

IES Partner Labs:



Microreactor Test Bed:



# Nuclear-Renewable Integrated Energy Systems

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*MicroReactor Workshop  
Idaho Falls, Idaho*

www.inl.gov



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# Energy Reimagined

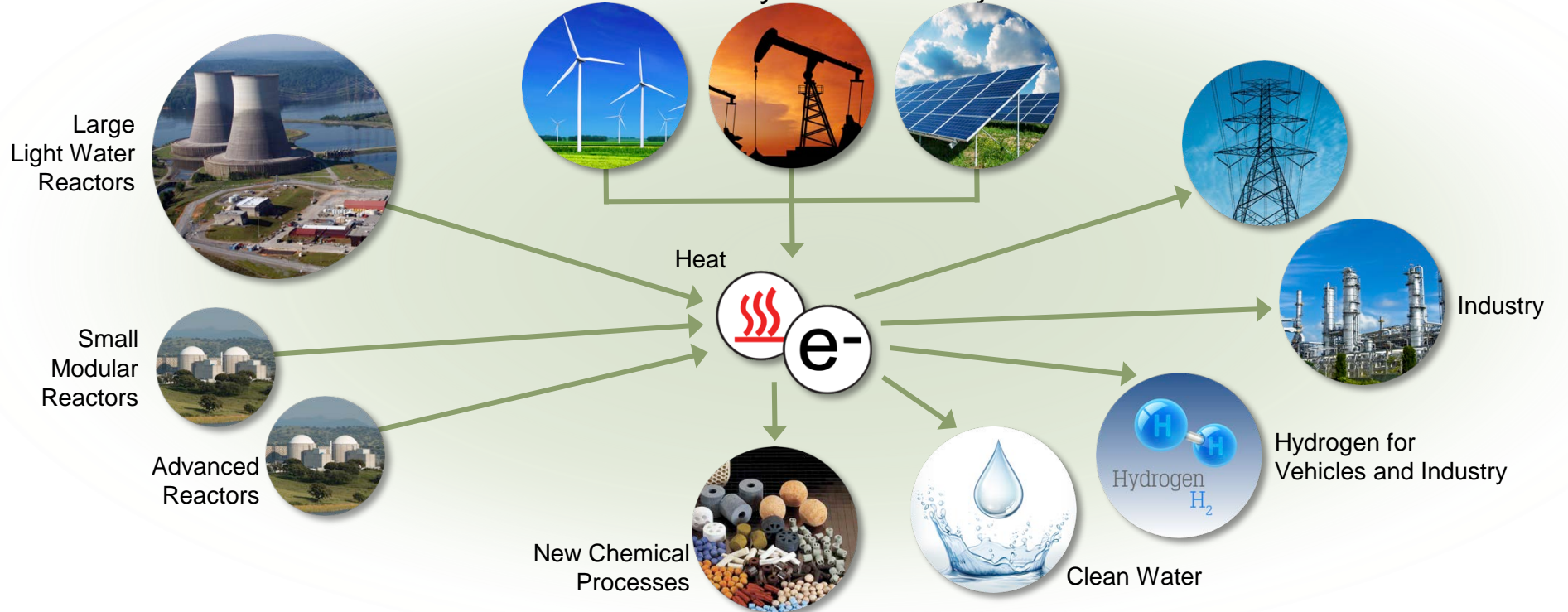
Maximizing energy utilization, generator profitability, and grid reliability and resilience through novel systems integration and process design

**Today**  
Electricity-only focus



## Potential Future Energy System

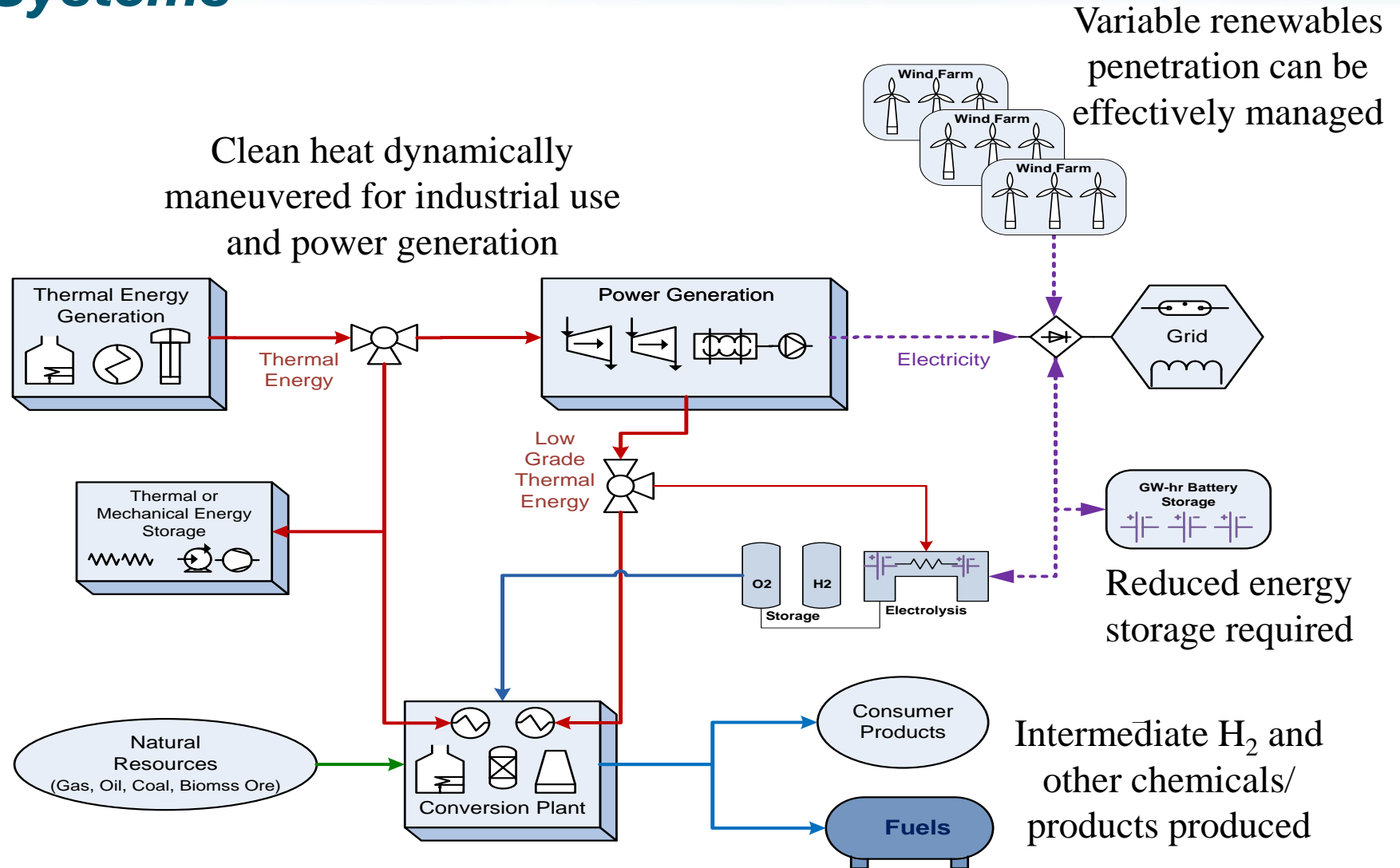
Integrated grid system that leverages contributions from nuclear fission beyond electricity sector



