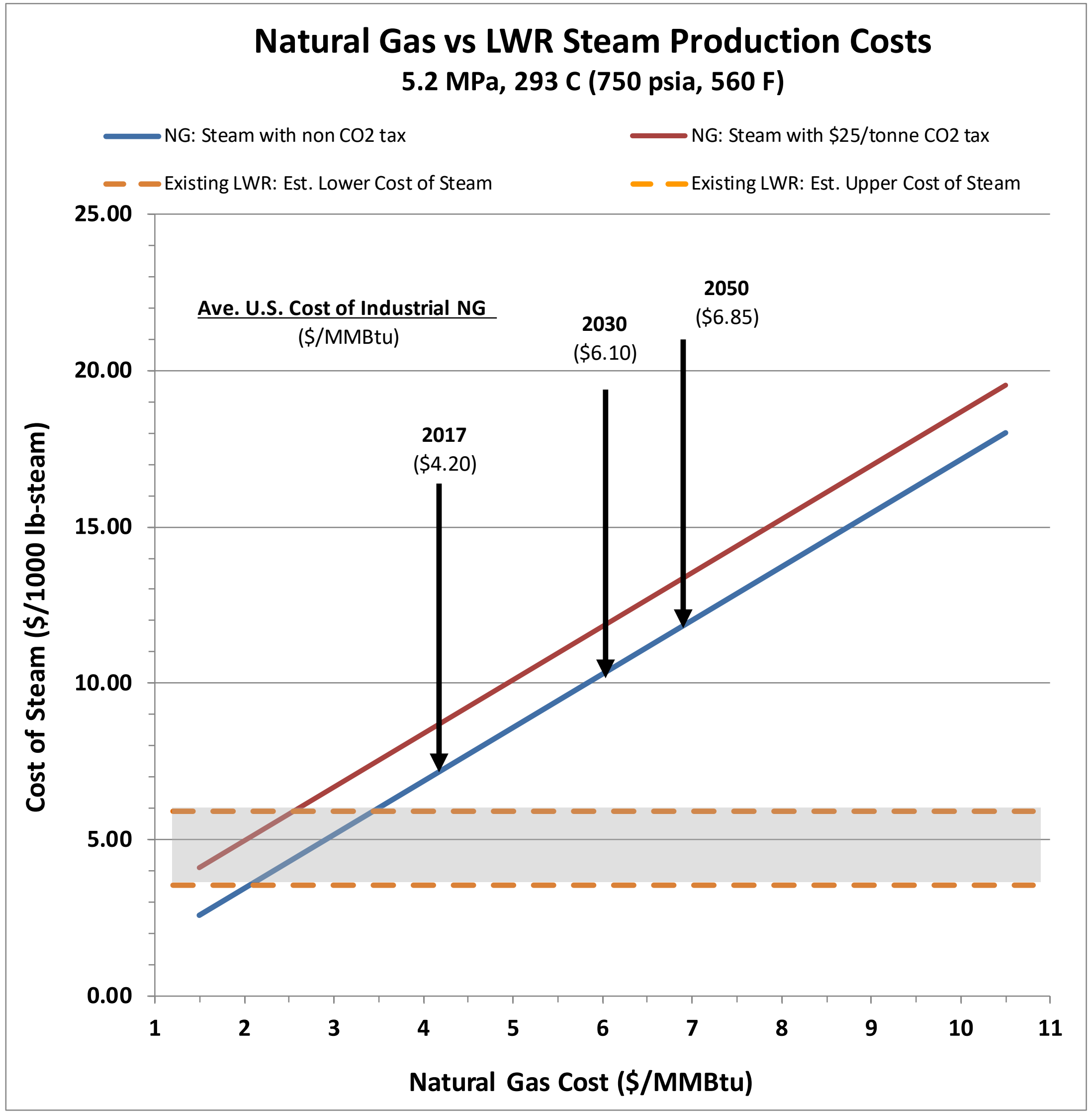
IES involve

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

Reactor sizes and temperatures align with the needs of each application

Source: INL, *National Reactor Innovation Center (NRIC) Integrated Energy Systems Demonstration Pre-Conceptual Designs*, INL EXT-21-61413, Rev. 1, April 2021

