

# IES

Integrated Energy Systems

## Dynamic Nuclear Thermal Energy Integration for High Temperature Electrolysis

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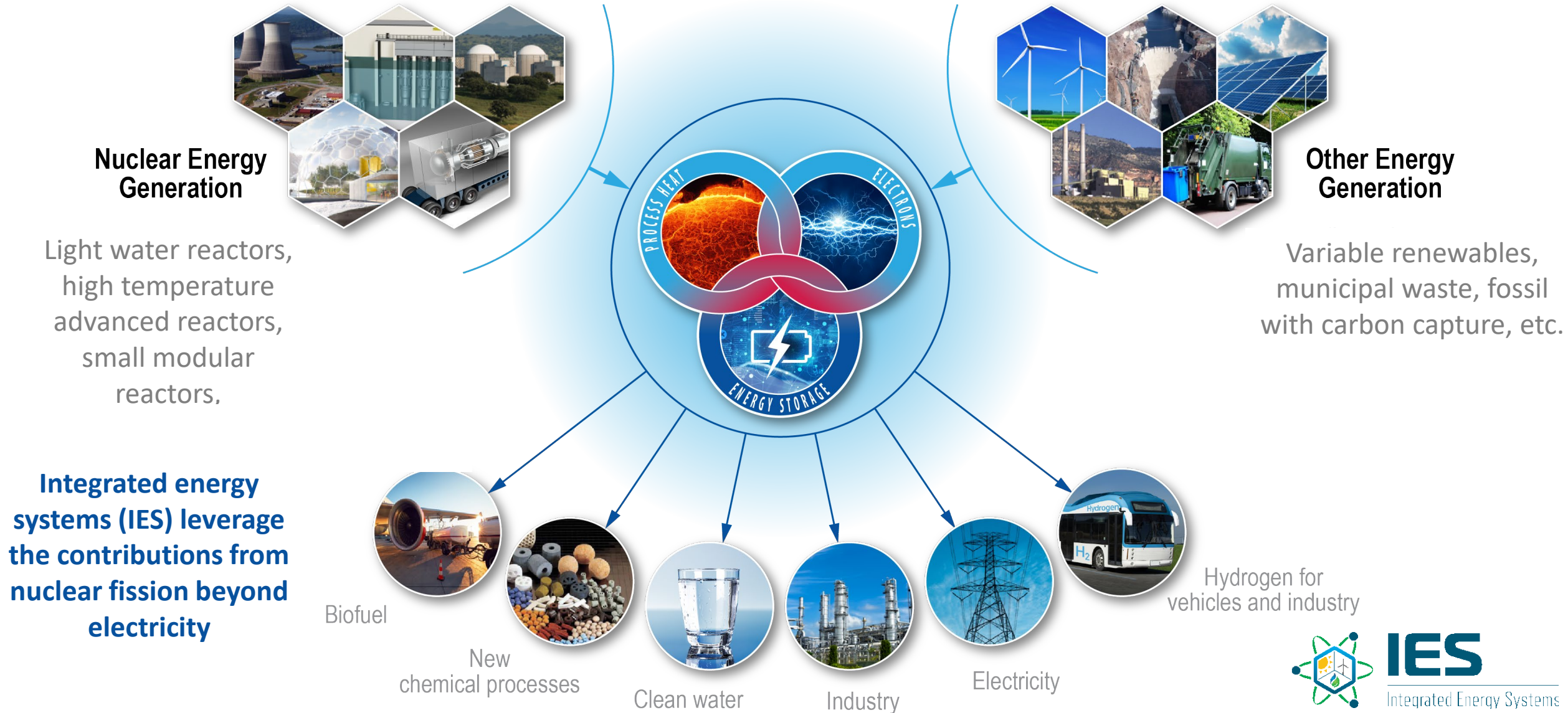
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# Motivation and challenges

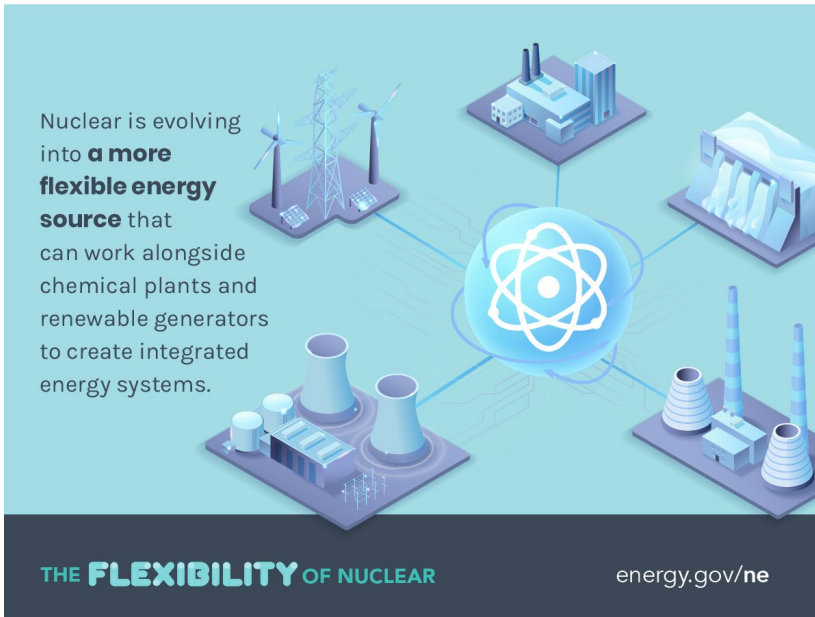
- Evolution in the electric power sector
  - Advent of variable renewables → increased variation in net load
  - Transition away from traditional baseload resources
  - Increased need for generator flexibility while ensuring grid resilience, reliability
- Ambitious goals for deep decarbonization (“net-zero”)  
U.S. targets:
  - Zero emissions from electricity sector by 2035
  - Economy-wide net-zero emissions by 2050 → industry, transportation
- Traditional energy planning tools are often limited in applicability to new scenarios, technologies, opportunities
  - Cross-sectoral energy utilization from a single generator not represented