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

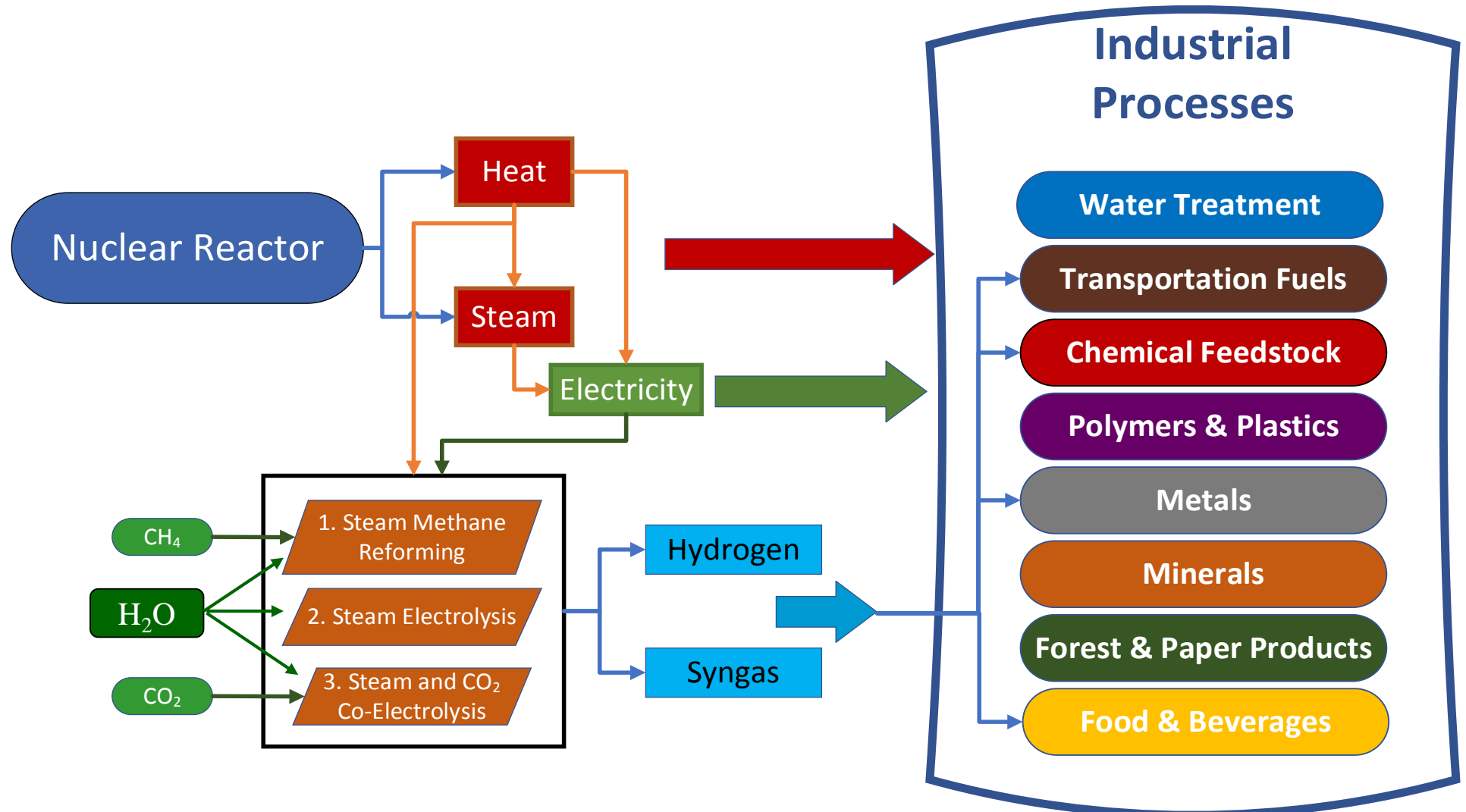
# Integrated Energy Systems

- Technical Feasibility:**  
 Tightly coupled systems involve dynamic exchange of energy streams, process conditions data, and diagnostics/prognostics control commands.
- Economic Feasibility Requires Efficient Capital Utilization:**  
 The impact of improved capital utilization, increased reliability, and enhanced maintainability on overall plant revenue must be characterized and understood.

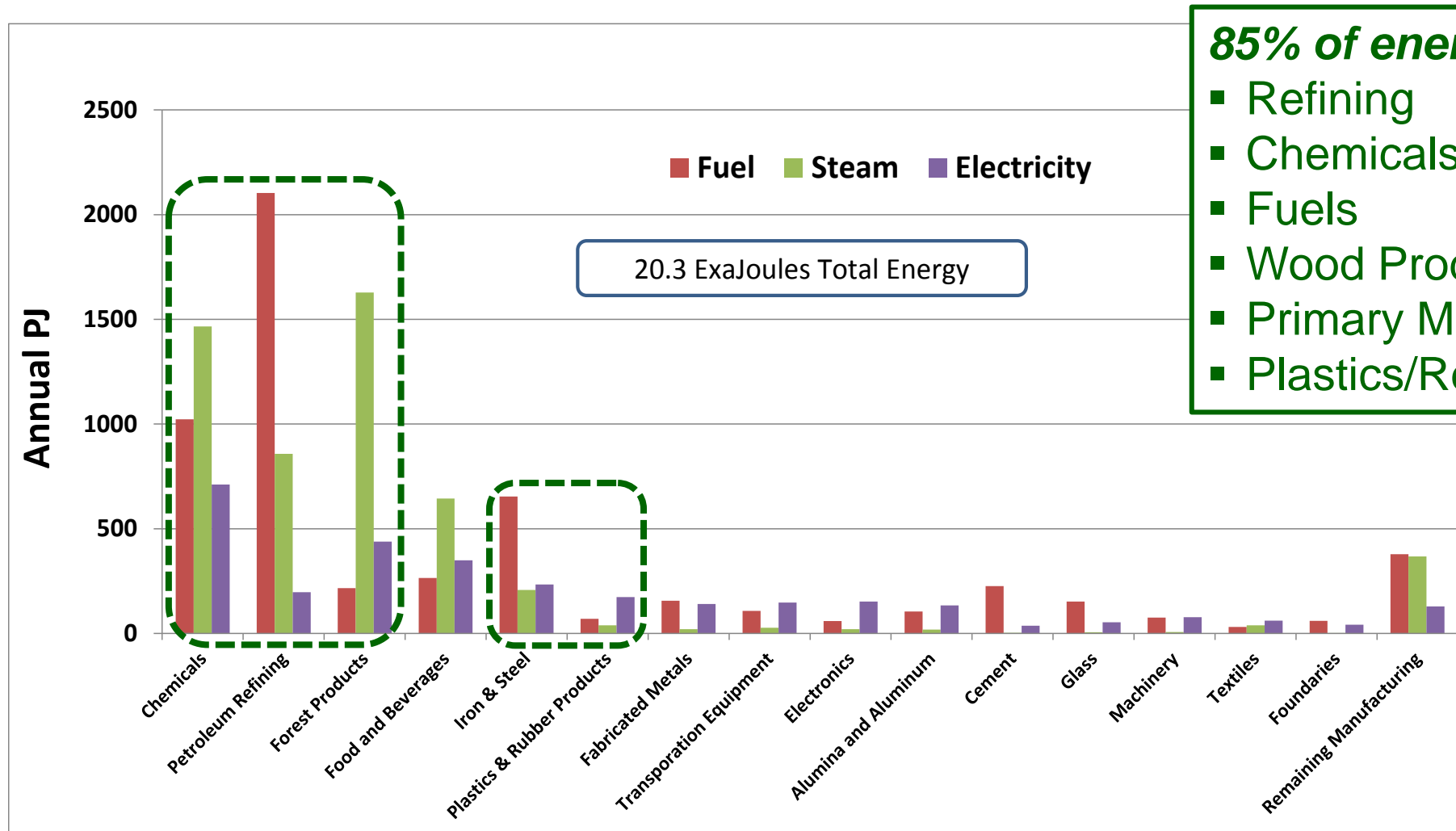


# Flexible Nuclear-Industrial System

\*May be loosely coupled with **renewable generators** in the regional grid balancing area that cause increased variation in net demand.



