Nuclear-Renewable Hybrid Energy Systems Program

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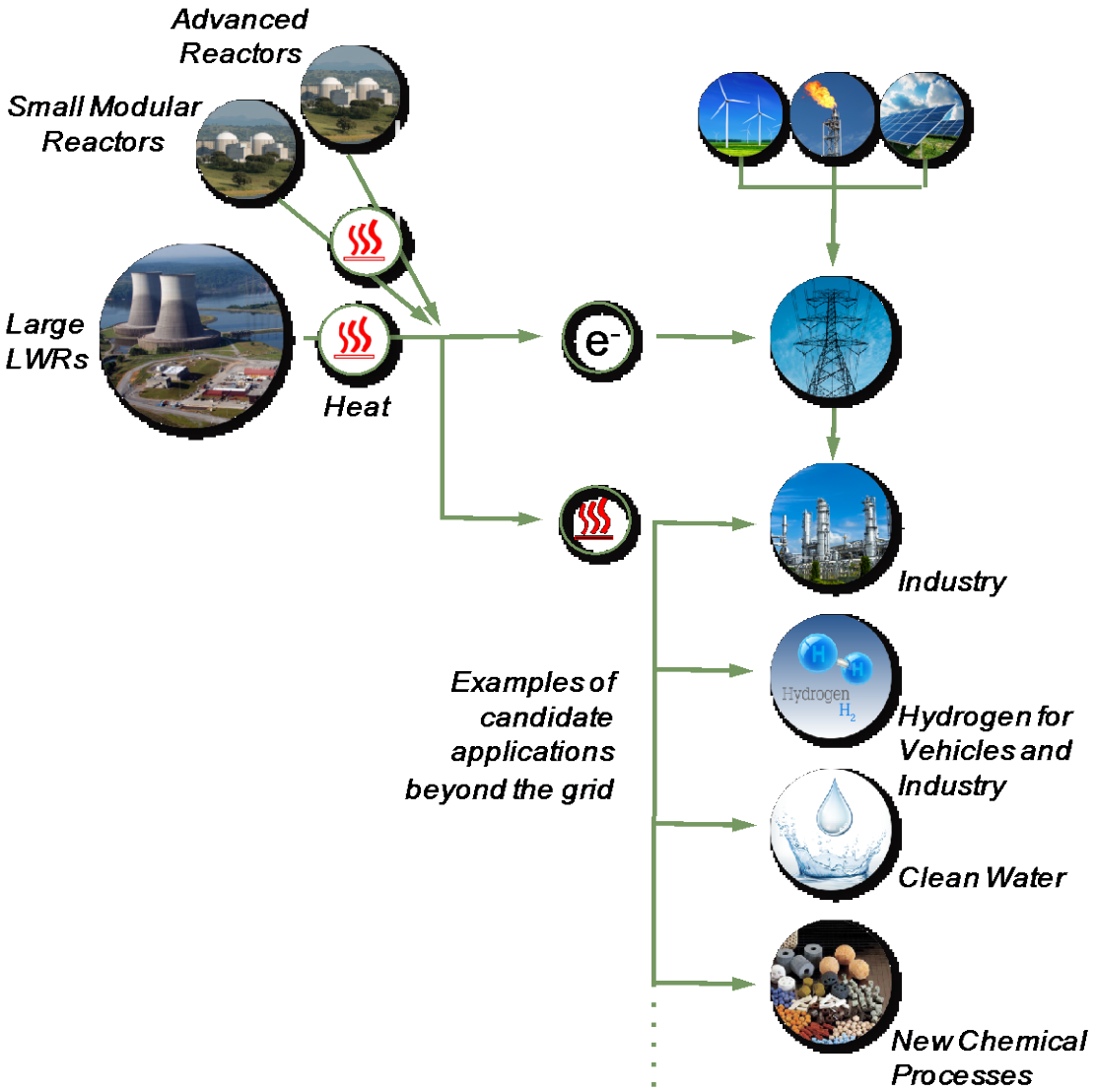
For reference, see: N-R HES 2016 Technology Development Program Plan, https://www.osti.gov/scitech/servlets/purl/1333006

U.S. DEPARTMENT OF ENERGY

Energy System Flexibility

- **Goal:** A sustainable and balanced energy portfolio for reliable, robust electricity at stable, affordable prices
- **Proposed solution:** An energy system dynamically integrated with other generation sources and industrial applications
  - Extend use of nuclear fission beyond electricity generation
  - **Hybrid Energy Systems (HES)** will maximize flexibility and economic performance while ensuring grid reliability and robustness/ resilience