# Future clean energy systems – transforming the energy paradigm



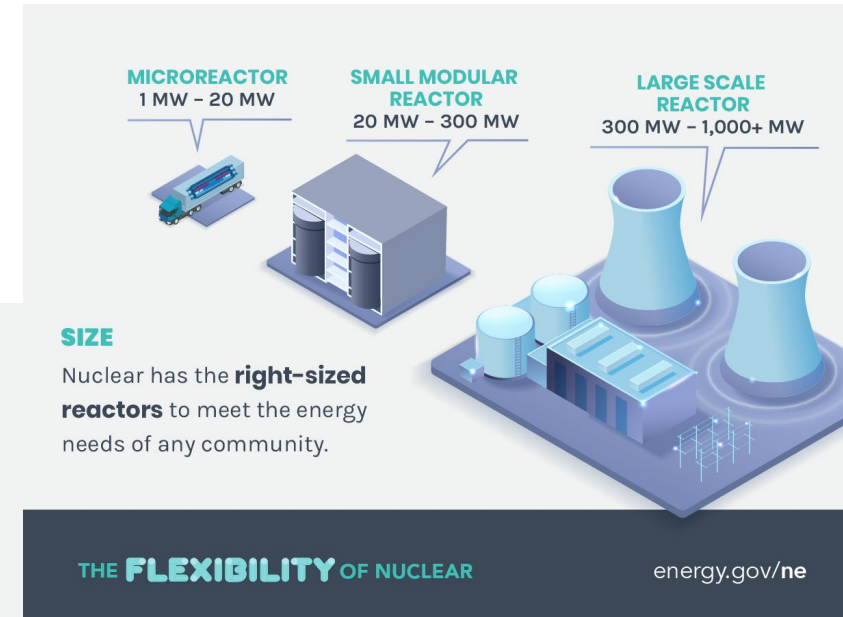
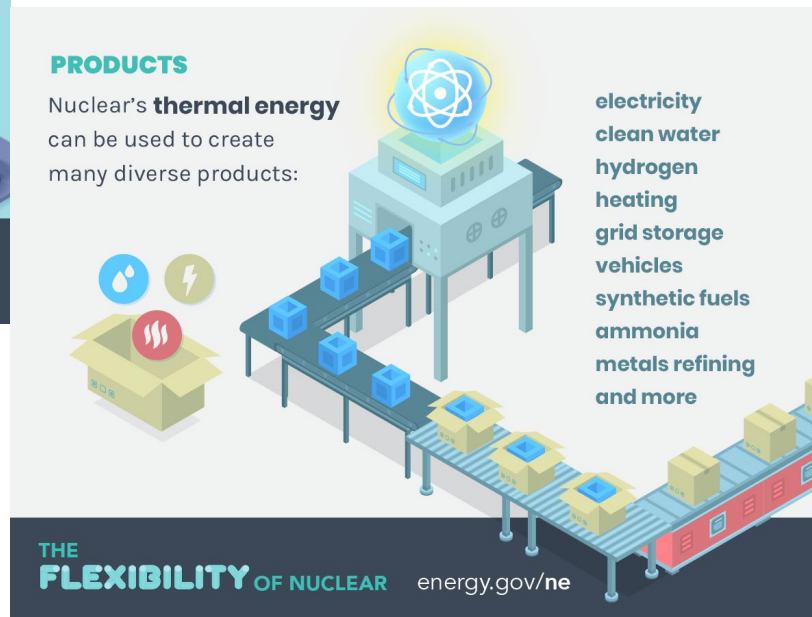


# Operational paradigms—nuclear energy flexibility



- **Operational flexibility**
- **Product flexibility**
- **Deployment flexibility**

*Nuclear flexibility is key to enabling other clean energy generators to provide deep decarbonization across multiple sectors.*



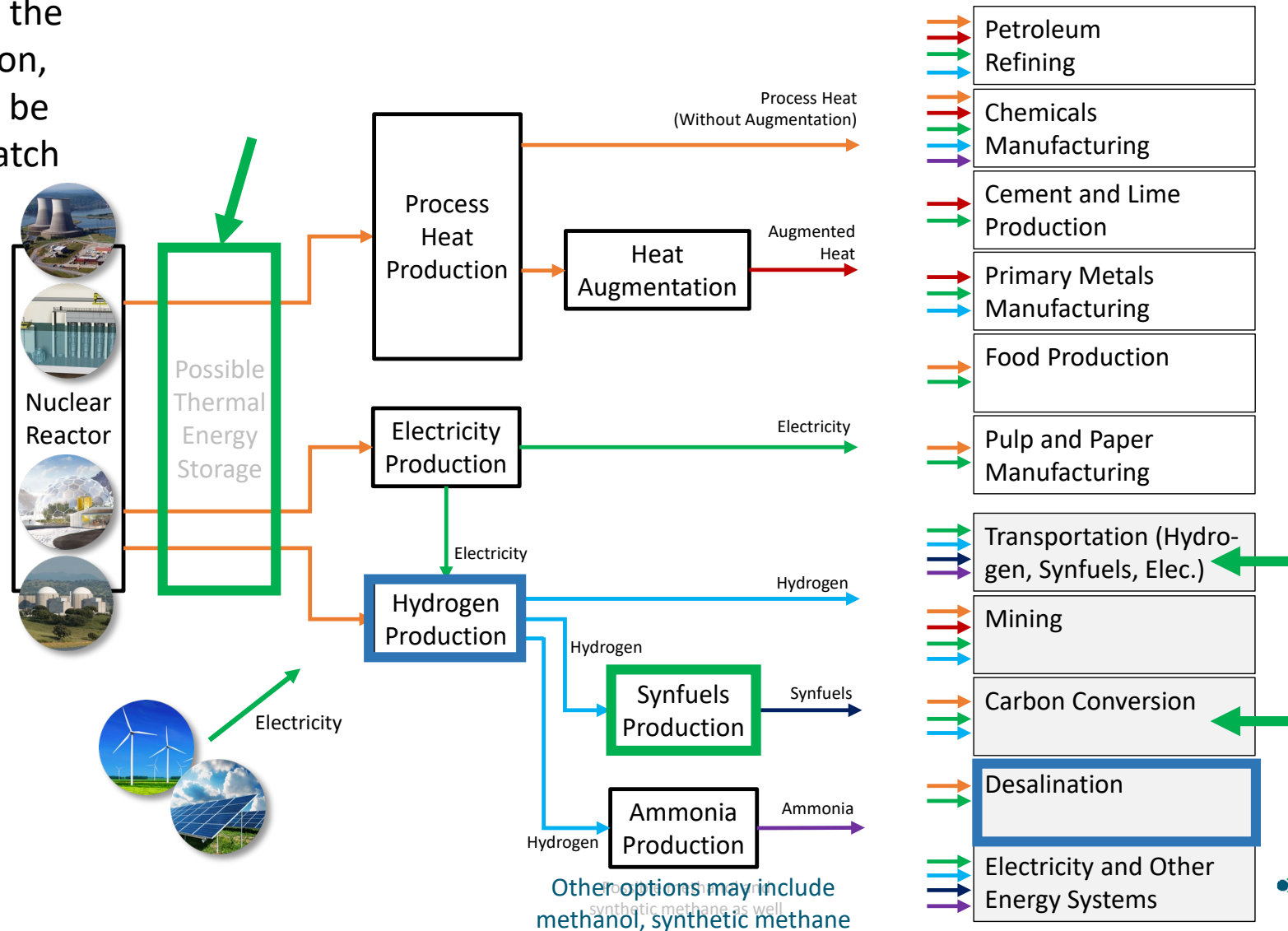
U.S. DEPARTMENT OF **ENERGY** | Office of **NUCLEAR ENERGY**



