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

Clean. Reliable. Nuclear.

INL Idaho National Laboratory

IES Integrated Energy Systems

# Integrated Energy Systems for Hydrogen & Chemicals Production

## Hydrogen and Fuel Cell Energy
Annual Merit Review
May 2020


Idaho National Laboratory

Shannon Bragg-Sitton, Ph.D. NE
Lead, Integrated Energy Systems
Nuclear Science & Technology Directorate

Richard Boardman, Ph.D. ChE
Technology Development Lead for Integrated Energy Systems
Energy and Environmental Sciences & Technology Directorate

# DESIGNING OUR FUTURE ENERGY SYSTEMS


*What goals are we trying to achieve?*

*How will energy be used?*

*What role(s) will nuclear fill?*

# INNOVATIVE NUCLEAR TECHNOLOGIES FOR CURRENT AND FUTURE ENERGY SYSTEMS

# ADVANCED REACTORS

**Benefits:**

- Enhanced safety
- Versatile applications
- Reduced waste
- Apply advanced manufacturing to reduce costs

## 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

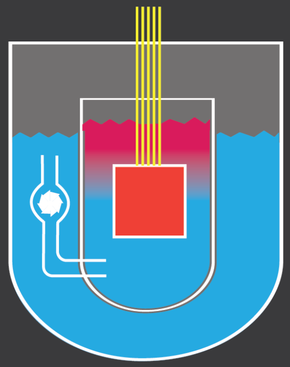
**300 MW to 1,000 + MW**

Full-size Reactors

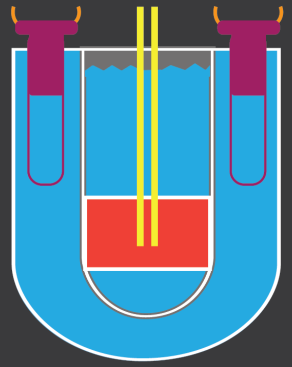
*Can provide reliable, emissions-free baseload power*

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

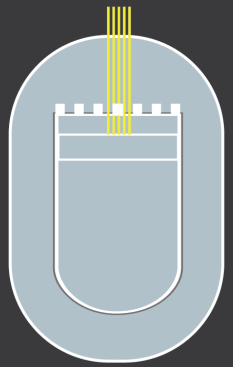
## TYPES



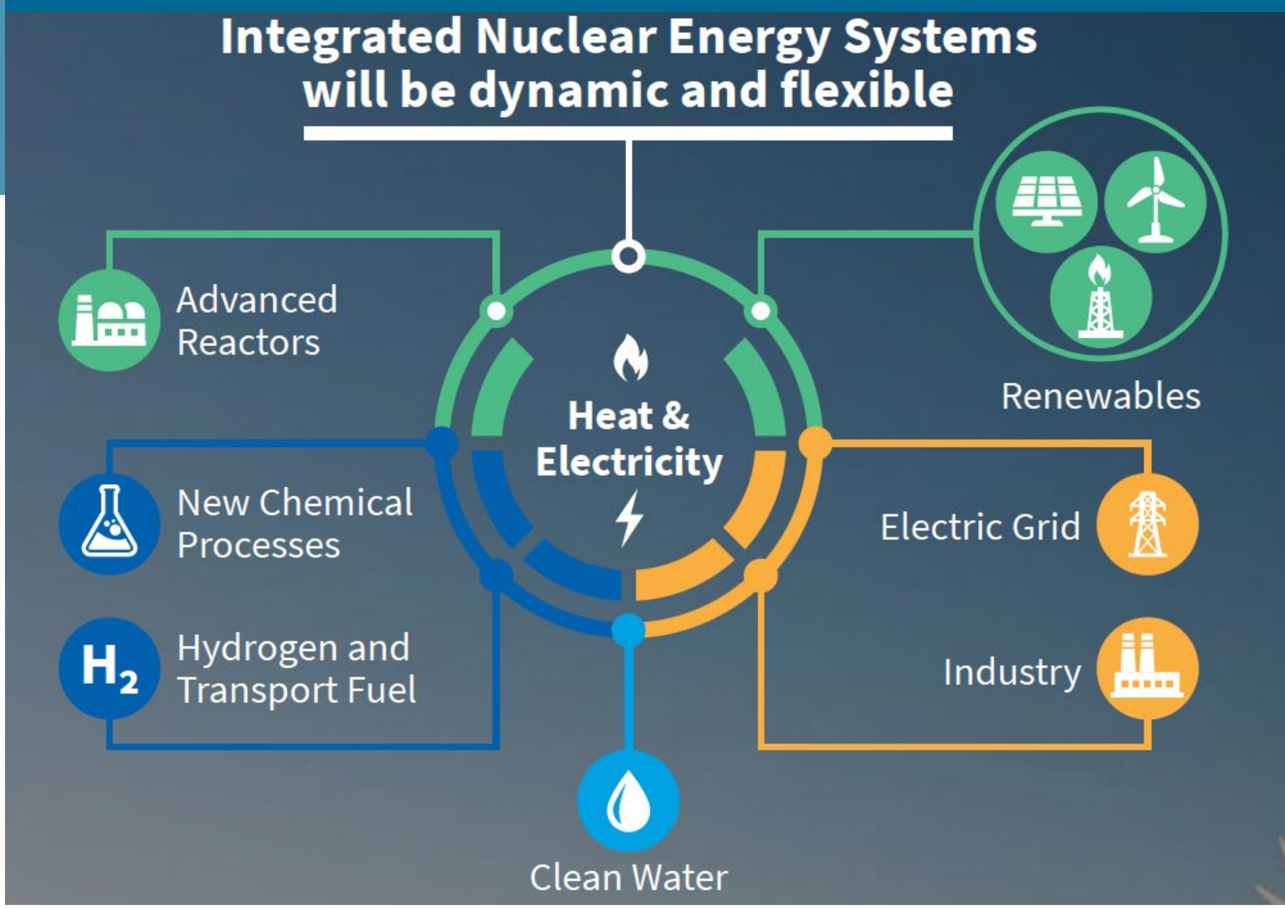
**MOLTEN SALT REACTORS –** Use molten fluoride or chloride salts as a coolant. Online fuel processing. Can re-use and consume spent fuel from other reactors.