# Large Industry Energy Use Breakdown (2010 Data)



**85% of energy used by:**

- Refining
- Chemicals
- Fuels
- Wood Products/Paper
- Primary Metals
- Plastics/Resins

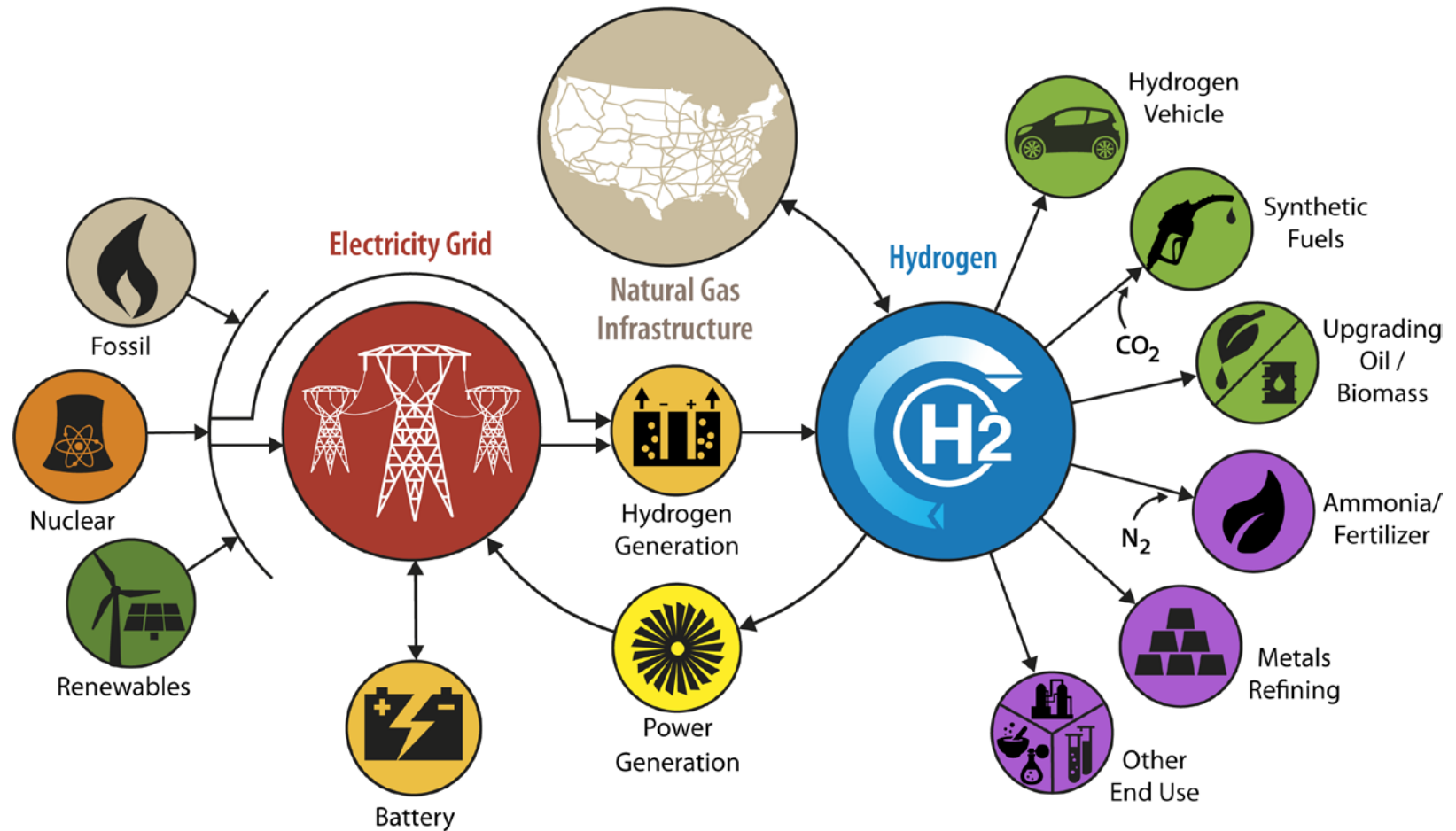
**Generation and Use of Thermal Energy in the United States Industrial Sector and Opportunities to Reduce its Carbon Emissions**, December 2016, INL/EXT-16-39680 and NREL/TP-6A50-66763, <http://www.osti.gov/scitech/biblio/1334495-generation-use-thermal-energy-industrial-sector-opportunities-reduce-its-carbon-emissions>

# Priority Application: Conceptual H<sub>2</sub>@Scale Energy System\*

Can hydrogen effectively be a new energy currency for LWRs?

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

\*\*H<sub>2</sub>@Scale is a complementary, collaborating program supported by the DOE Energy Efficiency & Renewable Energy Fuel Cell Technologies Office.



\*Illustrative example, not comprehensive

# ***DOE-NE Nuclear-Renewable Integrated Energy Systems (IES)***

- **Modeling and simulation**

Tool development and associated analysis to assess technical and economic viability and to determine optimal system design and energy dispatch. Detailed dynamic analysis with physics-based models, optimization using *RAVEN* (Reactor Analysis and Virtual control ENvironment).

- **Demonstration/experimental systems**

- Electrically heated system testing to emulate energy input from a fission reactor to demonstrate hardware interfaces, control systems, dynamic operation, etc.
- Nuclear demonstration planned for current-fleet LWRs (in partnership with plant owners/operators)
- Nuclear demonstration with small modular reactor (green-field installation)

- **Stakeholder engagement**

- Federal: DOE Offices of Nuclear Energy, Energy Efficiency and Renewable Energy, Fossil Energy, and Electricity
- Industry: Utilities (includes a Utility Advisory Committee; current fleet owners/operators), advanced reactor developers, electrical and thermal energy end users
- International: Clean Energy Ministerial – Nuclear Innovation: Clean Energy Future (NICE Future) initiative, various bilateral arrangements

# Technical & Economic Assessments (TEA)

## Resource Potential

- Market size
- Resource availability
- Resource attributes
- Infrastructure requirements