Flexible Nuclear Energy for Clean Energy Systems, September 2020  
<https://www.nice-future.org/flexible-nuclear-energy-clean-energy-systems>

# 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.



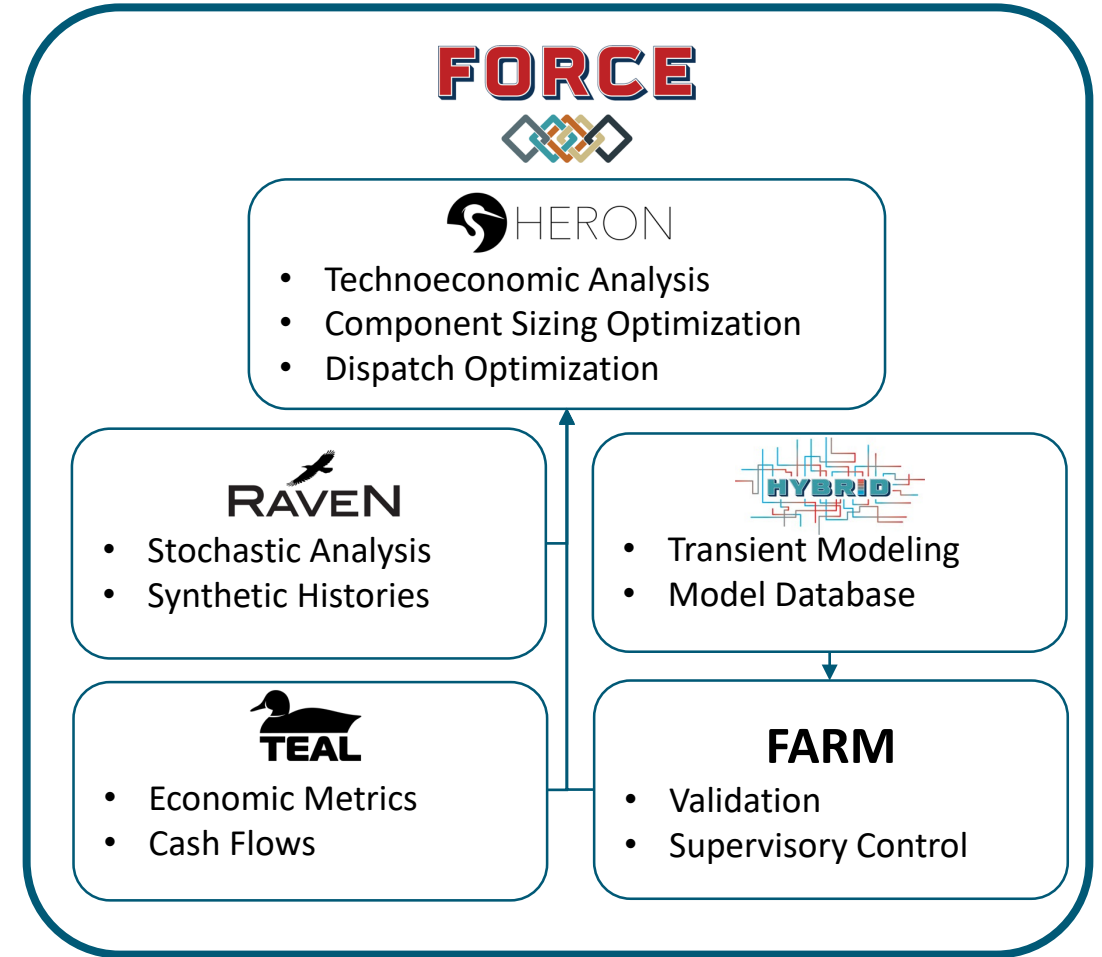
Source: INL, [National Reactor Innovation Center \(NRIC\) Integrated Energy Systems Demonstration Pre-Conceptual Designs](#), April 2021

# IES guiding questions

- 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 **optimal coupling strategies** between IES technologies and nuclear plants?

# 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](https://ies.inl.gov/SitePages/System_Simulation.aspx).

Recorded training modules can be viewed at [https://ies.inl.gov/SitePages/FORCE\\_2022.aspx](https://ies.inl.gov/SitePages/FORCE_2022.aspx).

# Analysis timeline

*Assessments Drive Development*

2016: RAVEN  
for  
Stochastic  
Economics

2018:  
Desalination  
in Arizona  
(APS)

2020: Hydrogen in  
NYISO (EPRI)  
Xcel Hydrogen TEA

2022:

- TES in NYISO
- Carbon conversion
- SynFuels

2017:  
Flexible  
Nuclear  
Dispatch

2019:  
Hydrogen in  
Midwest  
(Exelon)

2021:  
Thermal  
Energy  
Storage

Capacity  
Optimization

Industry  
Engagement

HERON, TEAL  
Released

- FORCE workshop
- Vertical integration
- Real-time  
optimization

Dispatch  
Optimization

Regulated,  
Deregulated  
Markets

FORCE,  
HYBRID,  
FARM  
Released



# Nuclear-H<sub>2</sub> 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<sub>2</sub> 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<sub>2</sub> 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 H<sub>2</sub> production, ~6-8 tons H<sub>2</sub>/day
  - Co-locate H<sub>2</sub> production at the site of use
  - H<sub>2</sub> storage + H<sub>2</sub> to gas peaking turbines (50%), syngas pilot
  - Contract arrangements currently in discussion



*Nine Mile Point  
Nuclear Power Plant  
LTE/PEM, nel hydrogen*



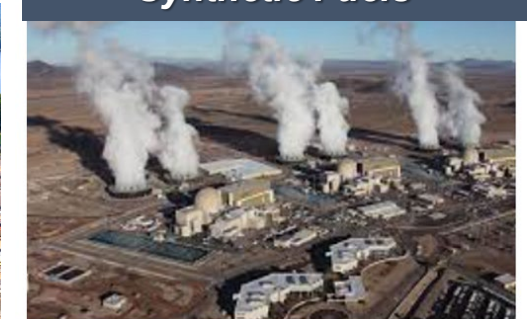
*Davis-Besse Nuclear  
Power Plant  
LTE-PEM Vendor 2*