**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.



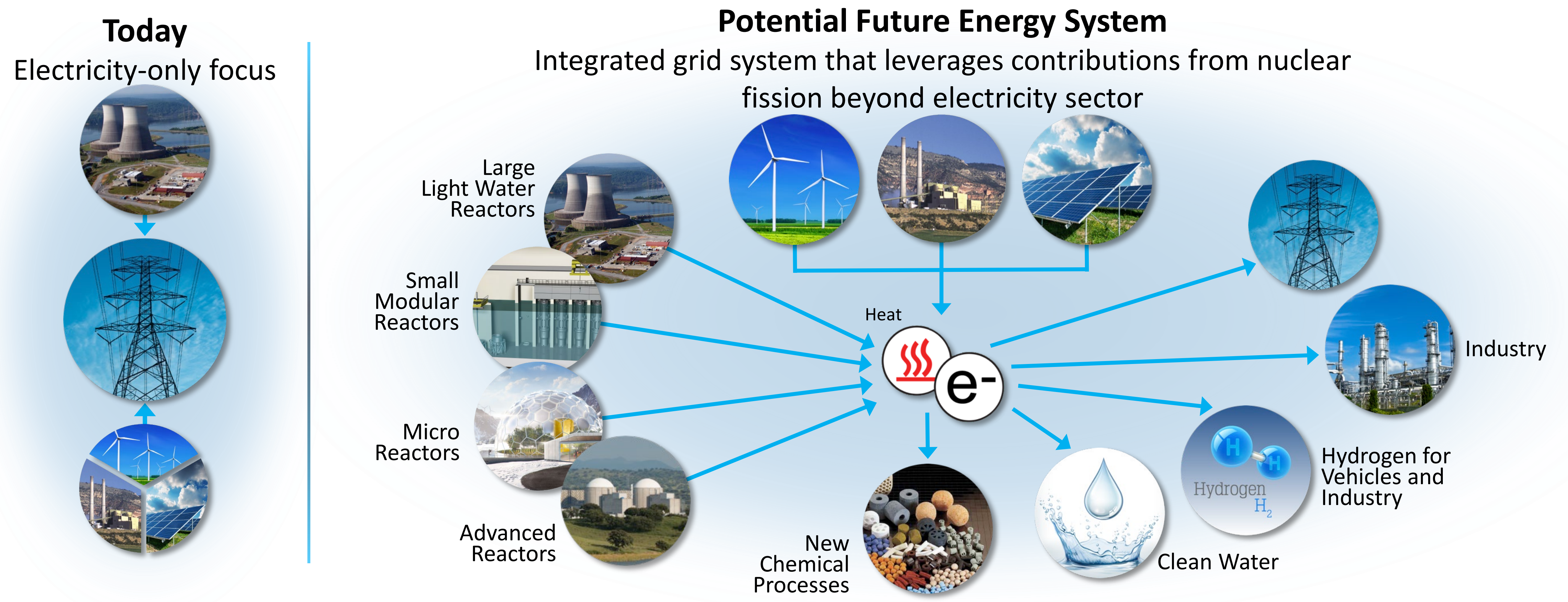
**GAS-COOLED REACTORS –** Use flowing gas as a coolant. Operate at high temperatures to efficiently produce heat for electric and non-electric applications.




# INTEGRATED ENERGY SYSTEMS

*Maximizing the contribution of carbon-free energy generation for electricity, industry, and transportation – while supporting a resilient grid and converting valuable resources to higher value products*

# Integrated Energy Systems: A Key Opportunity for Nuclear Energy

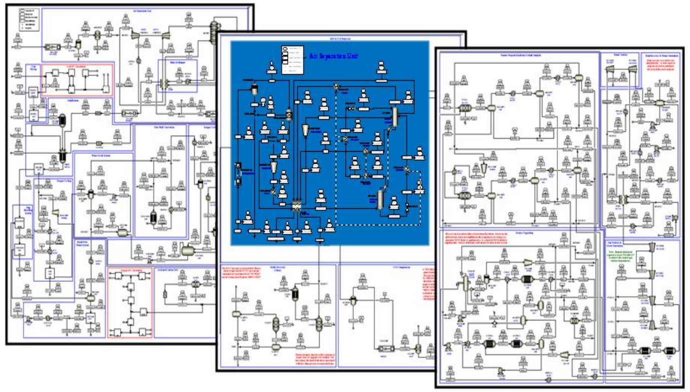



**Flexible Generators ❖ Advanced Processes ❖ Revolutionary Design**

# Cross-cutting Energy System Modeling, Analysis, and Evaluation

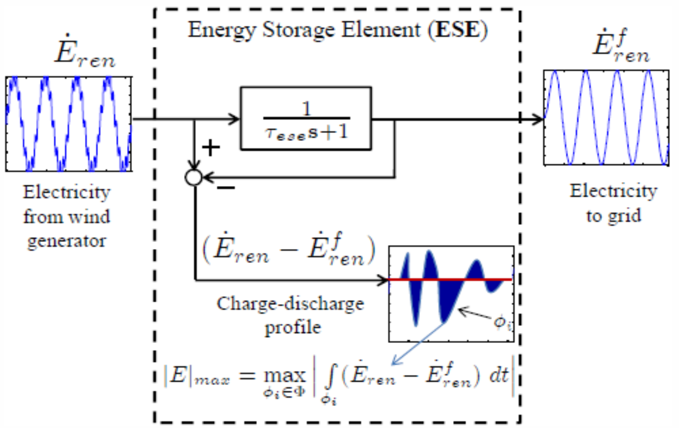
*Graded approach to identify design, and evaluate hybrid system architectures*

***Aspen Plus® and HYSYS® Process Models***



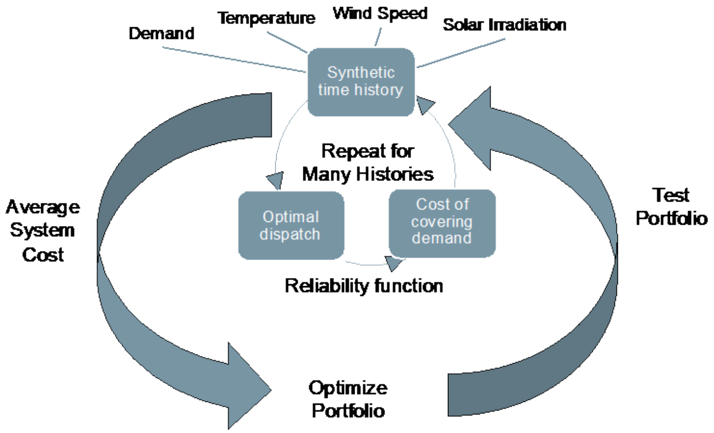
*Process modeling addresses technical and economic value proposition*