Natural gas versus LWR steam costs



- Plot shows estimated cost of high-pressure steam production using natural gas and nuclear energy
- Existing LWR plants produce high-pressure steam for $4.00–5.25/1000-lb ($8.80-11.55/1000-kg), depending on
  - Size of the nuclear plant
  - Capital recovery for upgrades to the plant.
  - This is currently 15–45% lower than the cost of producing steam using a NG package boiler (without CO2 emissions tax)
- Arrows indicate U.S. DOE Energy Information Agency (EIA) cost projections for natural gas

Figure extracted from Frick, et al., 2019, *Evaluation of Hydrogen Production for a Light Water Reactor in the Midwest*

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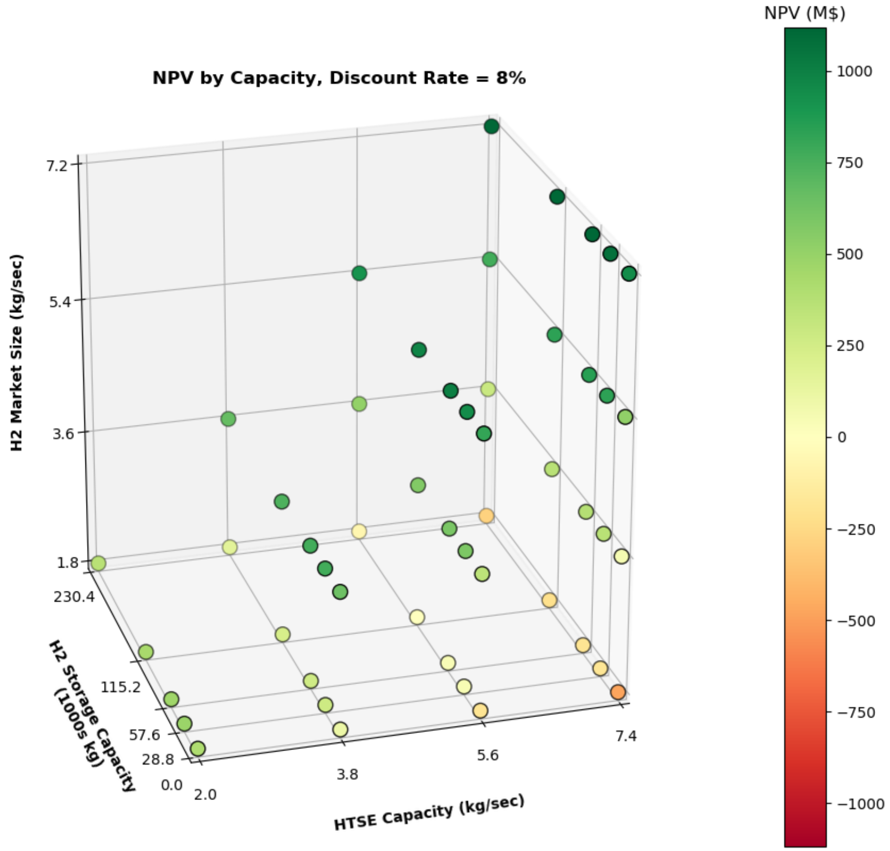
Identifying the right configuration: Analysis and optimization of integrated energy system options

Step	Notes
1. Identify IES scenarios of interest	Renewable availability, reactor type, energy needs, e.g., flexible electricity supply, heat, hydrogen, desalination
2. Specify data inputs for each scenario	Societal energy demand, approximate plant capacities, refueling cycle, outages, lifetimes, maintenance schedules, etc.
3. Specify economic inputs for each scenario	Capex, opex, energy price time series, interest rates, etc. using region-specific data
4. Apply suite of analysis tools to evaluate each scenario	Optimal sizing of coupled systems relative to societal energy demand and other production resources, optimal dispatch of energy from each resource, operational constraints, ranges of potential capex and opex during plant lifetimes, optimization of economic metrics, etc.