N-R HES Program Scope

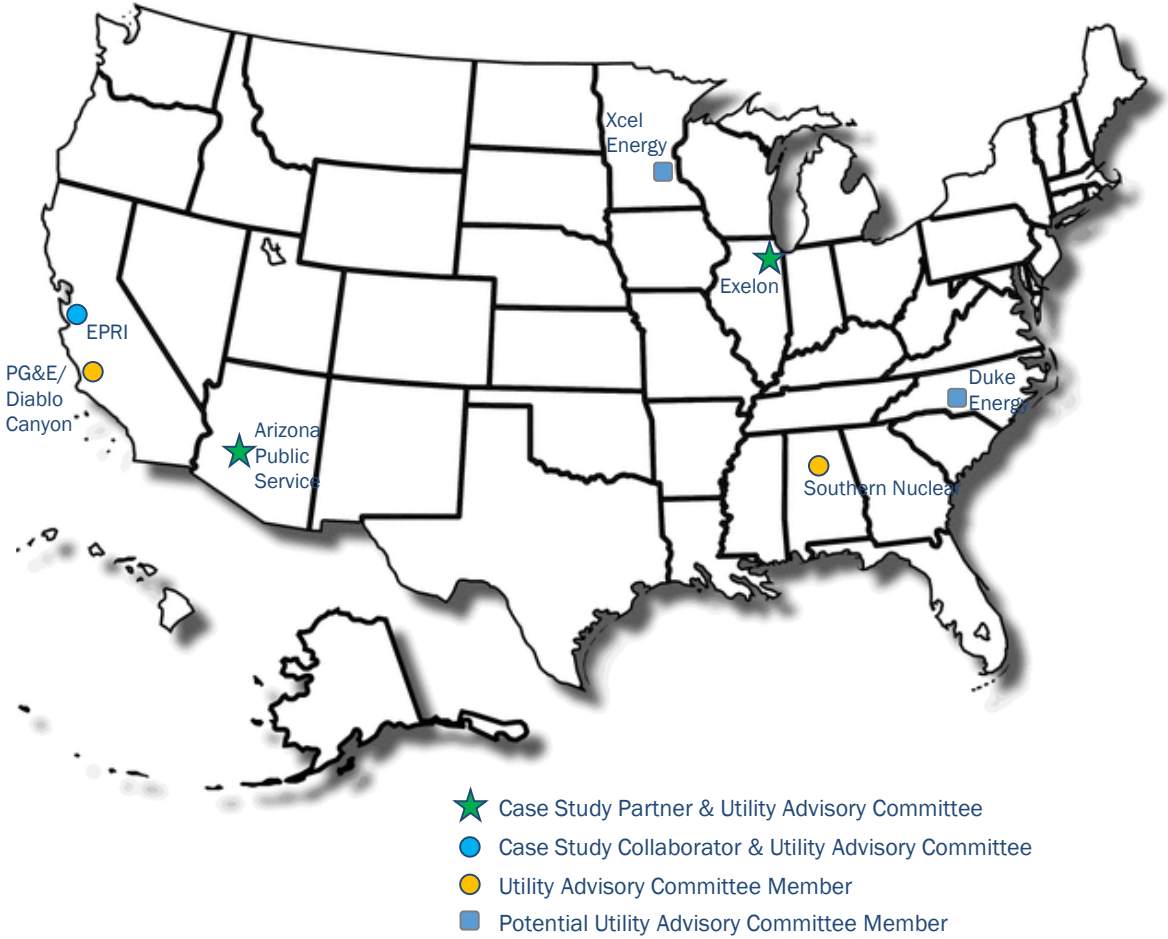
Focused R&D in HES design, optimization, and testing for promising hybrid system architectures, coupled with development of technology options, will enable more efficient, environmentally sustainable energy systems

- Modeling and Simulation: Tool Development & Associated Analysis
  - Assess technical and economic viability
  - Determine optimal system design and energy dispatch
  - FY-18 Focus: Pilot case studies for specific plants and regions with utility partners

- Demonstration/Experimental Systems (electrically heated)
  - Demonstrate hardware interfaces, control systems, dynamic operation, etc.
  - FY-18 Focus:
    - Design review for PWR-emulation loop
    - Design/build thermal energy distribution system (TEDS) to connect PWR loop & hydrogen electrolysis