***Modelica®, Aspen Dynamics®***




*Dynamic modeling addresses technical and control feasibility*

***RAVEN (INL System Optimization)***




*System modeling addresses whole-system coordination*

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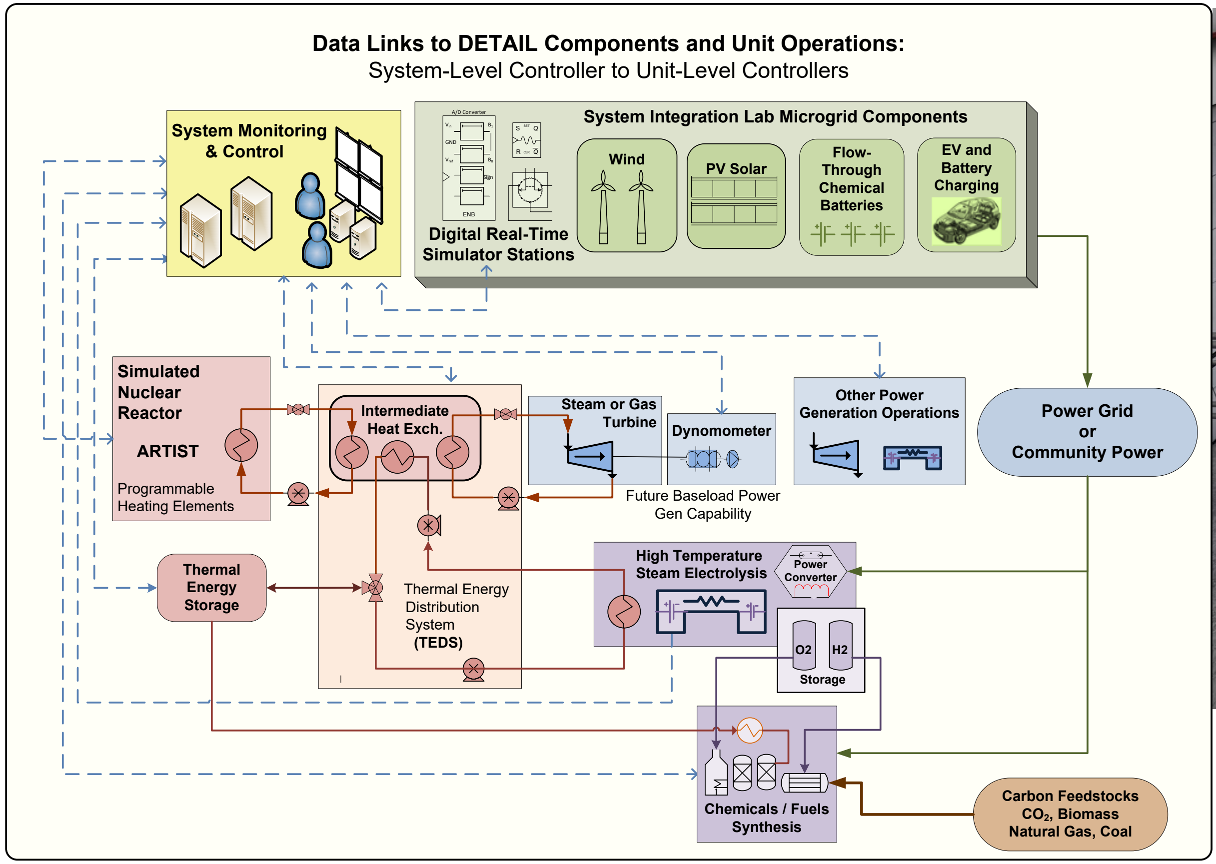
# INL Experimental Demonstration of Integrated Systems

## INL Dynamic Energy Transport and Integration Laboratory (DETAIL)

Establishing the experimental capability to demonstrate coordinated, controlled, and efficient transient distribution of electricity and heat for power generation, storage, and industrial end uses.