Example: Differential NPV over 17 years, co-generating nuclear station in PJM market, high hydrogen selling prices. Discount rate = 8%, corporate tax rate = 21%, yearly inflation = 2.188%.

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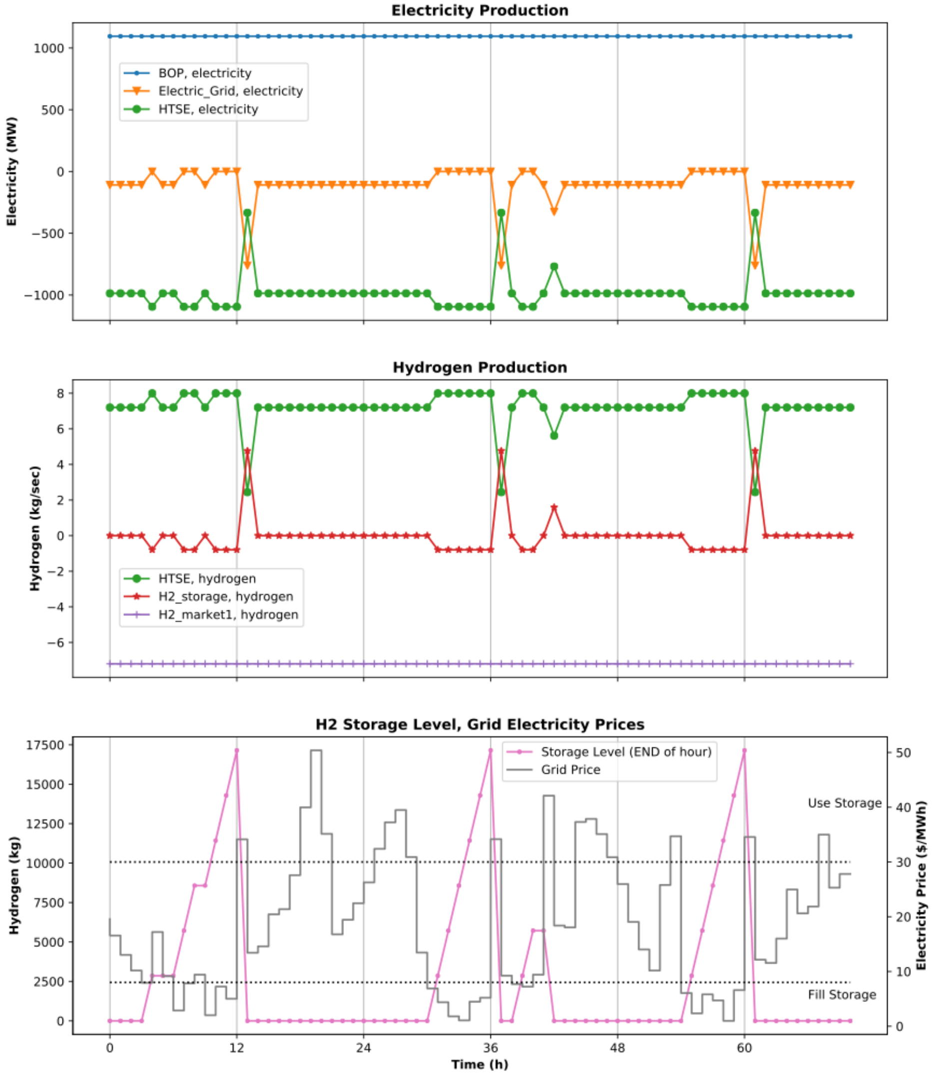