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

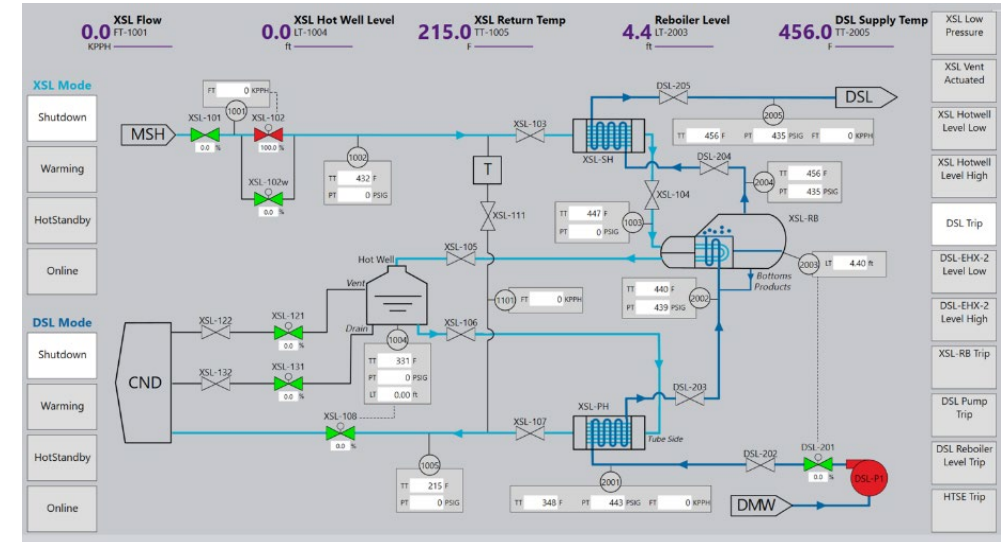


*Palo Verde Gen Station  
Hydrogen Production for  
Combustion and  
Synthetic Fuels*



# Operations with flexible thermal and electrical power dispatch

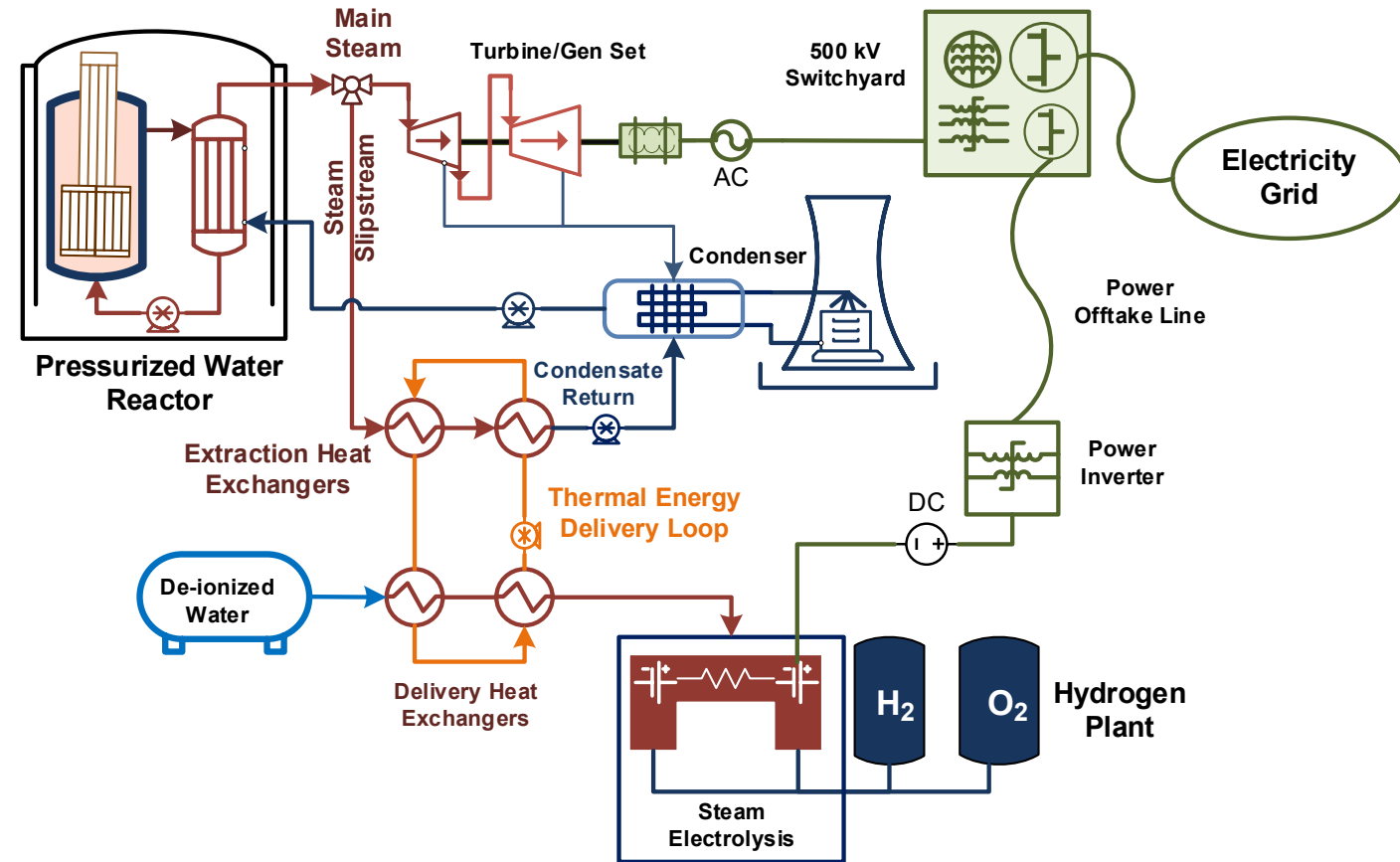
- The INL Human Systems Simulation Laboratory was used to test concepts for dispatching thermal and electrical power from nuclear reactors to a H<sub>2</sub> electrolysis plant
  - Two formerly licensed operators tested 15 scenarios
  - A modified full-scope generic Pressurized-Water Reactor was used to emulate the nuclear power plant
  - A prototype human-system interface was developed and displayed in tandem with the virtual analog panels
  - An interdisciplinary team of operations experts, nuclear engineers, and human factors experts observed the operators performing the scenarios
- This exercise emphasized the need to support the adoption of thermal power dispatch by
  - Leveraging automation to augment any additional operator tasking
  - Monitoring energy dispatch to a second user