TEDS: Thermal Energy Distribution System

MAGNET: Microreactor Agile Nonnuclear Experiment Testbed

HTSE: High Temperature Steam Electrolysis

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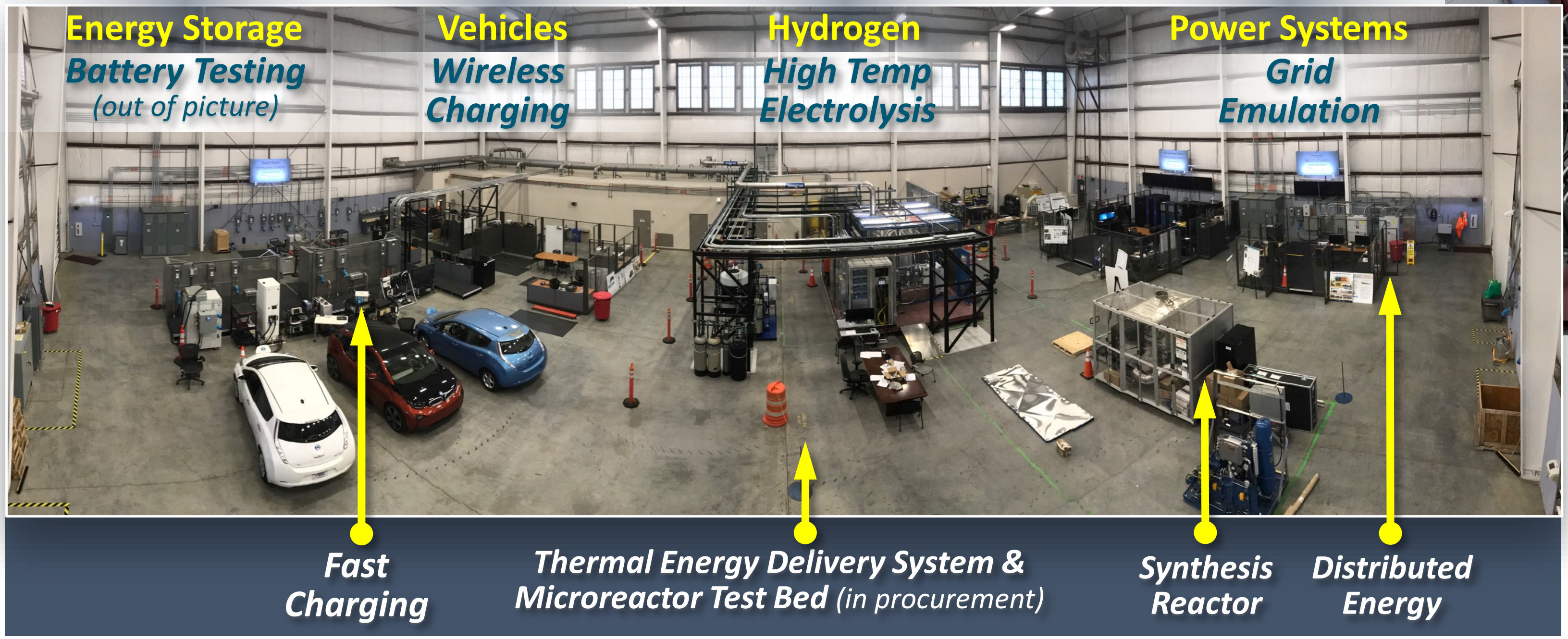
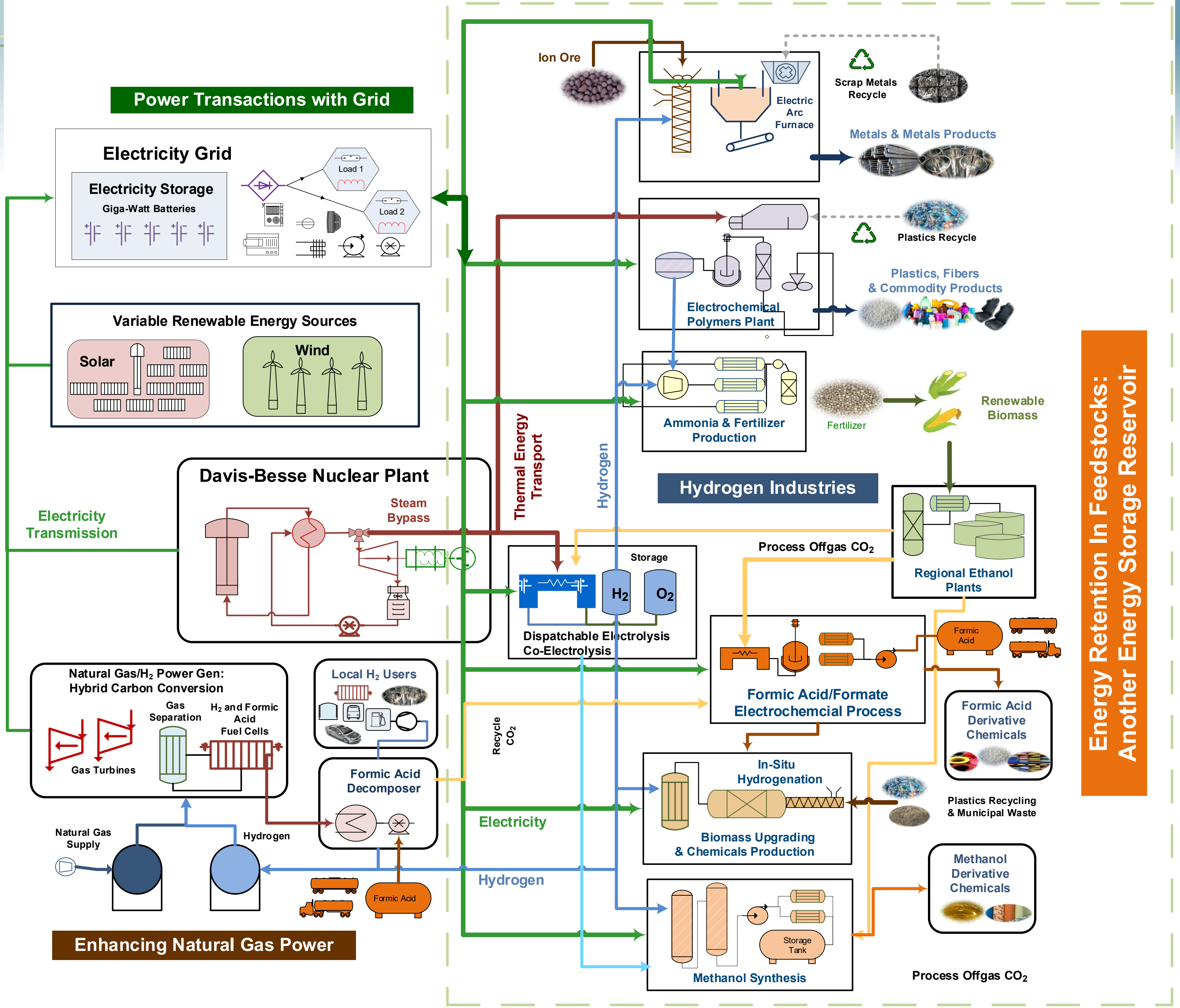


## *Coordinated Energy Systems*

- Holistic Integration of the energy system
- Involve electrical, thermal, and chemical networks
- Utilize energy storage on various scales
- Provide reliable, sustainable, low-emissions, most affordable energy

## *Tightly Coupled Hybrid Systems*

- Involve thermal, electrical, and process intermediates integration
- More complex 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)



# Recent Hydrogen Production Analyses for Current Fleet LWRs

INL issued public-facing reports on in FY19 that provide the foundation for demonstration of using LWRs to produce non-electric products:

- ***Evaluation of Hydrogen Production Feasibility for a Light Water Reactor in the Midwest***
  Repurposing existing Exelon plant for H2 production via high temperature electrolysis; use of produced hydrogen for multiple off-take industries (ammonia and fertilizer production, steel manufacturing, and fuel cells) (INL/EXT-19-55395)