Evaluating Technical and Economic Feasibility w/ Utility Partners

- **Case I: Nuclear-Renewable-Water Integration in Arizona**
  - *Electrical integration of existing nuclear generation and desalination processes in a region with significant solar generation*
  - *Collaboration with Arizona Public Service (APS), operating owner of Palo Verde Generating Station, with consultation from Electric Power Research Institute (EPRI).*
- **Case II: Nuclear-Industrial Process Variable Hybrid in the Midwest**
  - *Retrofit of an existing LWR to support an industrial application and electricity production in a region with significant wind generation*
  - *Focus on H2 generation and associated off-take industries (e.g., steel making or ammonia production)*
  - *Collaboration with multiple industrial partners, led by Exelon, with consultation from EPRI.*



Taking Simulation to the Next Step: Hardware-in-the-loop Demonstration

- Dynamic modeling, simulation and validation establishes a new paradigm for operating current baseload LWRs, future SMRs and other advanced reactors
  - Establish the value proposition for flexible operations via hybrid systems
  - Optimize systems design, control and operational dispatch
  - Demonstrate economic flexible energy dispatch with nuclear baseload (reduce commercial risk)

- Complementary nonnuclear demonstration facility, electrically heated PWR emulation
  - Demonstrate steam maneuvering at a rapid rate between power generator and process applications
  - Quantify/Measure/Observe impact (reliability, operations, and maintainability) on electrically simulated nuclear plant and systems integration components (heat exchangers, valves, pumps, pipes and fittings)
  - Demonstrate system sensors/measurements, data processing, and control logic (including human factors systems, e.g. Human Systems Simulation Laboratory)
  - Validate thermal hydraulic codes used for complex integrated system design and scale-up of commercial integrated systems

Electrically-Heated Integrated Systems Demonstration

- Dynamic Energy Transport and Integration Laboratory (DETAIL)
  - DETAIL will consist of multiple heat and electricity producers, thermal and electrical storage, and multiple heat and electricity customers coupled via a thermal and electrical network
  - The combined system will provide a demonstration of real-time integration with the electrical grid, renewable energy inputs, energy storage, and energy users
  - *Entire energy network can be simulated to understand how to optimize energy flows while maintaining stability and efficient operation of all assets in the system*
- Components under development:
  - Water/steam thermal hydraulic test loop (PWR emulation)
  - Thermal energy distribution system (TEDS)
  - High Temperature Electrolysis Demonstration Facility (hydrogen generation)

FY19 CINR Call for N-R HES

NE 2.1: Studies of Component/System Degradation

- Characterization of dynamic energy system behavior via modeling & hardware-in-the-loop (HIL) testing
- Objective:
  - Capture real-time, dynamic response behavior
  - Determine impact of thermal cycling on components and subsystems as it relates to component and system robustness, resiliency, response rates, etc.

NE 2.2: Cyber-Informed System Design for N-R HES

Grid Operations by Regional Transmission Organizations / Independent System Operators (RTO/ISO)

Enhanced Data Communications Protocol

w/ consideration for cybersecurity impacts

Front-end-controllers and control theory for optimal energy dispatch in tightly coupled integrated energy systems operations.

Cyber-informed engineering should be incorporated into the respective levels of data transmission and management, human monitoring and control performance, control signal processing, and device level control actions. Studies should include control hardware in-the-loop (CHIP).

NE 2.3: Systems Controls for N-R HES

Develop predictive load and supply forecasting (e.g. using predictive “agent-based” models)

- System control technology/approach development
- Objective:
  - Optimize energy dispatch in real time for integrated energy systems

Expected Outcomes with NEUP

- Engagement of university researchers having diverse expertise will bring new solutions to HES design, optimization, and demonstration
- NEUP modeling and simulation scope is intended to develop tools and techniques that can solve longer-term questions associated with hybrid energy systems design, design optimization, and operational optimization
- Results and outputs will enhance ongoing HES modeling and simulation work
  - Support longer-term needs, but could be integrated with the broader laboratory toolset as soon as they are available
  - Will be used as a component of follow-on system design and testing / to refine Hardware-In-the-Loop system design
- Requirements:
  - Analysis/evaluation approaches must be compatible with the laboratory developed toolset (RAVEN, Modelica) to allow for future integration
  - Deliverables should include modeling and simulation components that are ready for integration into the overall HES model architecture