## Technology Potential

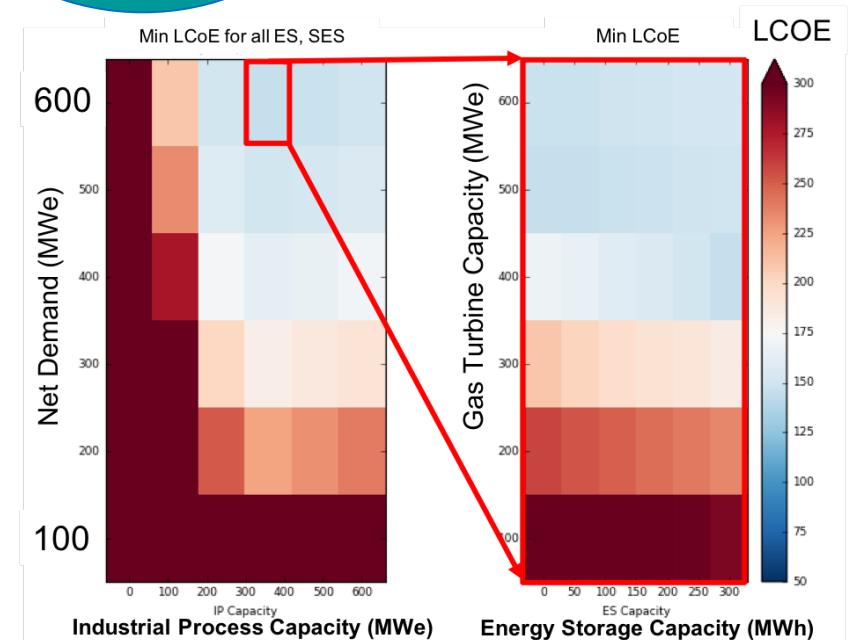
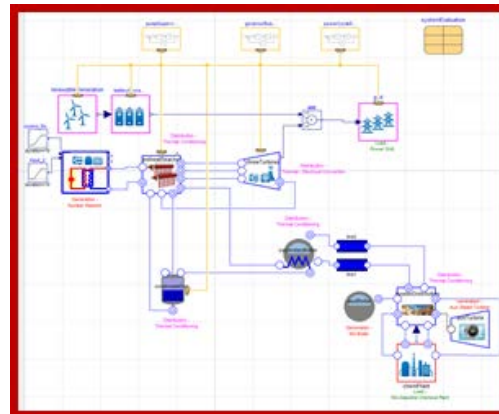
- Thermodynamics
- Performance
- Systems integration and control