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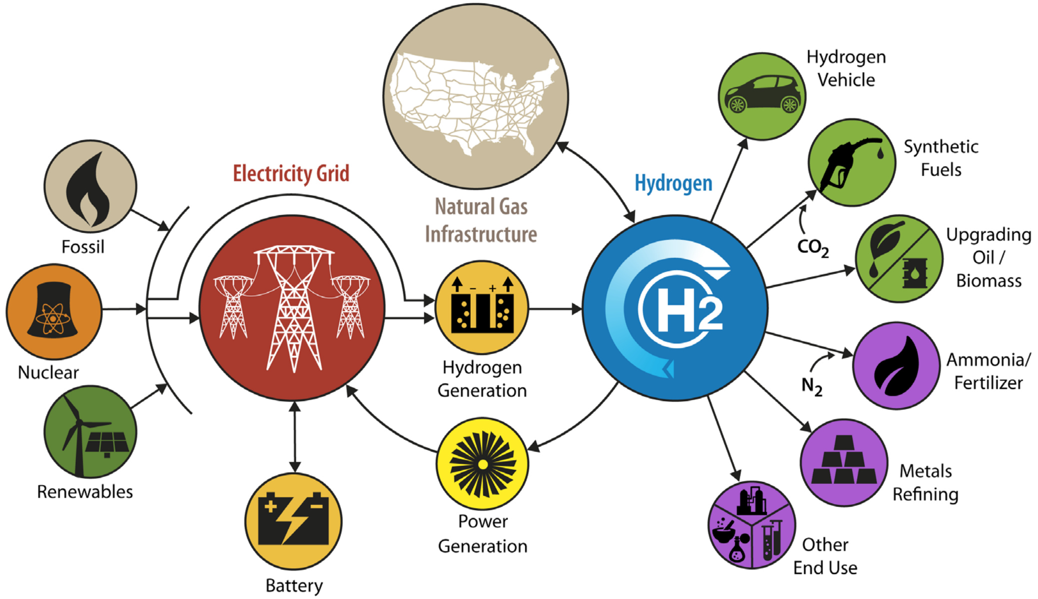
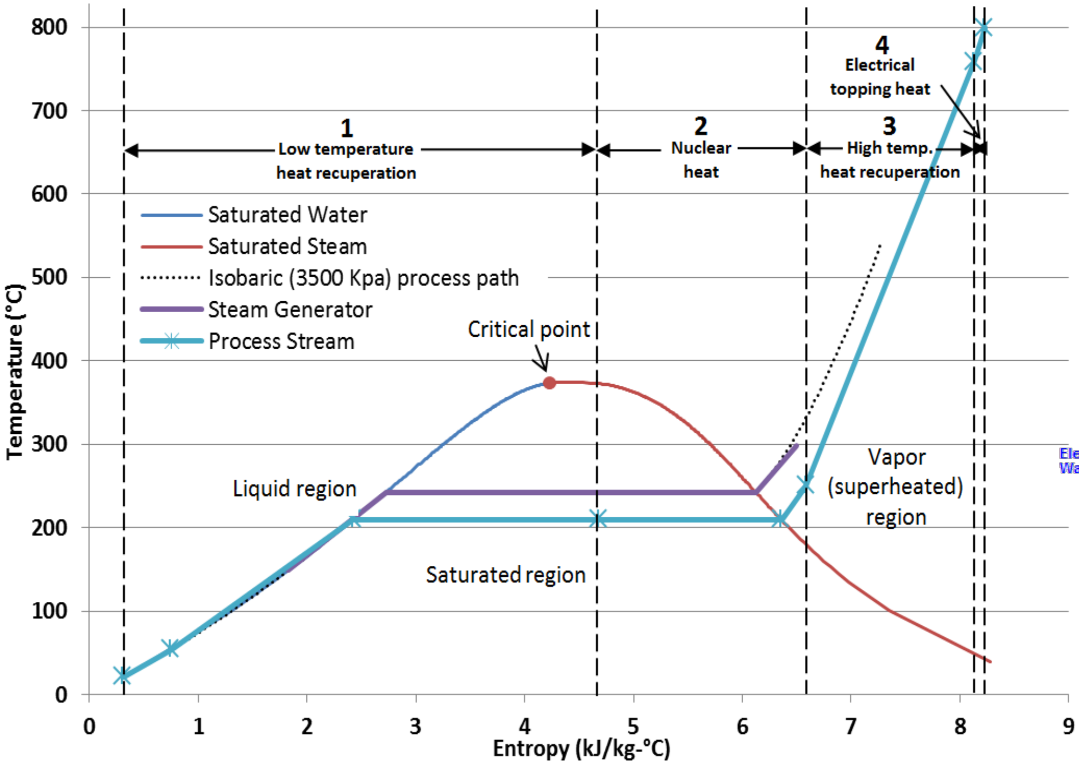
- ***Evaluation of Non-electric Market Options for a Light-water Reactor in the Midwest***
  LWR market opportunities for LWRs with a focus on H2 production using low-temperature and high-temperature electrolysis; initial look at polymers, chemicals, and synfuels (INL/EXT-19-55090)