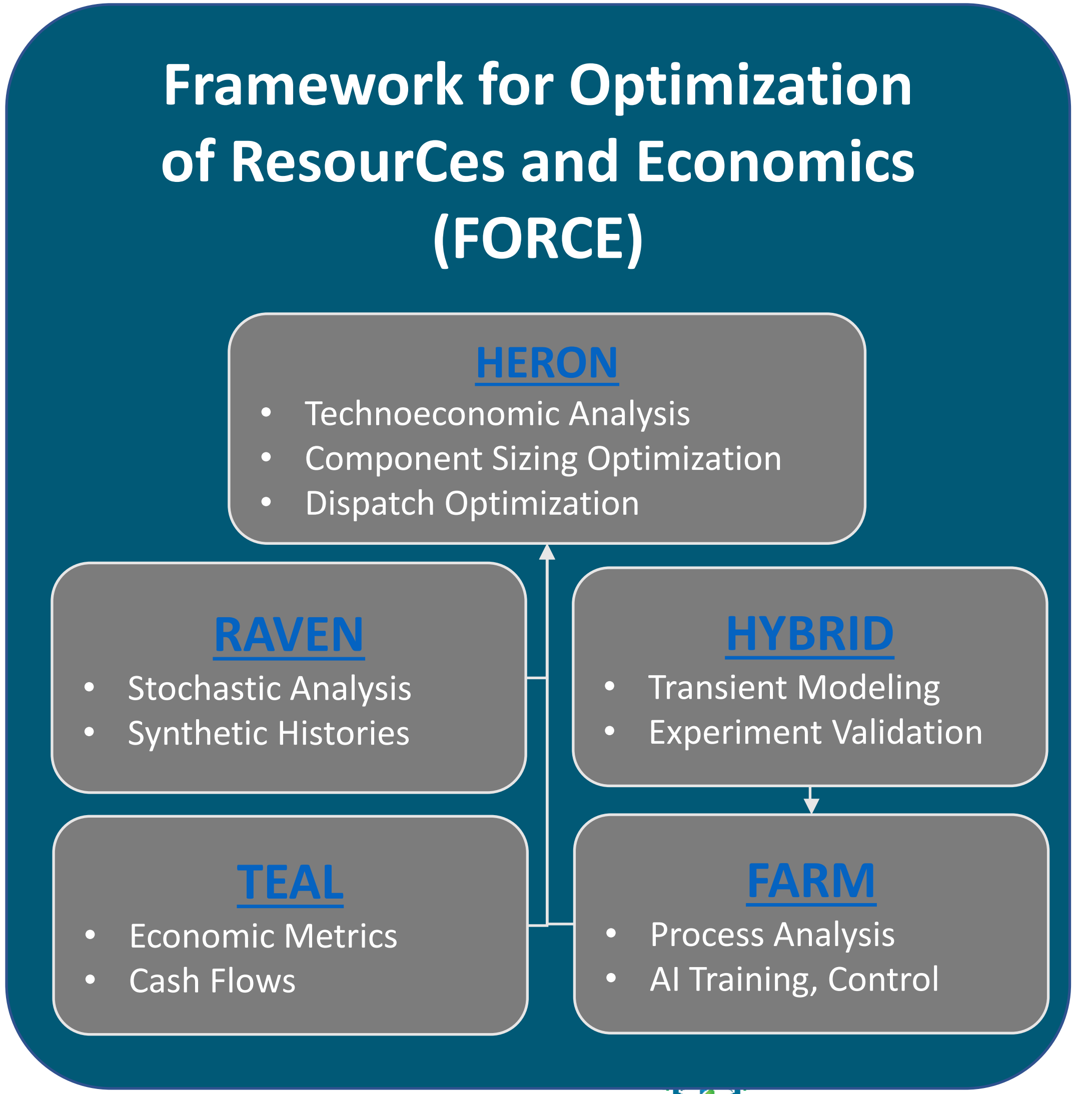


Integrated Energy Systems

Tool suite for technoeconomic assessment and optimization

Tools for technoeconomic assessment of IES configurations with workflow automation