# Thermal integration of steam electrolysis

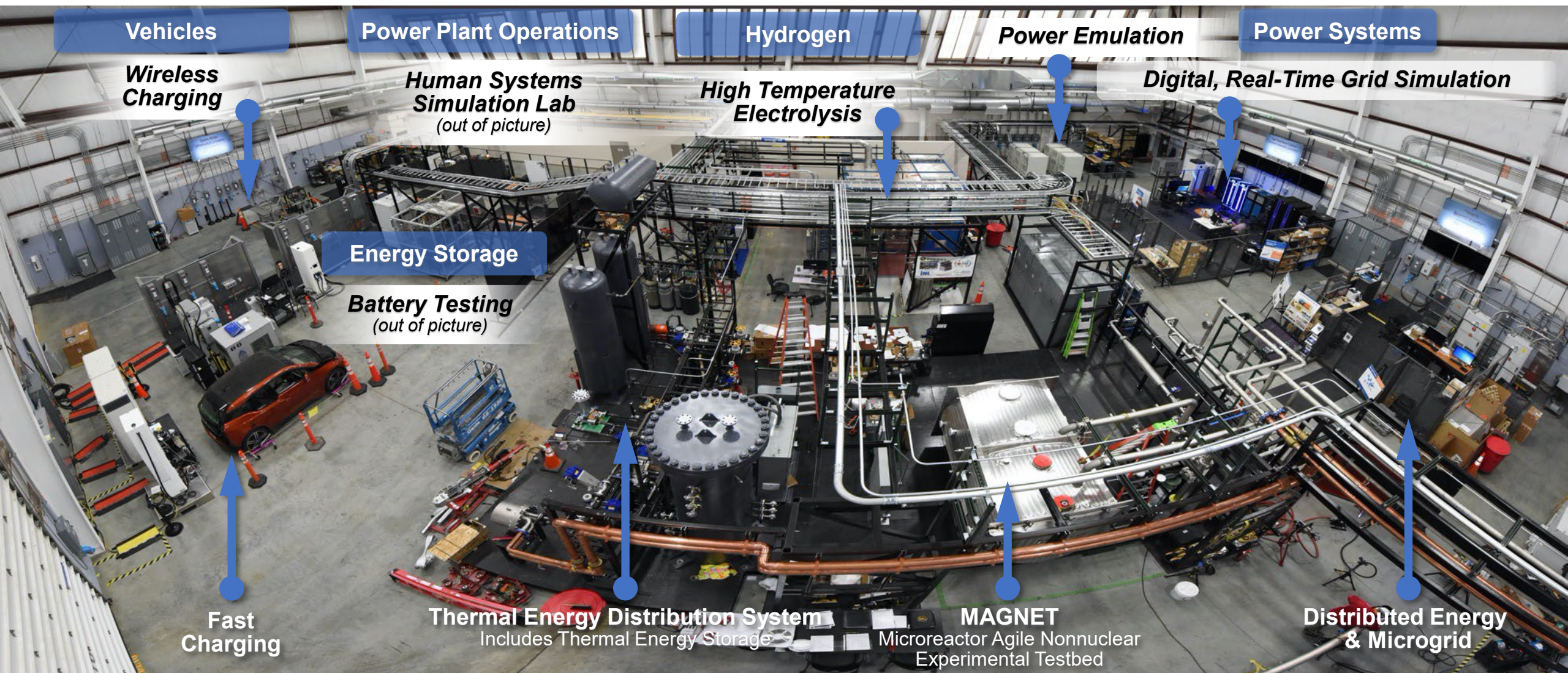
## Safety analysis summary conclusions

- The LWRs generic probabilistic risk assessment (PRA) investigation into licensing considerations concluded that following the assumptions made:
  - The licensing criteria is met for a large-scale HTE facility sited 1 km from a generic PWR and BWR
  - The safety case for less than 1 km distance is achievable
- Report available: INL/EXT-20-60104, *Flexible Plant Operation and Generation Probabilistic Risk Assessment of a Light Water Reactor Coupled with a High-Temperature Electrolysis Hydrogen Production Plant*, OSTI link: <https://www.osti.gov/biblio/1691486>





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





# Design parameters: DETAIL thermal input components

## Thermal Energy Distribution System (TEDS)

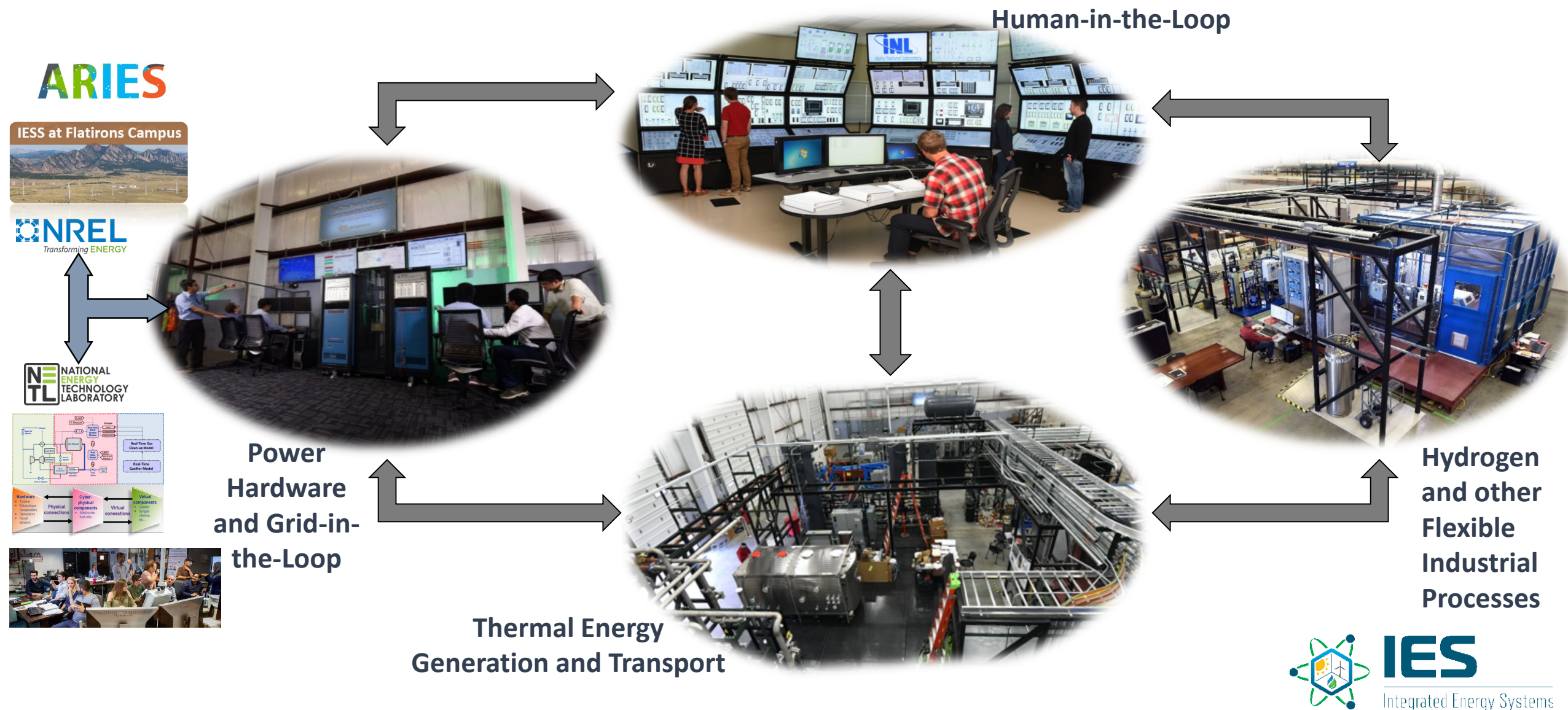
- Design Pressure 100 psig
- Design Temperature 340 °C
- Nominal Operating Temperature 325 °C
- Nominal Operating Pressure 14 psig
- Electric Heater Capacity 200 kW
- Nominal Flow Rate 14-33 gpm
- Working Fluid Therminol 66
- Therminol 66® Properties:
  - wide operating temperature range (-3 to 343°C)
  - low vapor pressure at high temperatures (10.3 psi at 340°C)
  - wide range of material compatibility