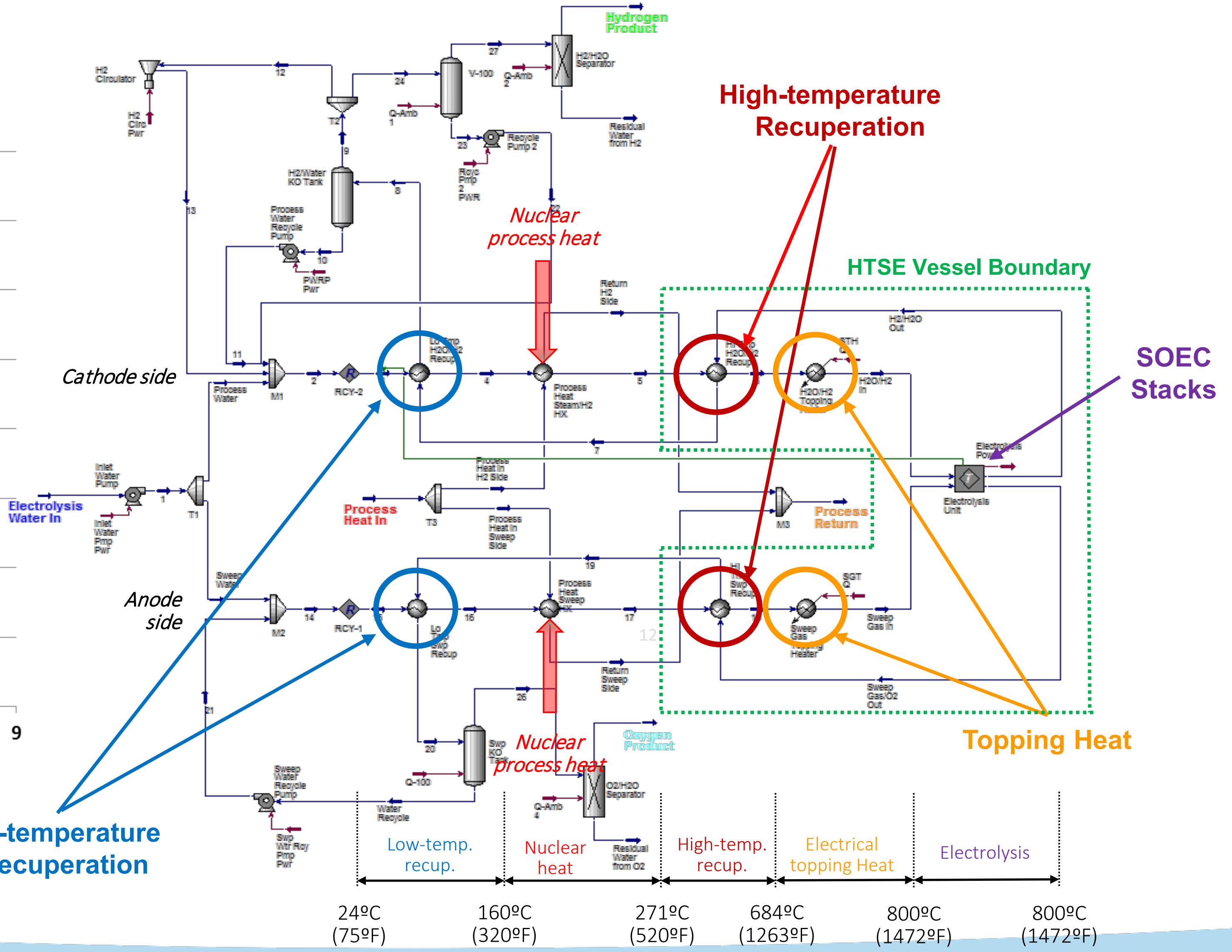
LWRS LIGHT WATER REACTOR SUSTAINABILITY




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

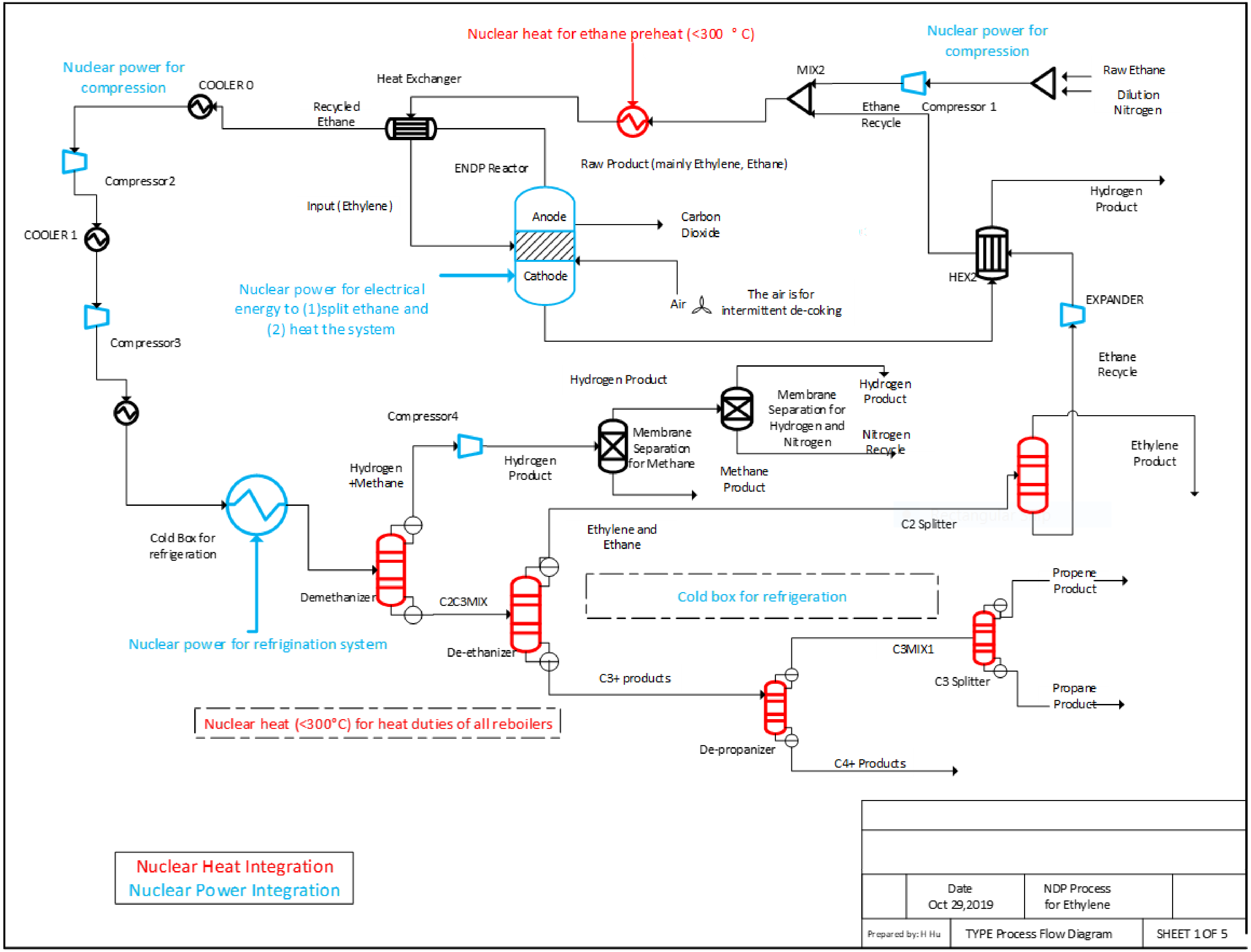
# Light Water Nuclear Reactor with HTE Process Heat Integration



# INL Preliminary Process Design Reference

- ❑ Thermal heat from LWR
- ❑ Electricity from LWR
- ❑ Membranes separations processes in design



# Nuclear Power Plant Hydrogen Production Demonstration Projects

- ***Purpose & Scope***

1. Demonstrate hydrogen production using direct electrical power offtake from a nuclear power plant for a commercial, 1-3 MWe, low-temperature (PEM) electrolysis module

2. Acquaint NPP operators with monitoring and controls procedures and methods for scaleup to large commercial-scale hydrogen plants

3. Evaluate power offtake dynamics on NPP power transmission stations to avoid NPP flexible operations

4. Evaluate power inverter control response to provide grid contingency (inertia and frequency stability), ramping reserves, and volt/reactive control reserve

5. Produce hydrogen for captive use by NPPs

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

- ***Two projects:*** *(1) Exelon, (2) Energy Harbor Partnership with Xcel Energy and APS*

- ***INL and NREL role:*** *Support utilities with project test planning, controls and monitoring environment implementation and testing, data collection, systems performance evaluation, and project reporting.*

- ***Project Funding***

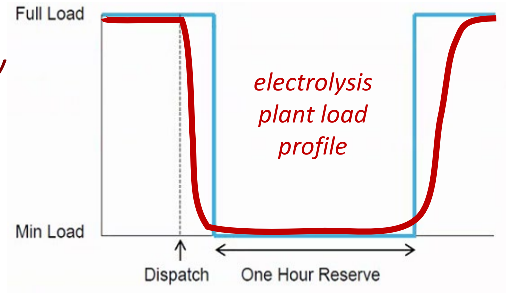
**Exelon:** $8 M, EERE Fuel Cell Technology Office & NE Crosscutting Technology Integrated Energy System Program cost-shared joint funding

**Energy Harbor Partnership:** $12.5 million, Light Water Reactor Sustainability Program cost shared; includes $1.6 M for Xcel Energy and APS techno-economic assessments, with FCTO H2@Scale Analysis support