- **FORCE**
  - Integrate physical plant modeling with technoeconomic optimization
- **HERON**: Holistic Energy Resource Optimization Network
  - Dispatch flexible systems and optimize technoeconomic analysis
- **RAVEN**: Risk Analysis Virtual ENvironment
  - Integrate physical input uncertainties and probabilistic time series data
- **HYBRID**: High fidelity, dynamic model repository
  - Simulation of physical plant processes
- **TEAL**: Tool for Economic AnaLysis
  - Integrate economic input uncertainties and calculate financial metrics
- **FARM**: Feasible Actuator Range Modifier
  - Supervisory control



See https://ies.inl.gov/SitePages/System_Simulation.aspx for more information and to access open source tools. Training opportunity for FORCE, March 17, 18, 23, 24 (12 hours) – see flyer for details.

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Nuclear-H_2 production demonstration projects

- **Constellation (Exelon): Nine-Mile Point NPP**
  - 1 MWe Low Temperature Electrolysis (LTE)/PEM, nel hydrogen
  - Using “house load” power
  - PEM skid testing underway at NREL
  - H_2 production beginning ~October 2022
- **Energy Harbor: Davis-Besse NPP**
  - 1-2 MWe LTE/PEM Vendor 2
  - Power provided by completing plant upgrade with new switch gear at the plant transmission station
  - Installation to be made at next plant outage
  - Contract start October 2021; H_2 production ~2023/24
- **Xcel Energy: Prairie Island NPP**
  - 150 kWe High Temperature Electrolysis (HTE)/SOEC Vendor 1
  - Tie into plant thermal line engineering is being planned
  - Design complete Q4 2022; Installation, testing complete Q1 2024
- **APS/PNW Hydrogen: Palo Verde Generating Station**
  - 15-20 MWe LTE H2 production, ~6-8 tons H2/day
  - Colocate H_2 production at the site of use
  - H_2 storage + H_2 to gas peaking turbines (50%), syngas pilot
  - H_2 production expected early 2024

Nine Mile Point Nuclear Power Plant LTE/PEM Vendor 2

Davis-Besse Nuclear Power Plant LTE-PEM Vendor 1

Thermal & Electrical Integration at Xcel Energy Prairie Island NPP HTE/Vendor 1

Palo Verde Gen Station Hydrogen Production for Combustion and Synthetic Fuels

PRA for thermal integration of steam electrolysis: Summary conclusions

- Generic probabilistic risk assessment (PRA) investigation into licensing considerations
- Identified top hazards
  - Internal: Steam line break, loss of offsite power
  - External: HTE H_2 leak or H_2 detonation
- Key conclusions
  - Licensing criteria is met for a large-scale HTE facility sited 1 km from a generic PWR and BWR
  - Safety case for less than 1 km distance is achievable
- Other insights
  - Individual site NPP and geographical features can affect the results of the generic PRA positively or negatively
  - Generic PRAs in the study are examples for official site studies for use in licensing

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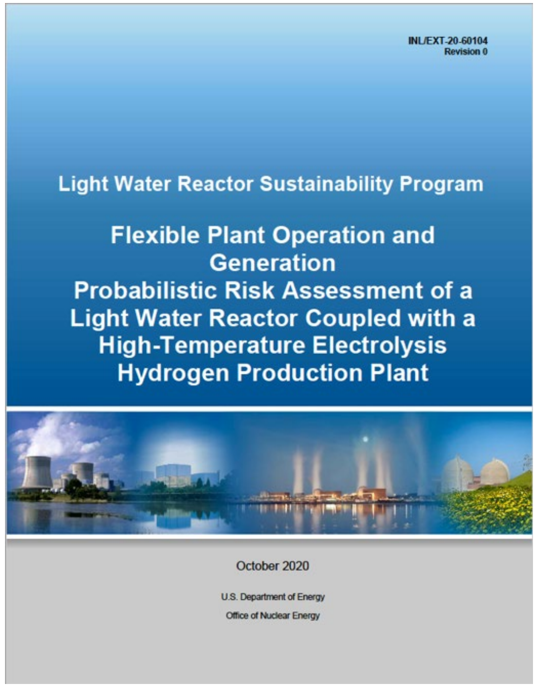
OSTI link: https://www.osti.gov/biblio/1691486