## Microreactor AGile Nonnuclear Experimental Test bed (MAGNET)

- Design heat removal capacity 250 kW
- Design pressure 22 bar<sub>g</sub>
- Hot section design temperature 650 °C
- Coolant Compressed N<sub>2</sub> or He
- Heat Sink Chilled water
- Expandable design with potential to add power conversion unit or HX interface with co-located system
- Recuperative HX (designed with air-Brayton cycle design parameters for T and P in mind)



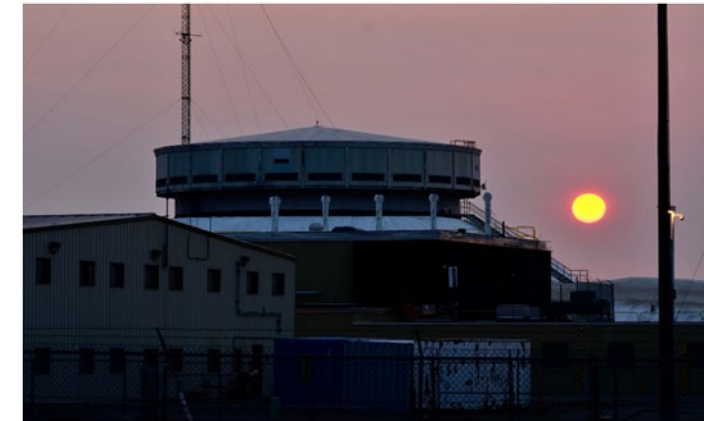
# DETAIL enables cross-complex laboratory connections



# National Reactor Innovation Center (NRIC) advanced reactor testing infrastructure



- Goal: Demonstrate two advanced reactors by 2025
- 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
- Capabilities:
  - NRIC DOME (Demonstration of Microreactor Experiments)
    - Advanced Microreactors up to 20 MWth
    - High-Assay Low-Enriched Uranium (HALEU) fuels < 20%
  - NRIC LOTUS (Laboratory for Operations and Testing in the US)
    - Up to 500 kWth experimental reactors
    - Safeguards category one fuels
  - Experimental Infrastructure
    - Molten Salt Thermophysical Examination Capability
    - Helium Component Test Facility



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

*For more information on NRIC and to download resources, see <https://nric.inl.gov/>.*



# Advanced Reactor Integrated Energy System (AR-IES) Demonstration Platform

**Advanced Reactor Company X:** I want to connect to a thermal load, and/or a thermal energy storage system. How will it perform? What are my options? How would the overall integration look like? How will energy dispatch be optimally controlled?

## Overall objective:

In collaboration with NRIC, the IES program will develop, design, and construct an advanced reactor integrated energy system (AR-IES) demonstration platform.

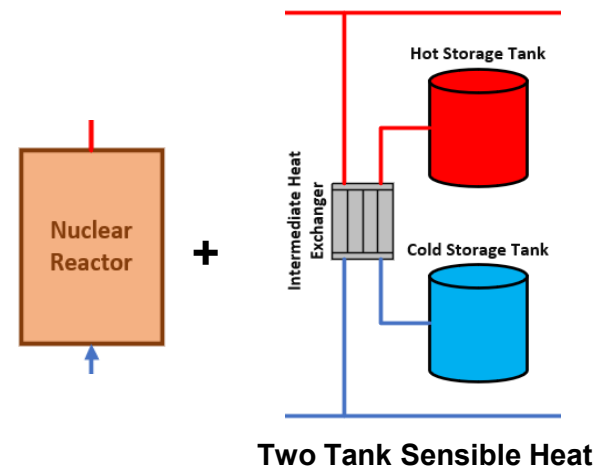
## Selected storage technology:

Liquid-based sensible heat Storage based on two-tank molten salt system.

Note: This selection should not be interpreted as the primary storage option for all AR-IES.

## Goal:

Demonstrate how advanced reactors can be coupled to thermal energy users, and how thermal energy storage can enable coupled operation of various thermal loads/users.



## Controllable load

bank of variable speed  
chillers  
(testing/demonstration)

or

Power peaking / Turbine

or

Industrial heat input  
or Secondary  
Process (Steel,  
Ammonia, H<sub>2</sub>, etc..)