- ***Project Schedule***

6 months — project planning, PEM provider due diligence, procurement/joint research agreements
6 months — **Exelon:** Select nuclear plant for demonstration
6-18 months — electrical tie-in engineering, site preparation, PEM module manufacturing, agency notifications, plant engineers, and operator training
18-24 months — **Exelon:** Commence testing and hydrogen supply
24-30 months — **Energy Harbor:** Commence testing and hydrogen supply

**Example Test for Non-Spinning Reserve:** *Electrolyzer ramps down in 10 mins while NPP dispatches electricity to the grid; then returns to full load after one hour.*



*NPP dispatches to gird*

Exelon — Site for demonstration under consideration

energy harbor
Xcel Energy
aps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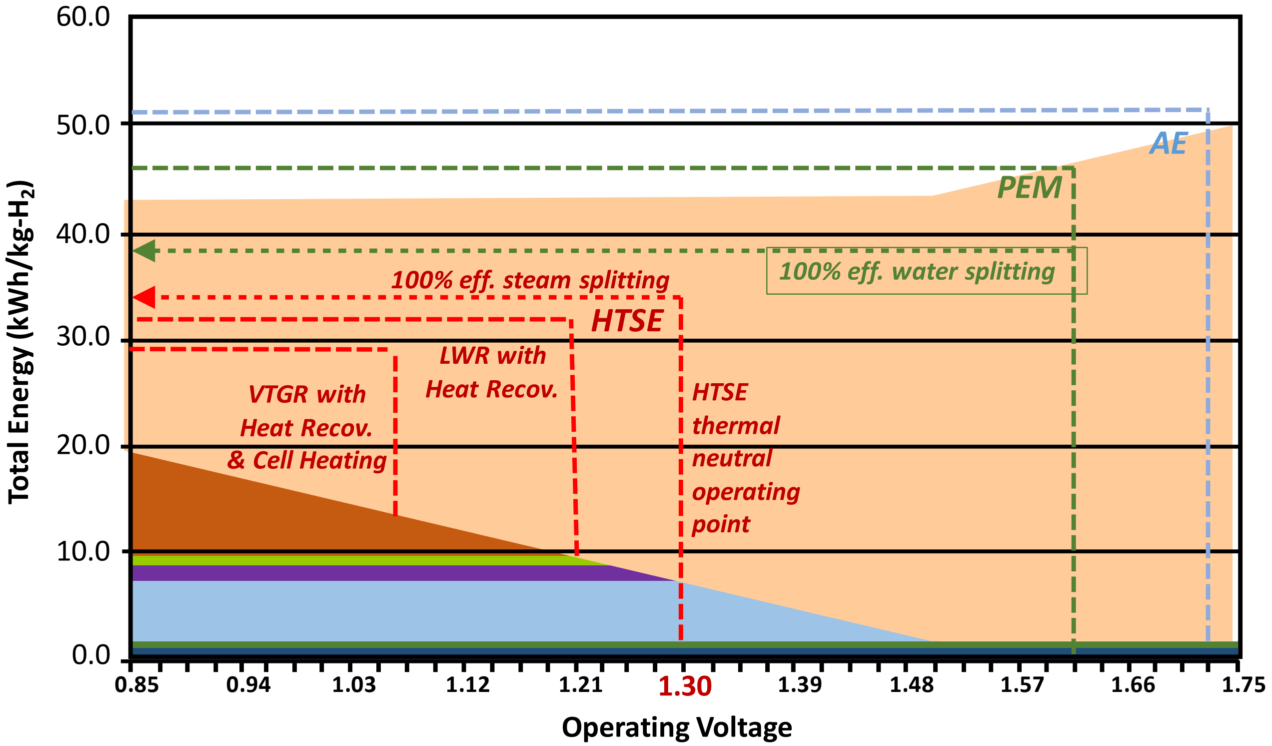
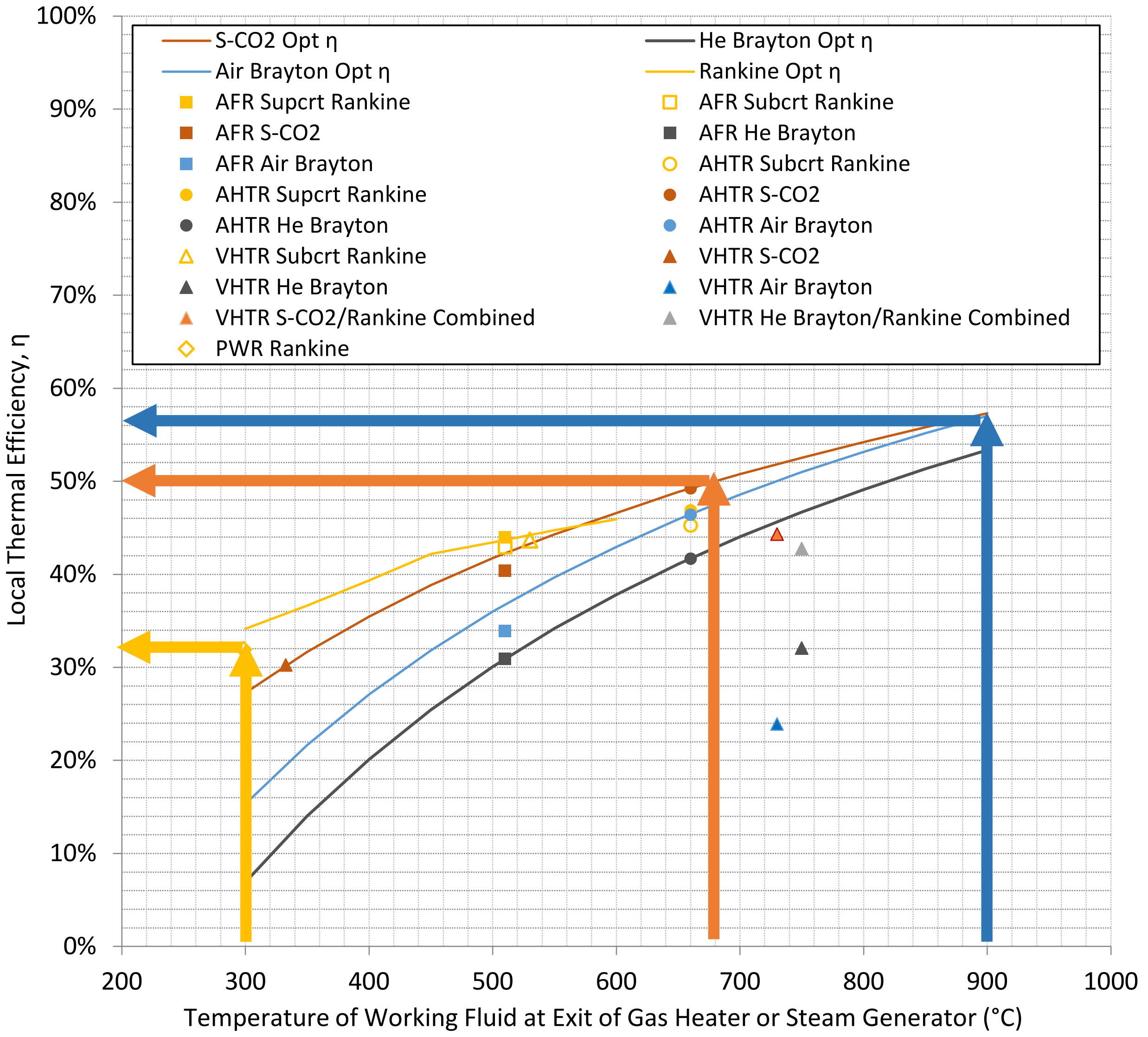
# Water Splitting and Power Thermodynamics