INL/EXT-20-60104
Revision 0

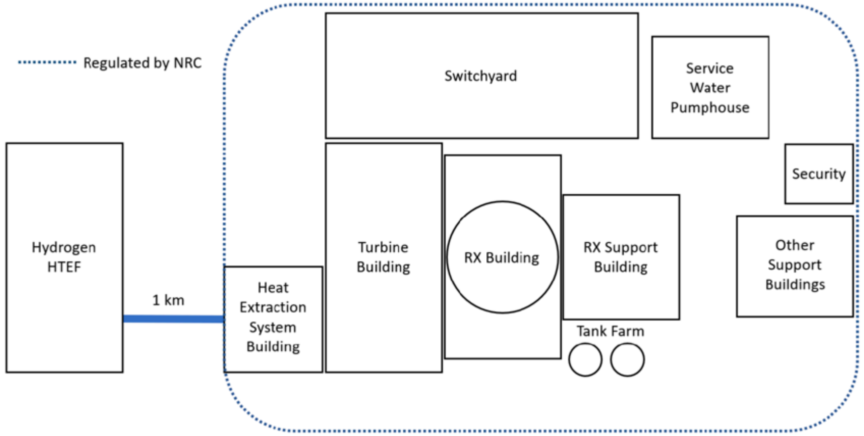
Light Water Reactor Sustainability Program

Flexible Plant Operation and Generation
Probabilistic Risk Assessment of a Light Water Reactor Coupled with a High-Temperature Electrolysis Hydrogen Production Plant