## Economic Potential

- Pro forma
- ROI / IRR
- Cash Flow

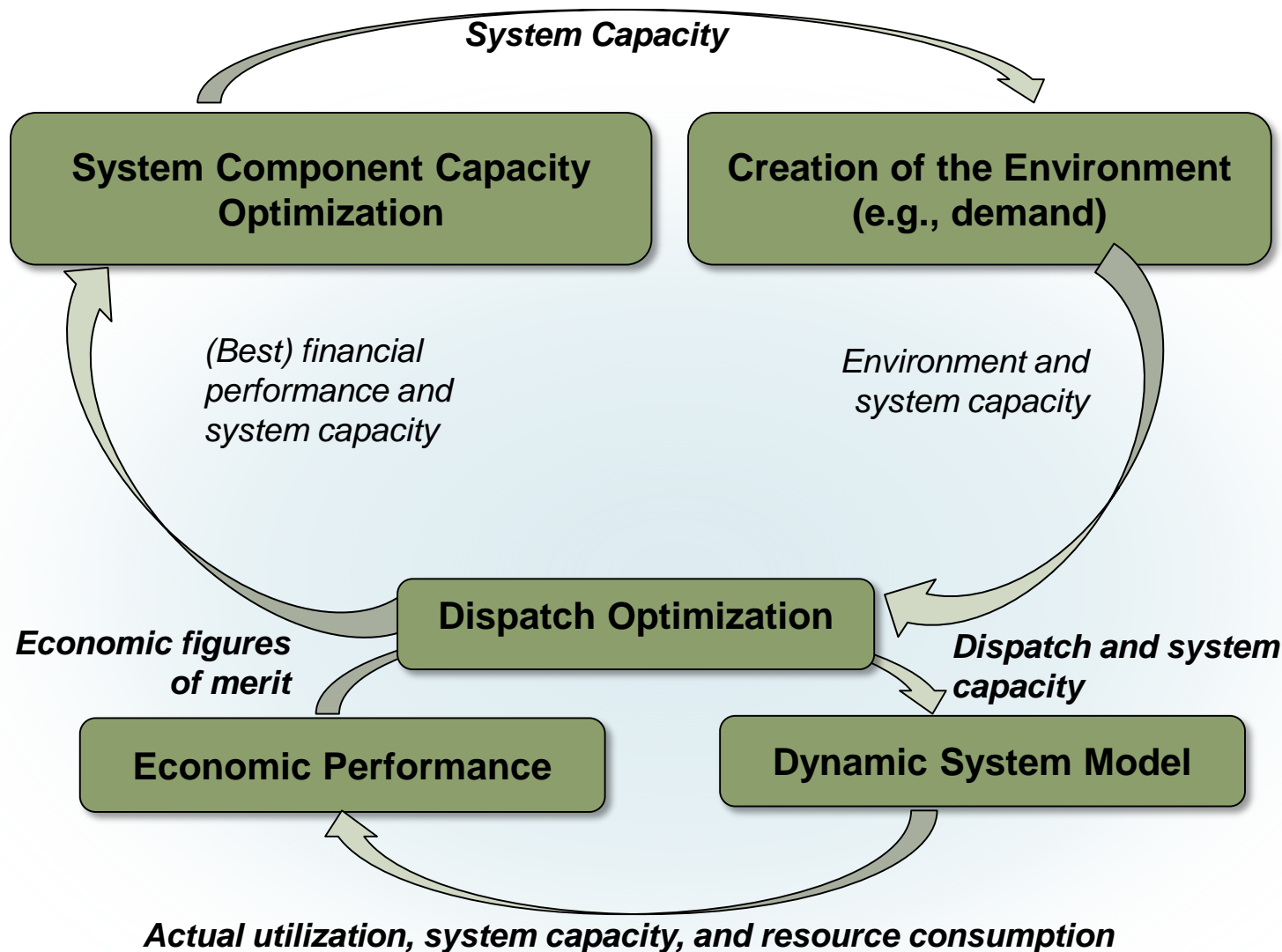
## Market Potential

- Competition
- Policy, Regs



# The Optimization Approach

M&S Lead: C. Rabiti, INL



**Goal:** Optimize economic performance under technical performance constraints and assurance of grid resilience.

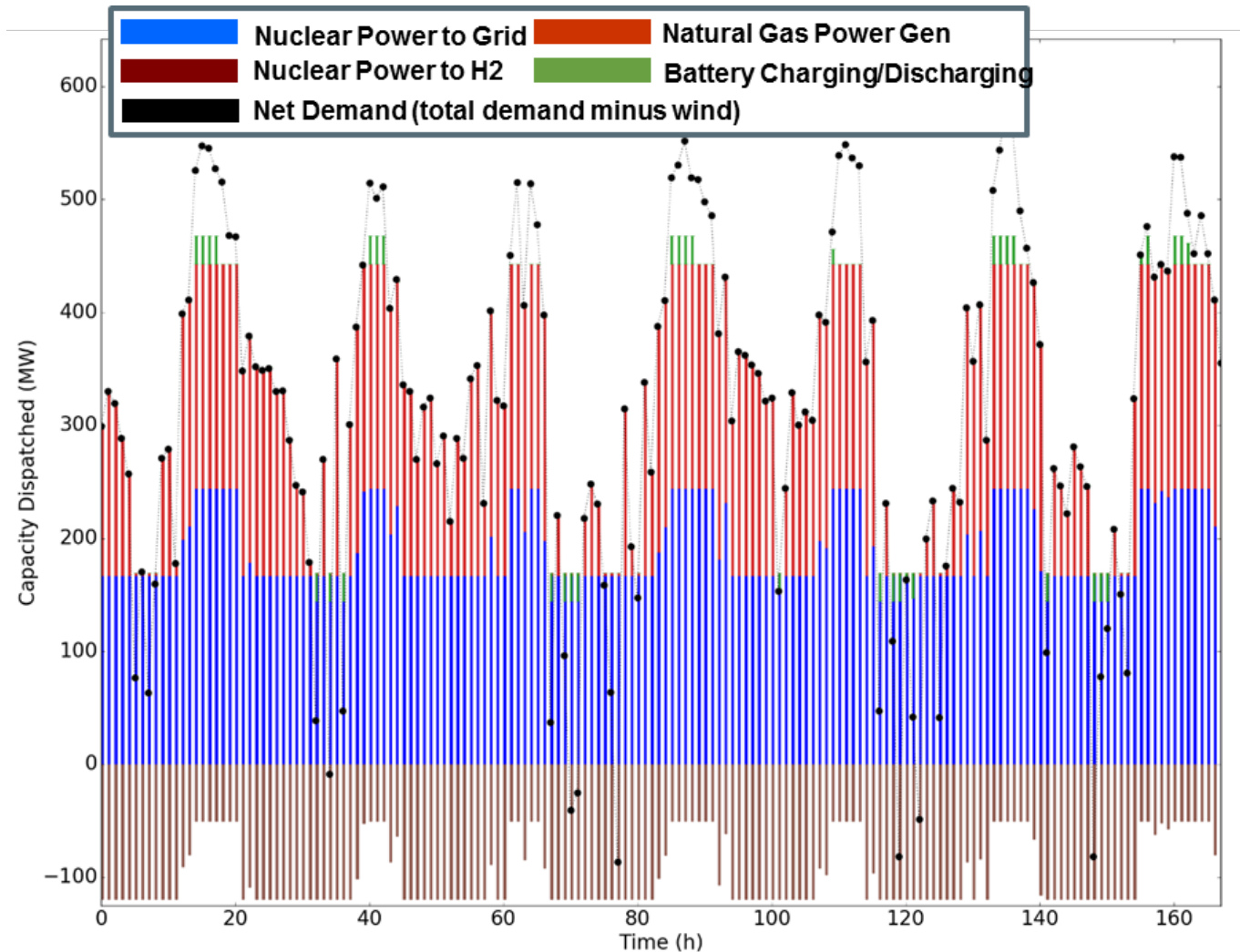
## INL-developed code for optimization: RAVEN

Reactor Analysis and Virtual Control Environment (RAVEN)

*Allows researchers to understand and manage the probabilistic nature of complex systems and their numerical representation*

# Example Optimized Hybrid System Performance Results INL-Developed Toolset

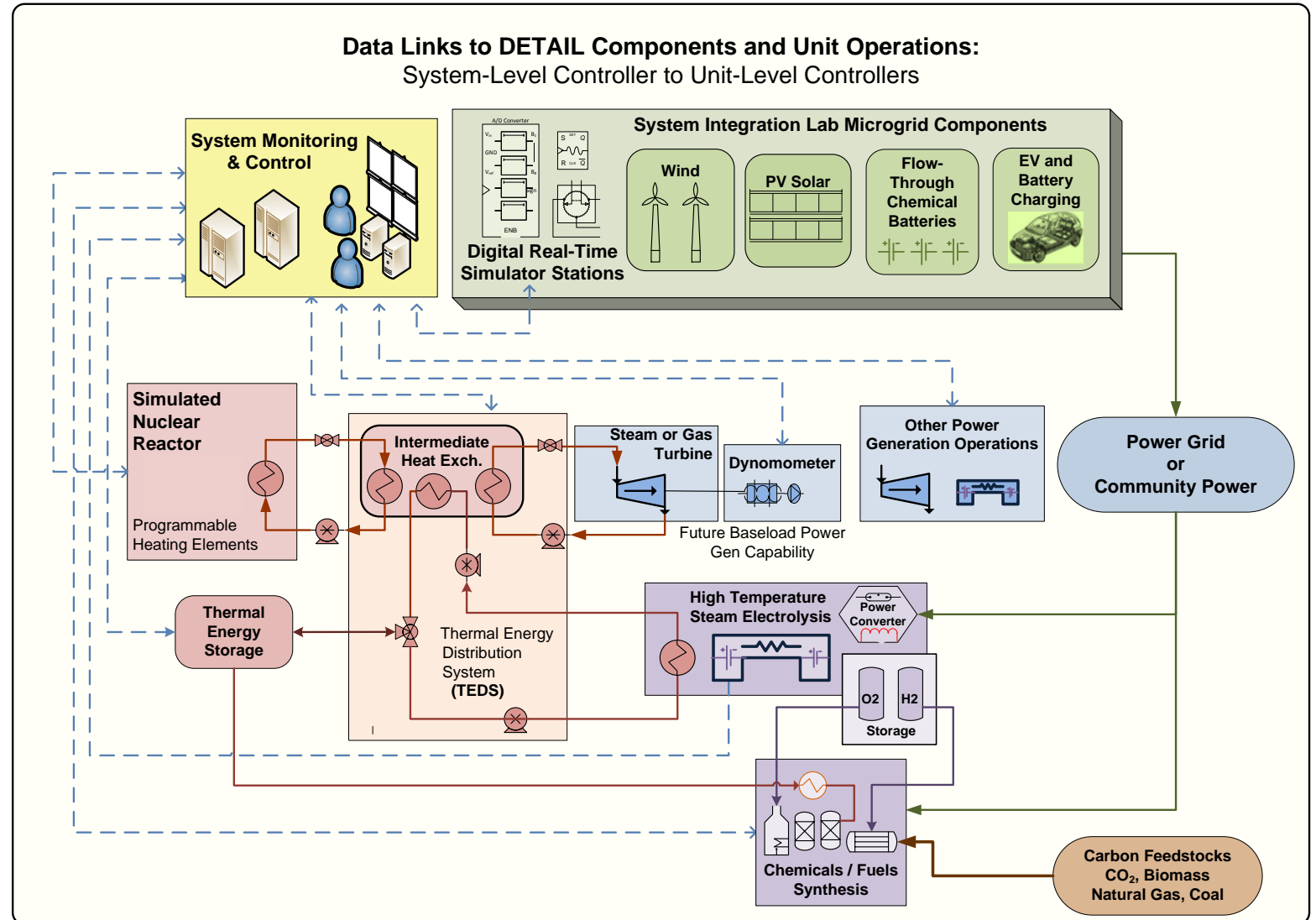
- System design optimization using time histories for one year
- Results shown for a selected time history, one week period (hourly resolution)
- Optimized component capacities
  - Nuclear Reactor 300 MW<sub>e</sub>
  - Hydrogen Plant Capacity 120 MW<sub>e</sub>  
*(shown as negative – electricity input; 70% turndown limit; H<sub>2</sub> market price - \$1.75/kg-H<sub>2</sub>)*
  - Gas turbine 200 MW<sub>e</sub>
  - Electric battery 100 MWh
  - Wind penetration 400 MW<sub>e</sub>  
*(100% of mean demand, installed capacity, 27% capacity factor)*
  - Penalty function applied for over or under production of electricity.