or

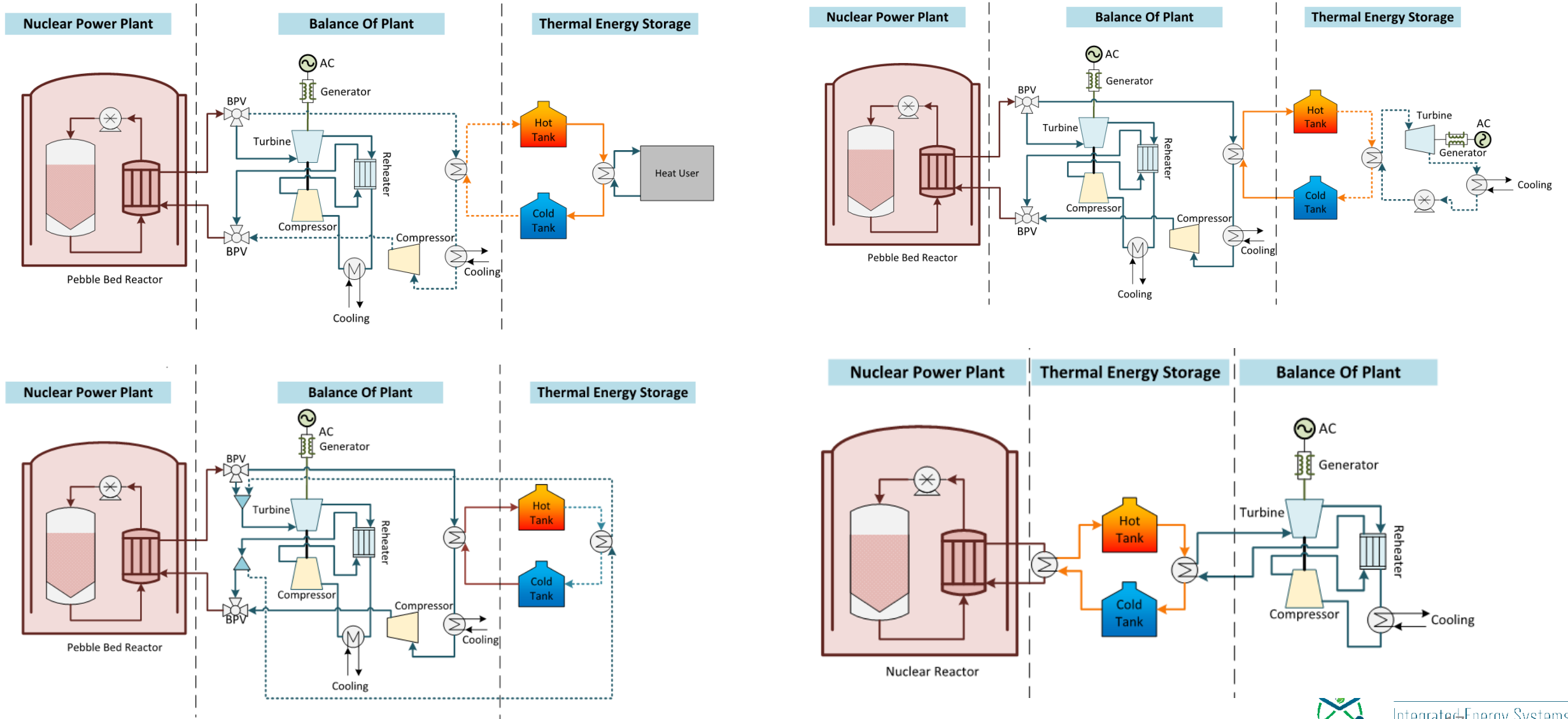


IES

Integrated Energy Systems



# Coupling options



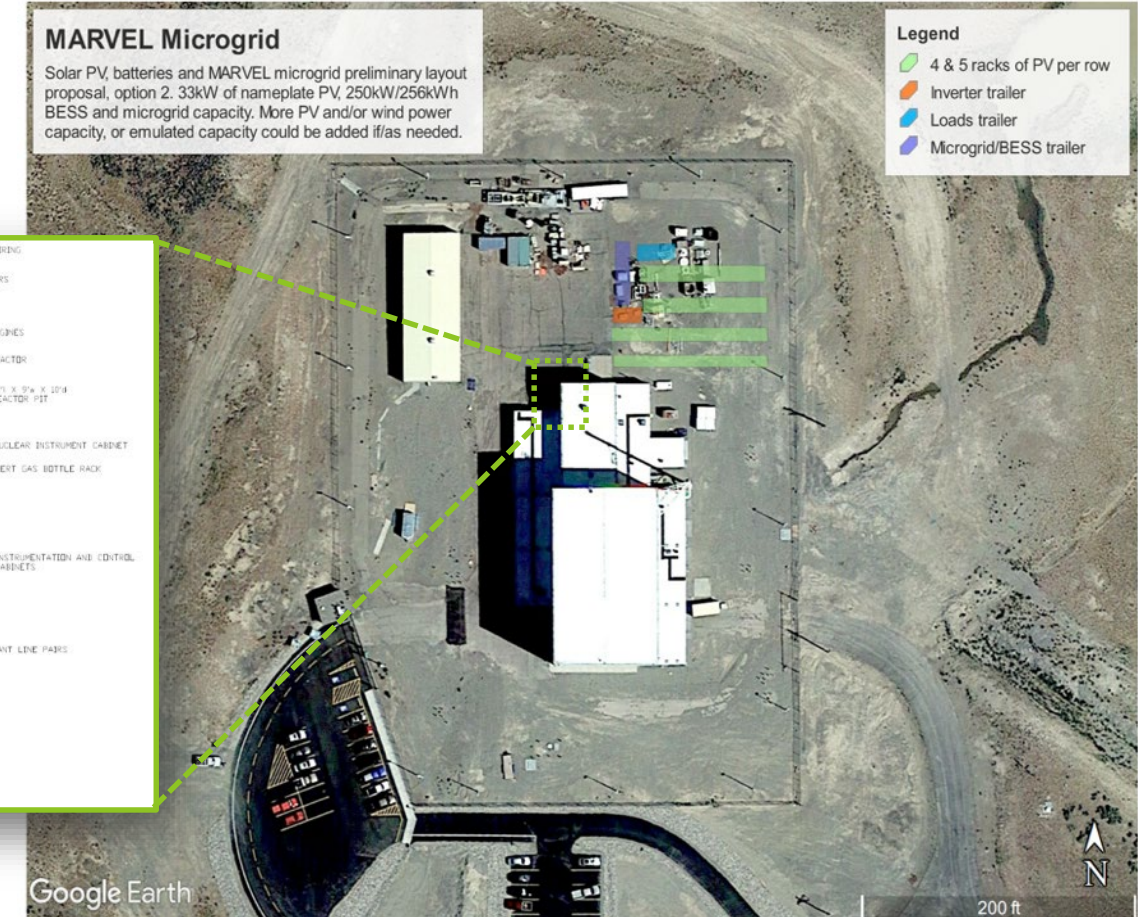
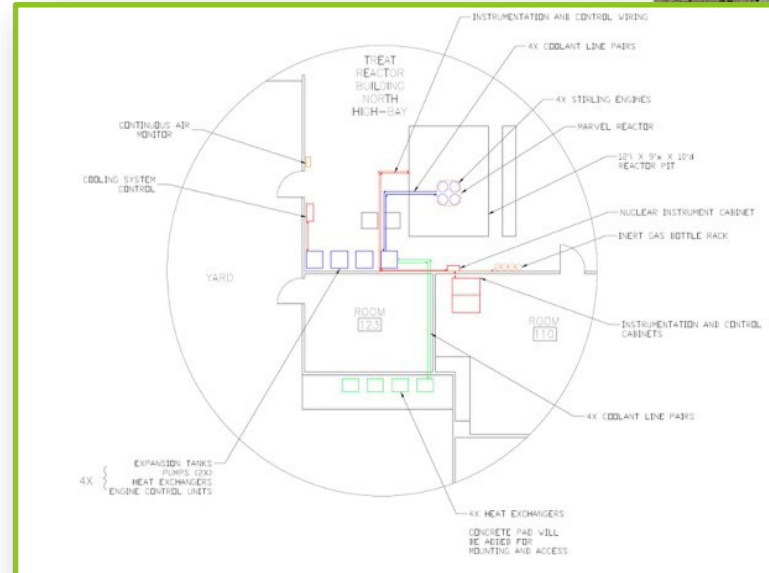
# Integration of the MARVEL microreactor with a microgrid



## Microreactor Applications Research Validation and Evaluation (MARVEL) Objective:

Operational reactor that produces combined heat and power (CHP) to a functional microgrid

Will demonstrate nuclear microgrid operations and provide opportunity to demonstrate operation with coupled energy users, such as hydrogen production and desalination.