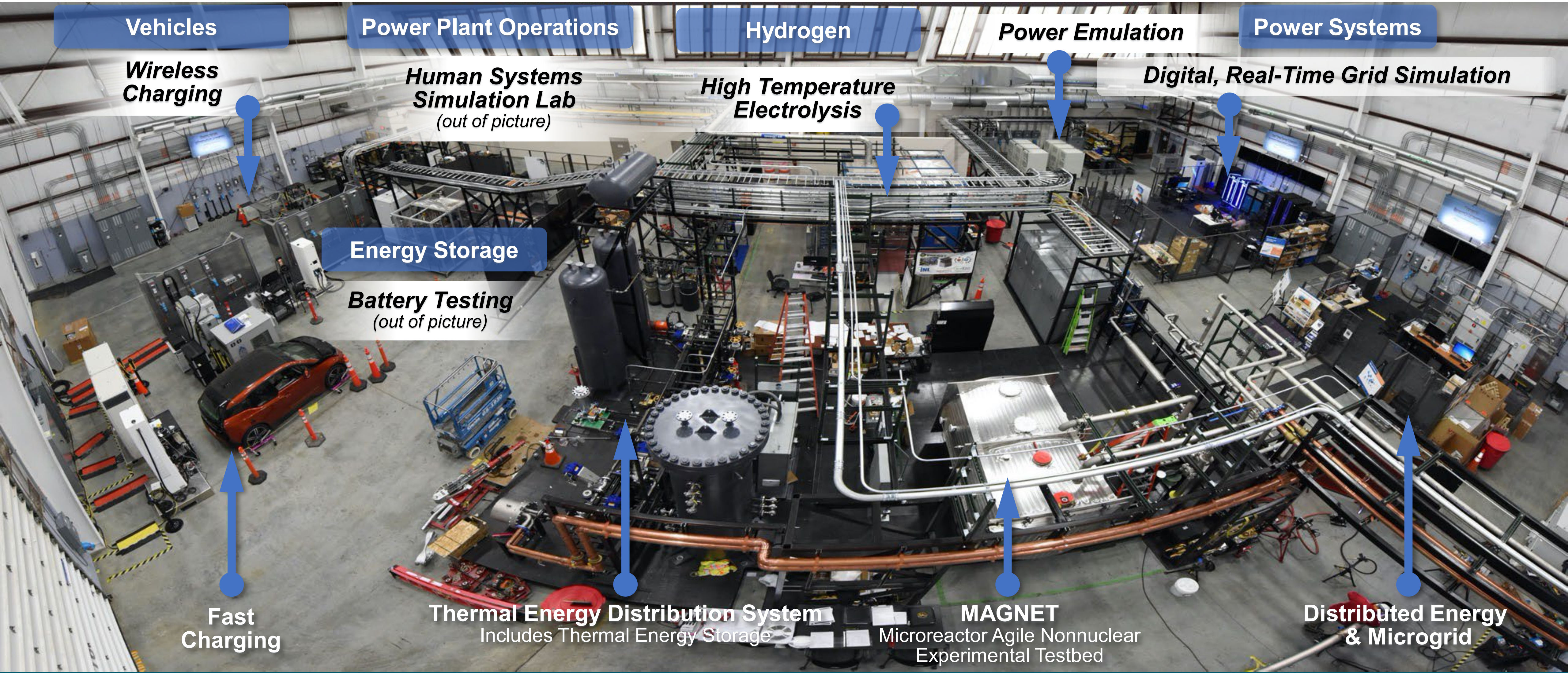
October 2020

U.S. Department of Energy
Office of Nuclear Energy

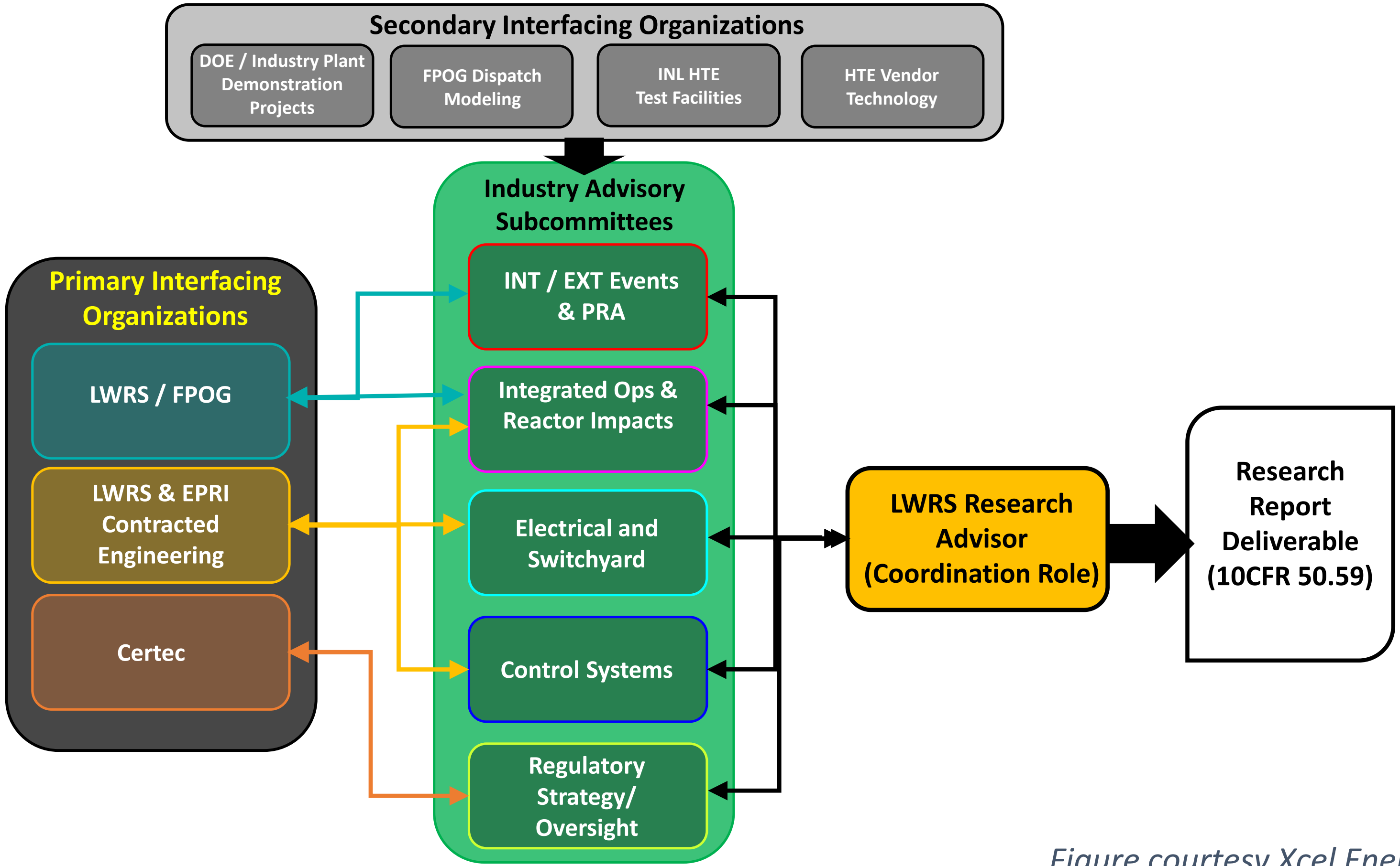
NRC jurisdictional boundary for LWR servicing an HTE facility