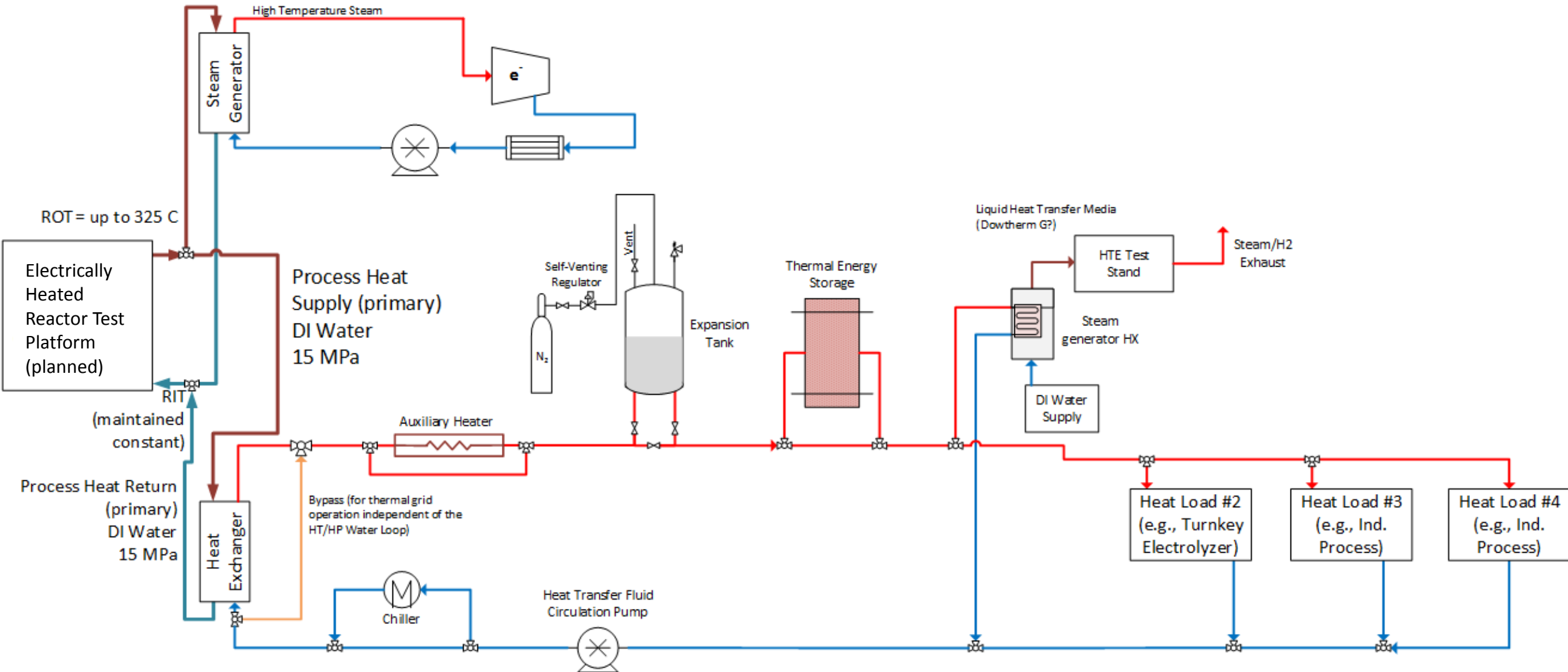
# Experimental Demonstration of Integrated Systems

## Dynamic Energy Transport and Integration Laboratory (DETAIL)

**Objective:** Demonstrate simultaneous, coordinated, controlled, and efficient multi-directional transient distribution of electricity and heat for power generation, storage, and industrial end uses.



# Thermal Energy Distribution System – Conceptual Design



# INL Systems Integration Laboratory



**Energy Storage**

**Battery Testing**  
*(out of picture)*

**Vehicles**  
**Wireless Charging**

**Hydrogen**  
**High Temp Electrolysis**

**Power Systems**

**Grid Emulation**

**Microreactor Test Bed**

**Fast Charging**

**Synthesis Reactor**

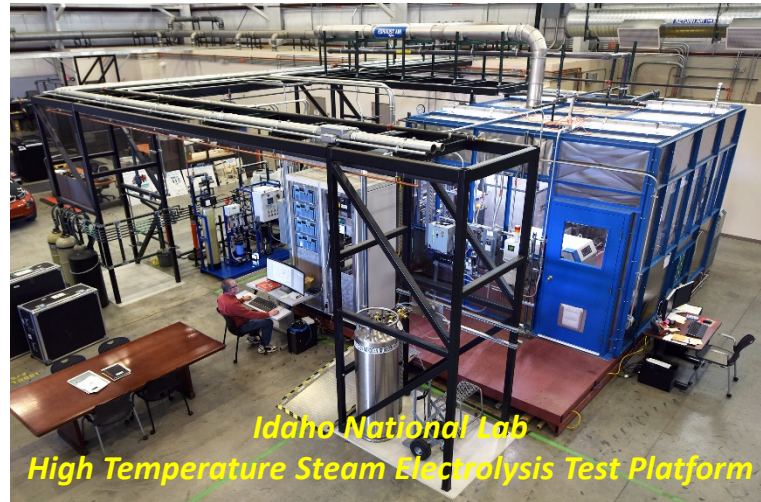
**Thermal Energy Distribution System**  
*(in final review for construction)*

**Distributed Energy**

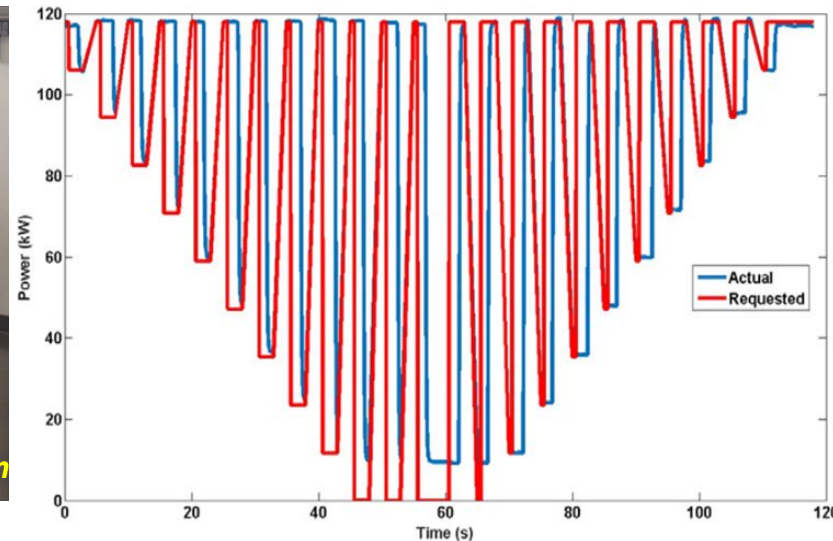
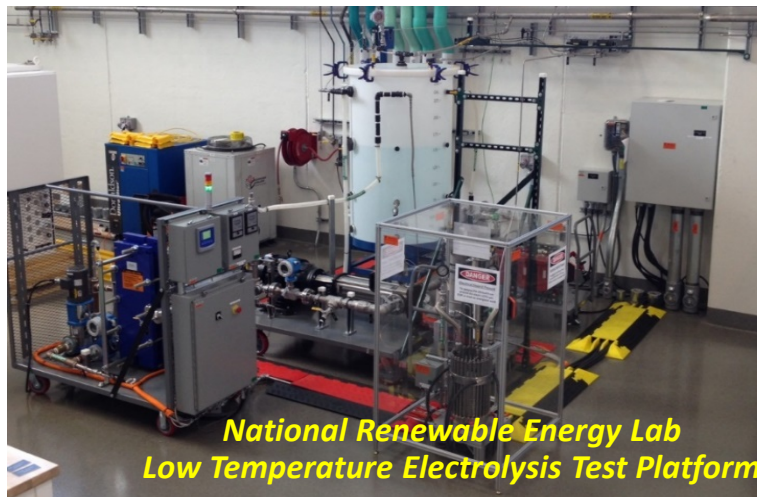