Additional Information: Modeling & Simulation Approach

INL M&S Capabilities for N-R HES

Cristian Rabiti
N-R HES M&S Lead

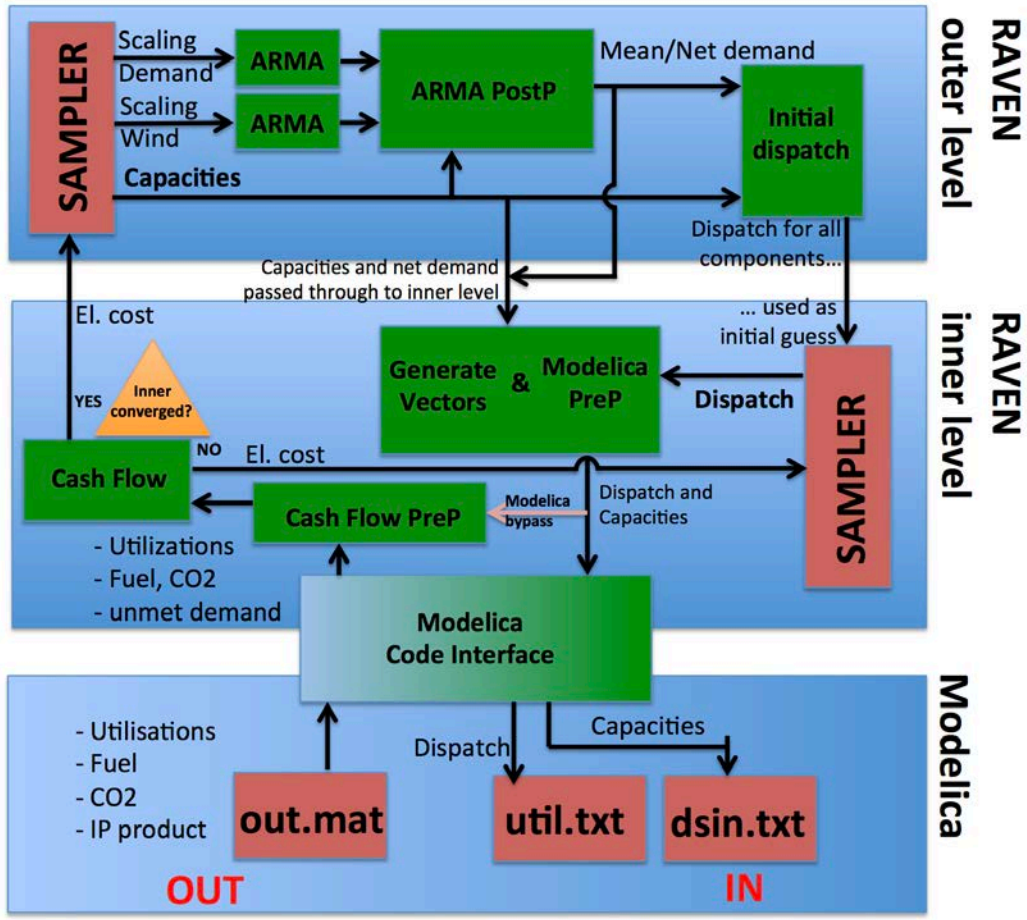
#INLCINRWorkshop

Tools

- RAVEN
  - Stochastic scenario generation
  - Stochastic Optimization
  - Financial Analysis
  - Reduced order modeling
  - (aging effects)

- Modelica
  - N-R HES system
  - (Control system)