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



Hydrogen Regulator Research & Review Group (H3RG)



LWRS LIGHT WATER REACTOR SUSTAINABILITY

INL Leads:
Jason Remer
Jack Cadogan

Flexible Plant Operations & Generation Pathway (FPOG)

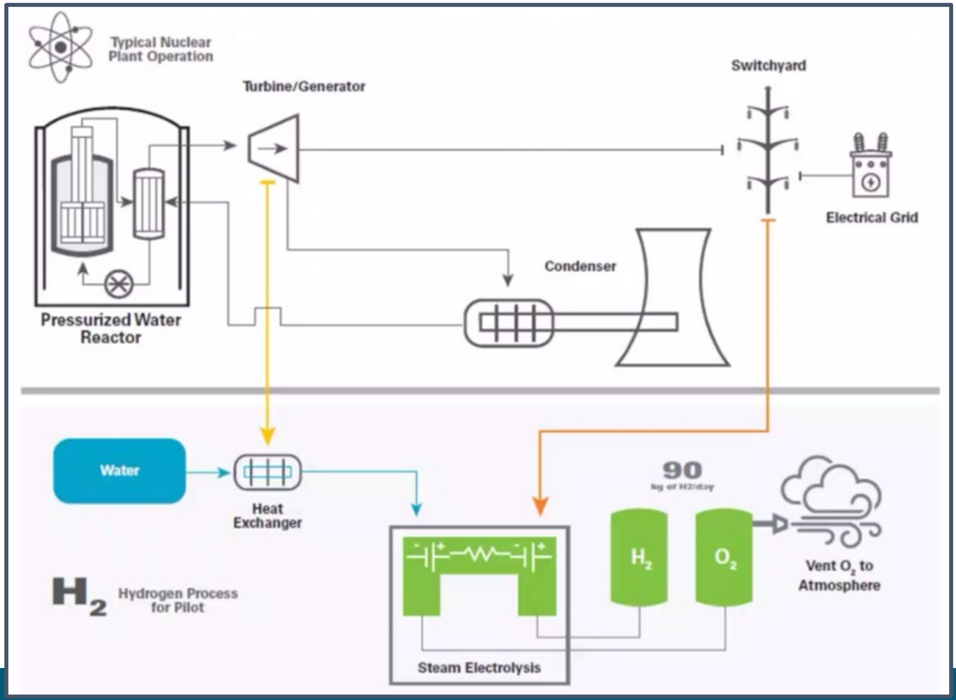


Figure courtesy Xcel Energy

Example of NPP integration with high temperature electrolysis

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