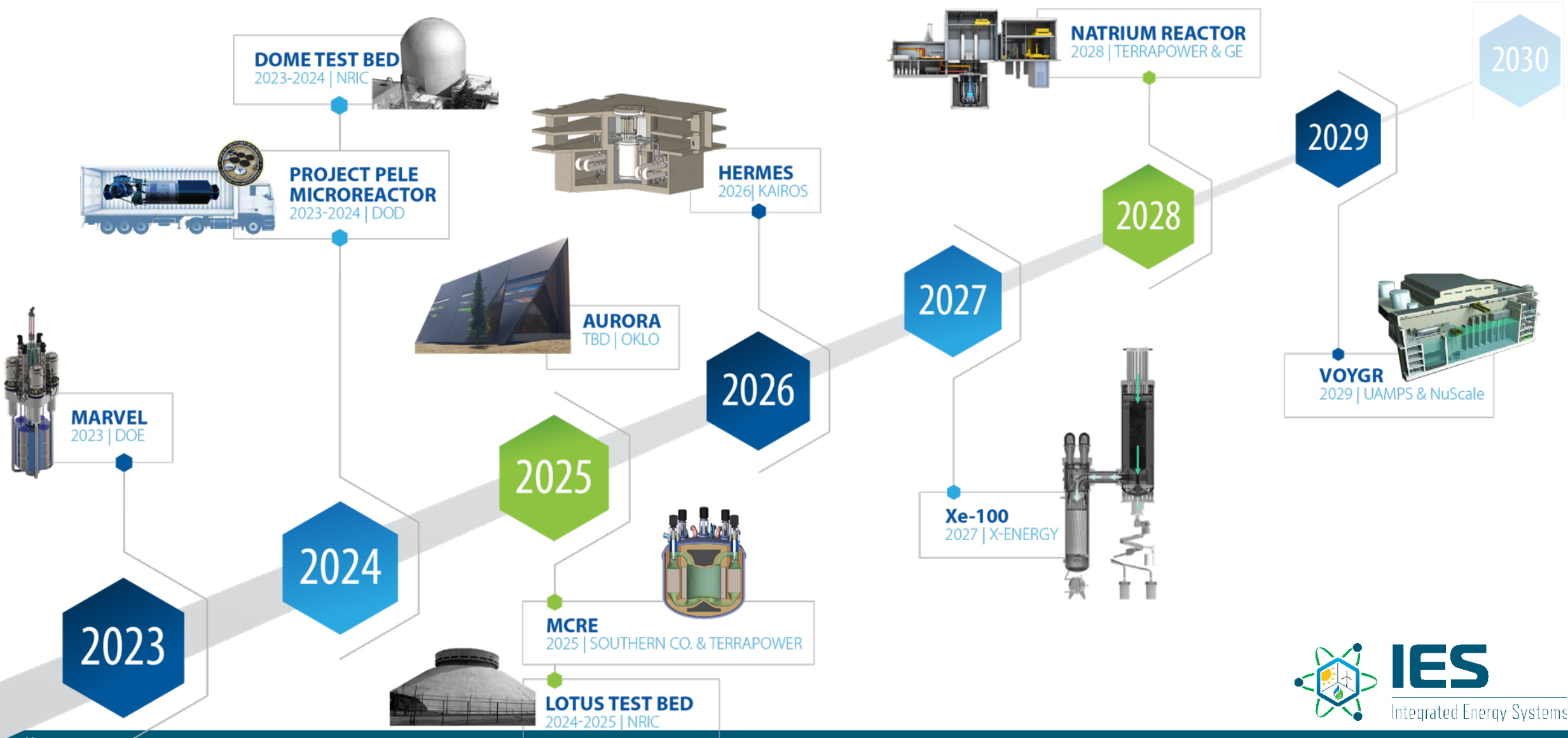


MARVEL Construction: Dec 2022  
MARVEL Criticality: Dec 2023





# Accelerating advanced reactor demonstration & deployment



# Summary of nuclear-integrated energy systems progress

The DOE-NE IES program conducts research, development, and deployment activities **to expand the role of nuclear energy beyond supporting the electricity grid**. Expanded roles include supplying energy to various industrial, transportation and energy storage applications. Focusing IES development on **enhanced utilization of low- or non-emitting energy generation** options will help the U.S. to achieve the bold goal to achieve a **100% clean energy economy and net-zero emissions**.

## Integrated energy systems leverage the contributions from nuclear fission beyond electricity

Light water reactors, high temperature advanced reactors, small modular reactors, microreactors, etc.

Variable renewables, municipal waste, fossil with carbon capture, etc.

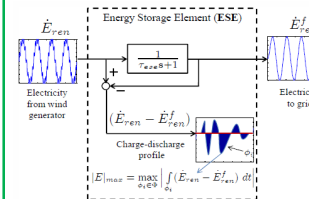


## IES FY22 major program achievements



### FORCE Tool Development

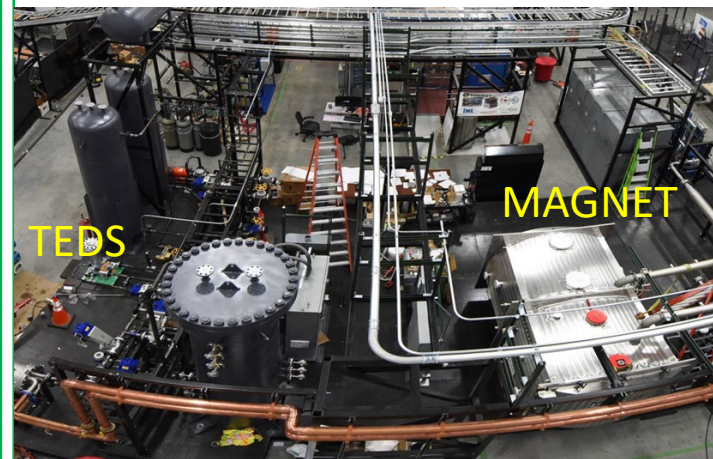
**Expanded capabilities** of our Framework for Optimization of Resources and Economics (FORCE) simulation ecosystem to **expand the capability for evaluating additional IES configurations**.



### Use Cases and Industry Collaborations

With inputs from industry, **performed initial techno-economic assessment** of nuclear energy use to support **synfuel production, carbon conversion and thermal energy storage**.

### Laboratory-scale Experimental Demonstrations



- Dynamic Energy Transport and Integration Laboratory (DETAIL) integrates independent systems funded from multiple programs.
- **Thermal integration** of Thermal Energy Distribution System (TEDS) and **MAGNET** has been started.
- Explored **Real-time Optimization (RTO)**, **Digital Twin (DT)** and **experiment scaling** capabilities for FORCE tool suite to support DETAIL experiments.





# INL

## Idaho National Laboratory



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