LWR HTSE: 30% more efficient than PEM

VTGR HTSE: 37% more efficiency than PEM

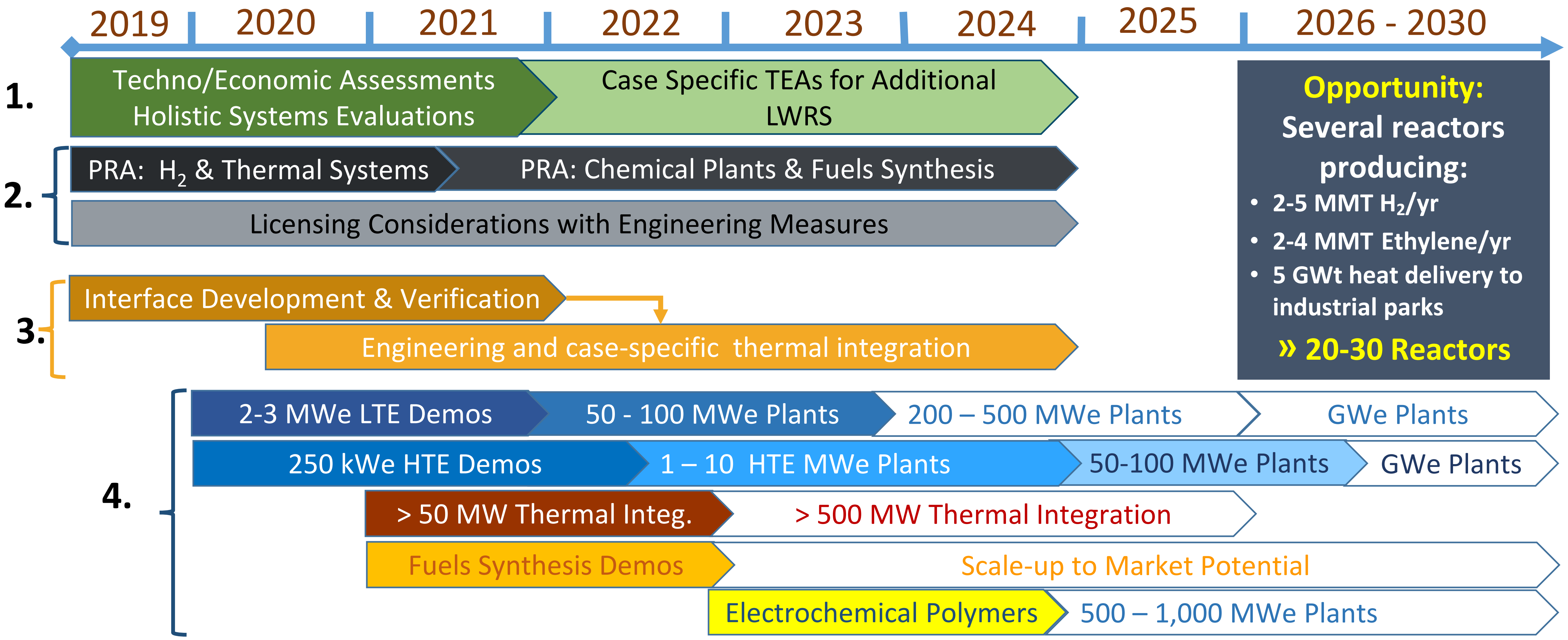


# Electrolysis Efficiencies vs Nuclear Reactor Type

| Reactor Type | T-Out (Celsius) | Power Cycle | Power Cycle Eff. | Carnot Eff. | Electrolysis Electricity (kWh/kg-$H_2$) | Over Thermal Energy Efficiency for H2 Production |
|---|---|---|---|---|---|---|
| LWR | N/A | Rankine | 32% | 50% | 39 (PEM) | 26% |
| LWR | 300 | Rankine | 32% | 50% | 32 (HTSE) | 38% |
| Sodium Fast Reactor (SFR) | 500 | Supercritical Rankine | 44% | 63% | 30 (HTSE) | 54% |
| Advanced High Temp Reactor (AHTR) (Molten Salt Reactor, MSR) | 700 | Sup-crit. $CO_2$ | 50% | 70% | 29.5 (HTSE) | 62% |
| Very High Temp Reactor (VHTR) | 900 | Air Brayton | 56% | 75% | 29 (HTSE) | 70% |

**Thermal efficiency gain; LWR-PEM vs VHTR-HTSE = 169 %**

# Flexible Plant Operations & Generation Timeline to Bolster U.S. Nuclear Reactors



# GAIN WEBINAR SERIES

GAIN Gateway for Accelerated Innovation in Nuclear

- **Objective:** The **GAIN Clean Nuclear Energy for Industry Webinar Series** highlights the innovations in nuclear energy and associated integrated-energy options that may be beneficial to a wide range of industrial energy applications. The intent is to develop connections between the nuclear community and the energy end-use community to communicate the benefits of clean, reliable, and resilient nuclear energy.
- Part 1: Introduction (April 16, 2020)
- Part 2: Advanced Nuclear Technologies (May 29, 2020)
- Part 3: The Case for SMRs and Microreactors in Puerto Rico (June 18, 2020)
- Visit https://gain.inl.gov/SitePages/GAINWebinarSeries.aspx to view previous webinars in this series and to register for upcoming webinars.

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# What might the future entail for nuclear?

Image courtesy of GAIN and ThirdWay, inspired by *Nuclear Energy Reimagined* concept led by INL.

Download this and other energy park concept images at: https://www.flickr.com/photos/thirdwaythinktank/sets/72157665372889289/

For more information, contact:
Shannon.Bragg-Sitton@inl.gov

Idaho National Laboratory