## INL High Temperature Electrolysis Test Platform for Nuclear Energy Integration

# DOE Nuclear Energy Integration with Electrolysis

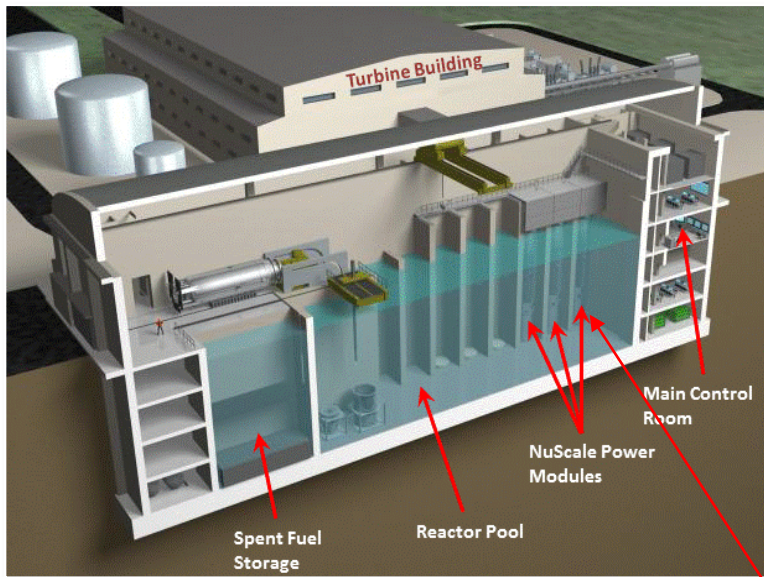


Testing and demonstration across multiple, geographically distributed laboratories to create a broader “integrated” laboratory via digital real-time simulator connection.

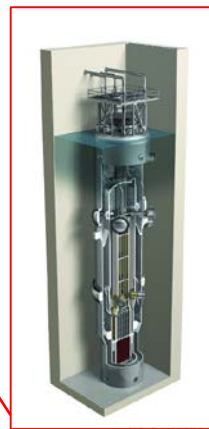


# Small Modular Reactors and Integrated System Operation

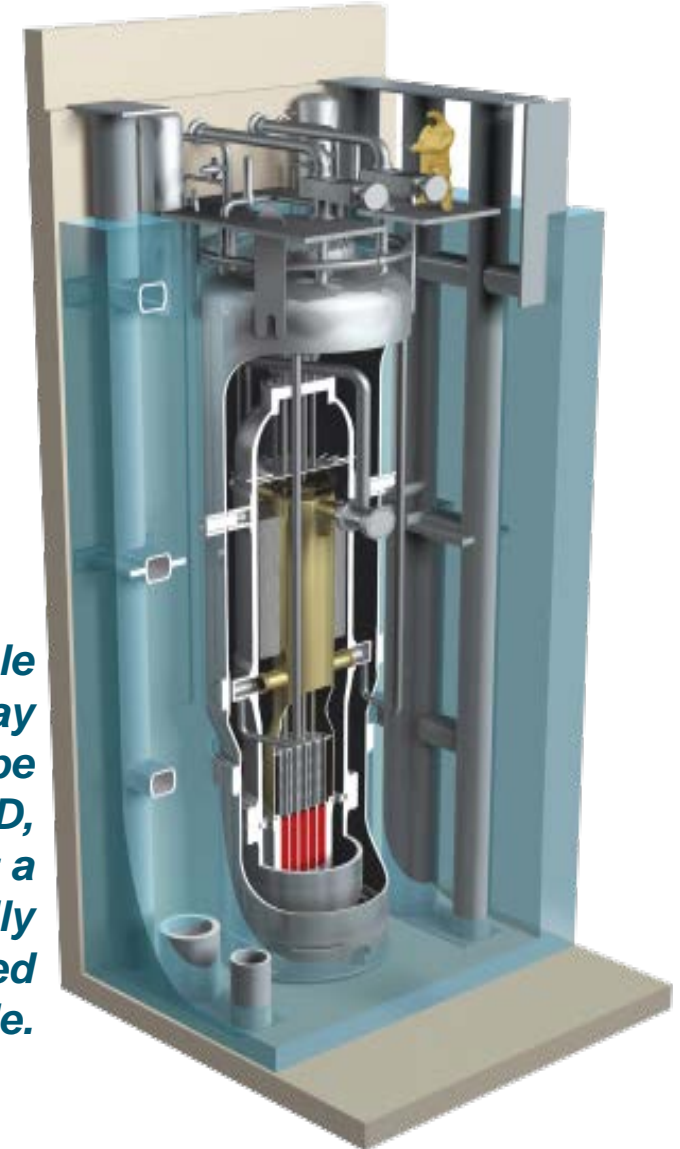
- Joint Use Modular Plant (JUMP) Program is a key aspect of the Carbon Free Power Project (CFPP) that will build the first NuScale Nuclear Power Plant (operational late 2026)
- The JUMP Program would support Research, Development & Demonstration (RD&D) activities *and* commercial use within a single multi-module nuclear plant, wherein a specific module is allocated to RD&D