Workflow Example

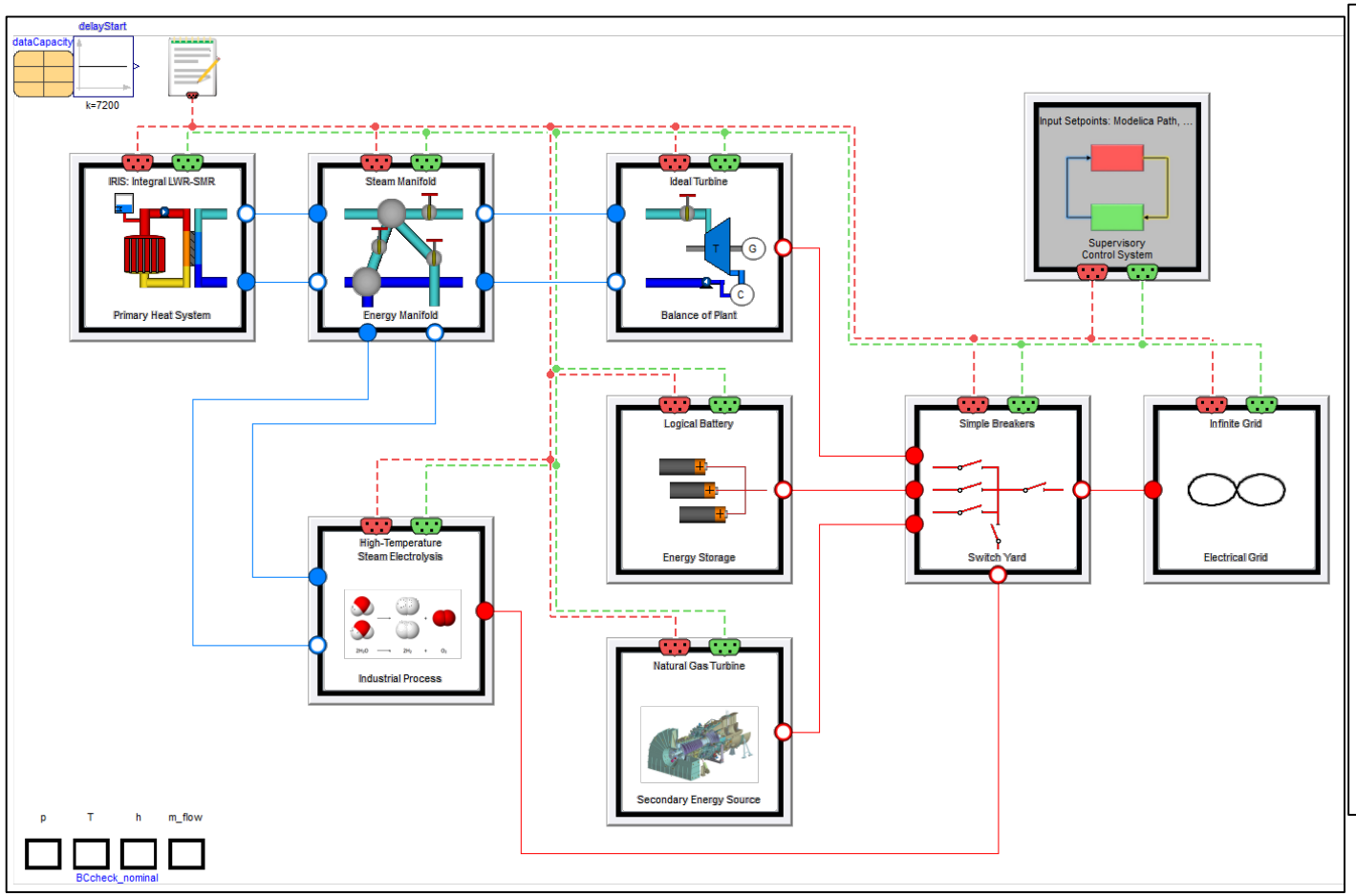


- Input
  - CAPEX
  - Scaling factors
  - Fixed O&M
  - Variable O&M
  - Tax rate, inflation rates, etc.
- Output
  - Optimal dispatch
  - Optimal system composition