**3-D view of Six NuScale Modules**

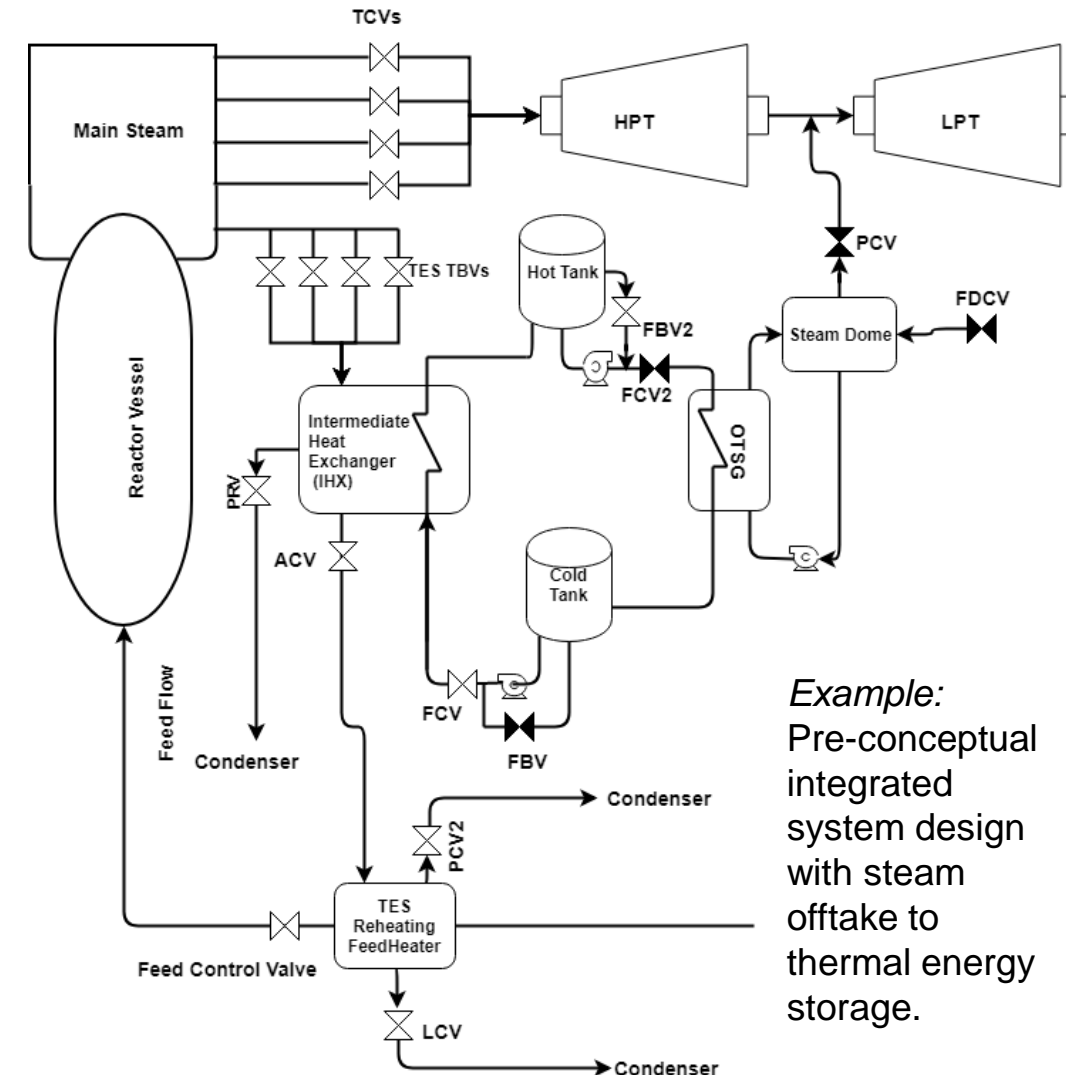


**Single NuScale Module within its operational bay – One bay would be dedicated to JUMP RD&D, with ability to support a standard module initially or a future modified module.**



# JUMP Demonstration of Integrated Energy System Concepts

- Coordinated operation with nearby renewable installations
- Front-end control approaches, communications standards, control reliability
- Data collection and analytics to maintain process stability
- Thermal and electrical energy delivery system effectiveness
  - Tighter coupling of nuclear plant output required to achieve highly efficient integrated energy systems
  - JUMP provides opportunity to measure energy transport phenomena for non-steady-state process operations
- Multiple energy users/industrial applications:
  - Energy storage (electrical, thermal, chemical)
  - Industrial process pilot scale demonstration:
    - Hydrogen generation, desalination, carbon conversion, etc.
    - Verify process chemistry, operational stability
  - Grid emulation environment to replicate arbitrary grid conditions
- Demonstrate human factors aspects of integrated system operation
- Exercise new regulatory approaches



*Example:*  
Pre-conceptual integrated system design with steam offtake to thermal energy storage.

# Innovative Technologies and Approaches

## Advanced Instrumentation, Model Verification & Validation (V&V)

- Test and demonstrate advanced instrumentation and sensor technologies in relevant reactor conditions
- Collect valuable data for system characterization, model development and V&V; reduce design conservatisms

## Fuels and Materials Testing, Characterization

- Provide prototypic commercial operating conditions
- Characterize materials as a function of design, fabrication methods, operating parameters, load cases
- Test advanced fuels under various operational conditions; leverage module ability to accept full assemblies
- Provide data to support licensing

## Human Factors

- Measure and evaluate human performance via a realistic operational environment
- Inform future control rooms and training simulator designs, increase reliability of safety critical systems, and increase operator awareness in unfamiliar operating environments

## Cybersecurity

- Demonstrate operator situational awareness in cyber-attack scenarios
- Evaluate supply chain security

## Regulatory Research

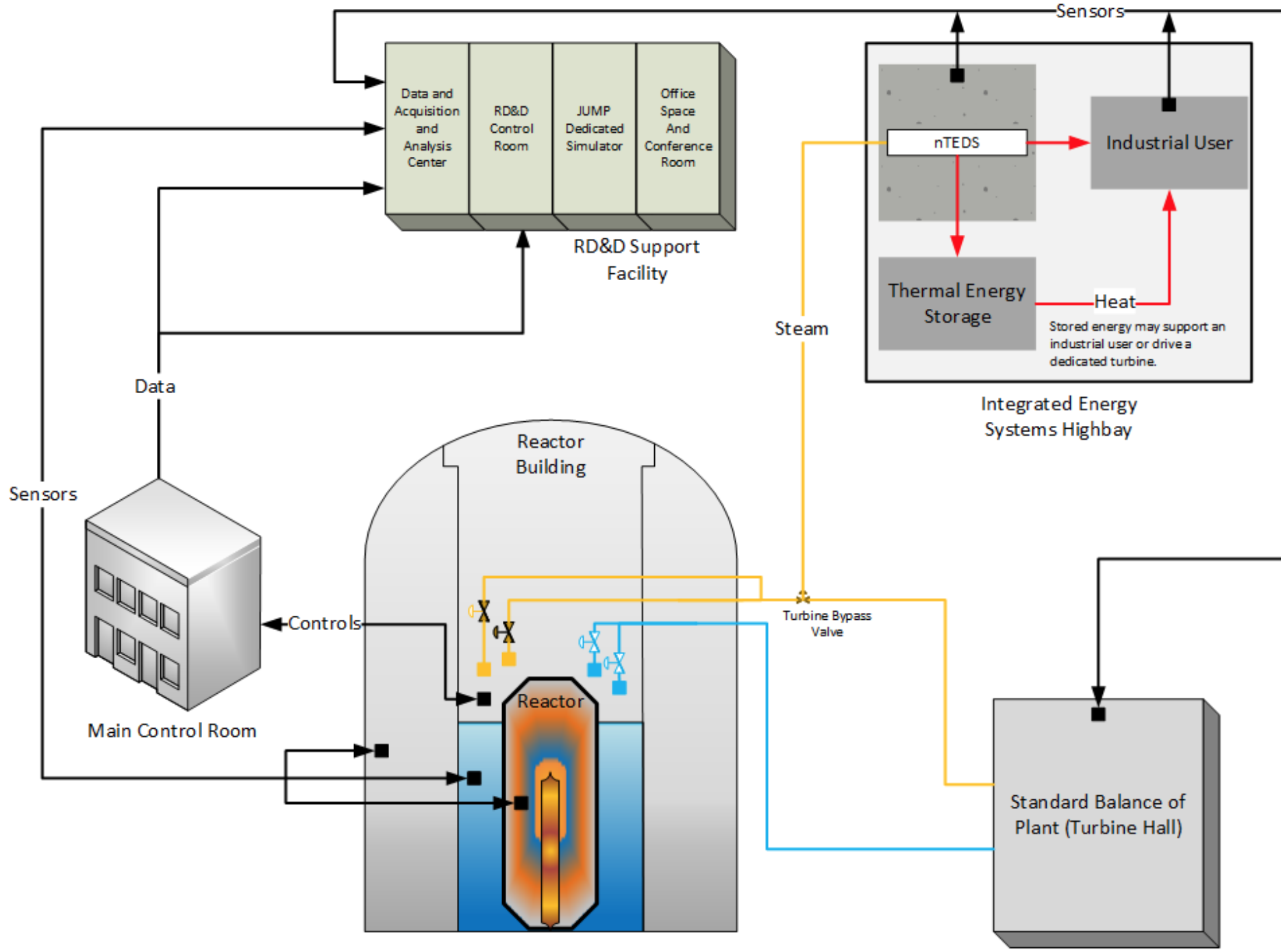
- Inform regulatory approach for fully digital I&C
- Exercise specialized licensing paths for non-traditional applications

## Safeguards Research

- The integration of features to support domestic/IAEA safeguards & security into the design process for a new or refurbished nuclear facility



*Image taken from June 2018  
NuScale Power advanced  
technology presentation  
available at <https://gain.inl.gov>.*



**Overview of the JUMP concept relative to the NuScale module in the UAMPS commercial facility**



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

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



Idaho National Laboratory