MODELICA

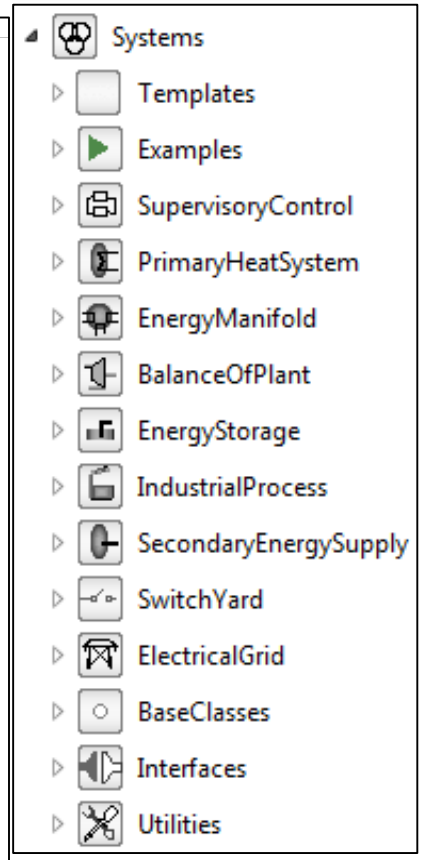
Legend

- Fluid
- Electricity
- Sensor Output
- Actuator Input

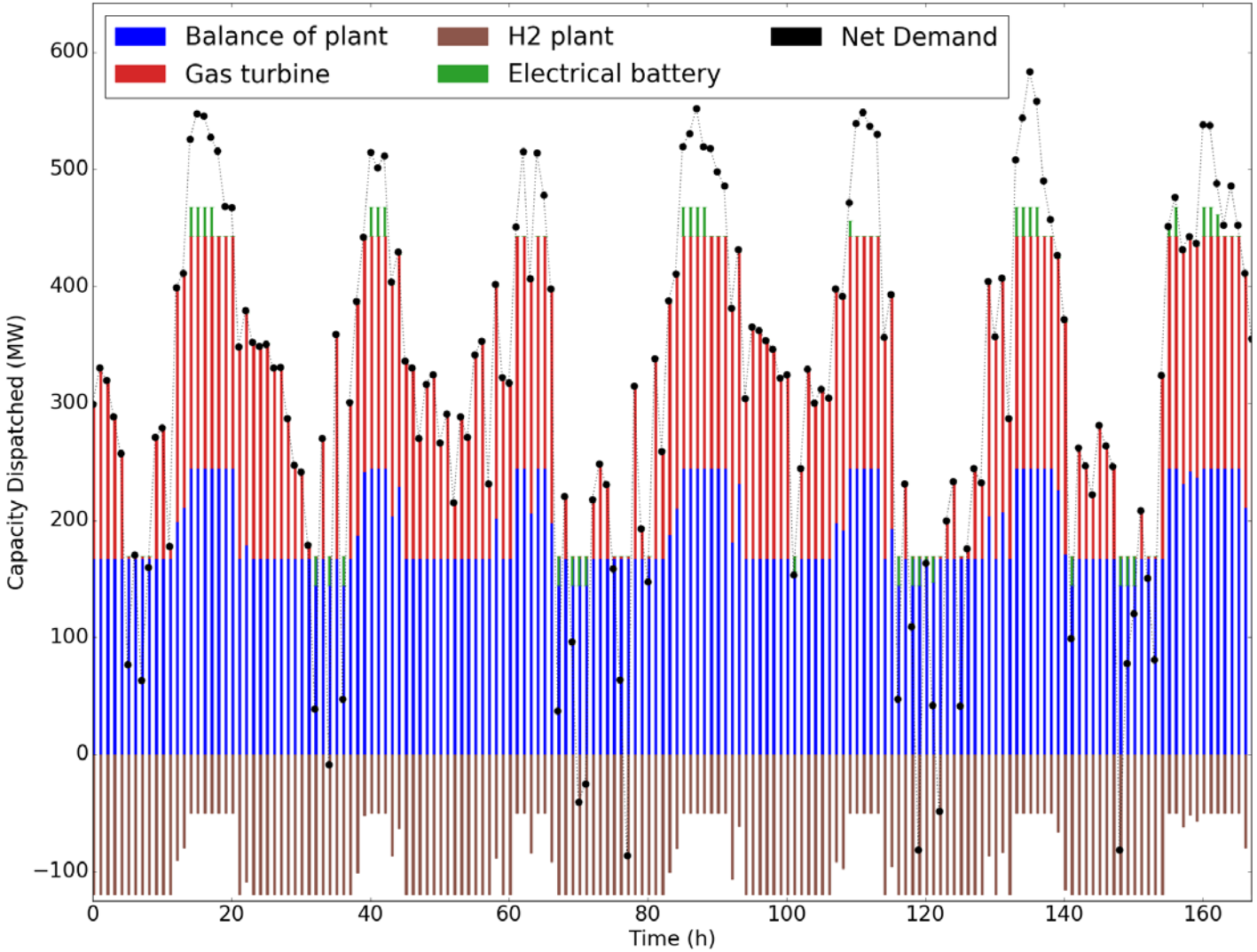


Overall System Architecture

NHES Modelica Library



RESULTS



Reactor	:	300MWe
Mean demand	:	400 MW
IP capacity	:	120 MW
Gas turbine	:	200 MW
Battery	:	100 MWh
H_2 price	:	1.75 $/kg
Wind penetration	:	100% (installed capacity)

QUESTIONS?