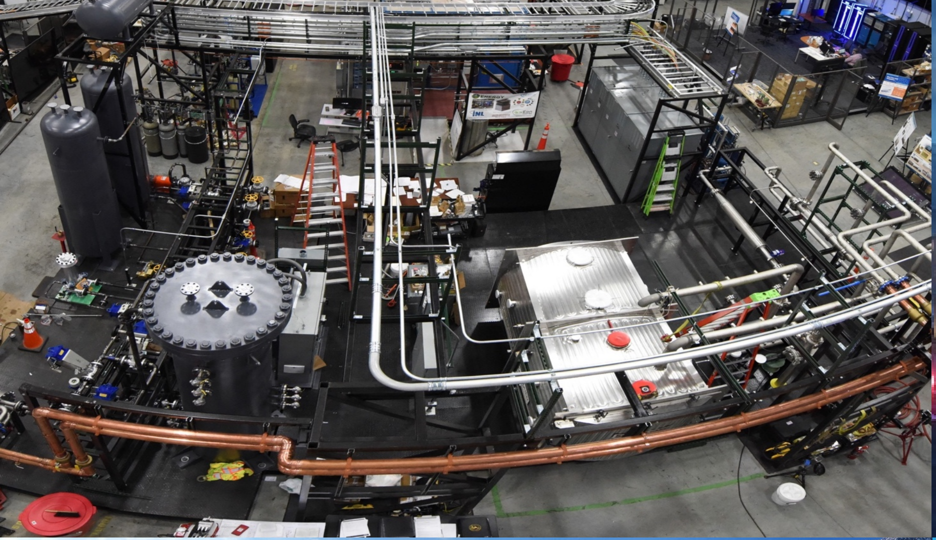


BYU, UT

Optimization of Integrated Energy Systems

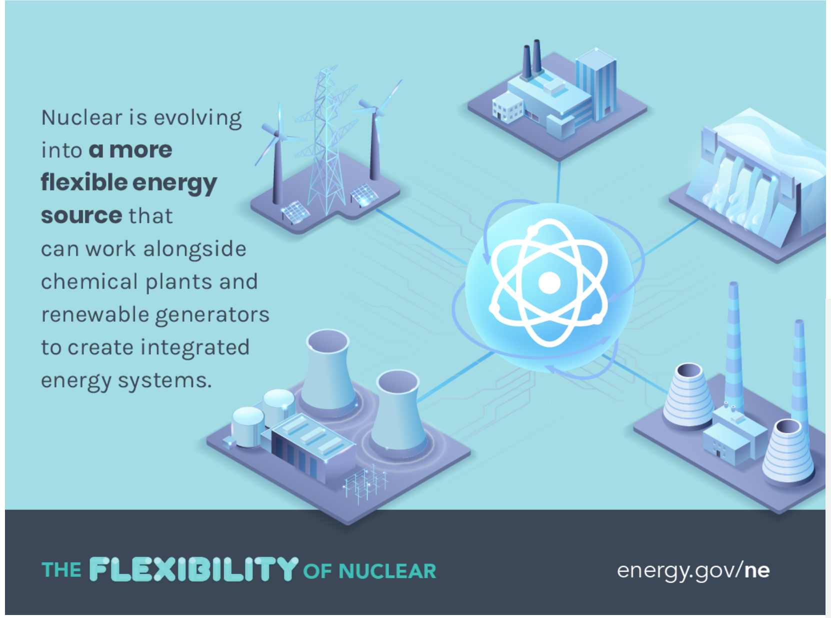
10 November 2022

Daniel Garrett, PhD
Integrated Energy Systems
Nuclear Science & Technology Directorate
daniel.garrett@inl.gov

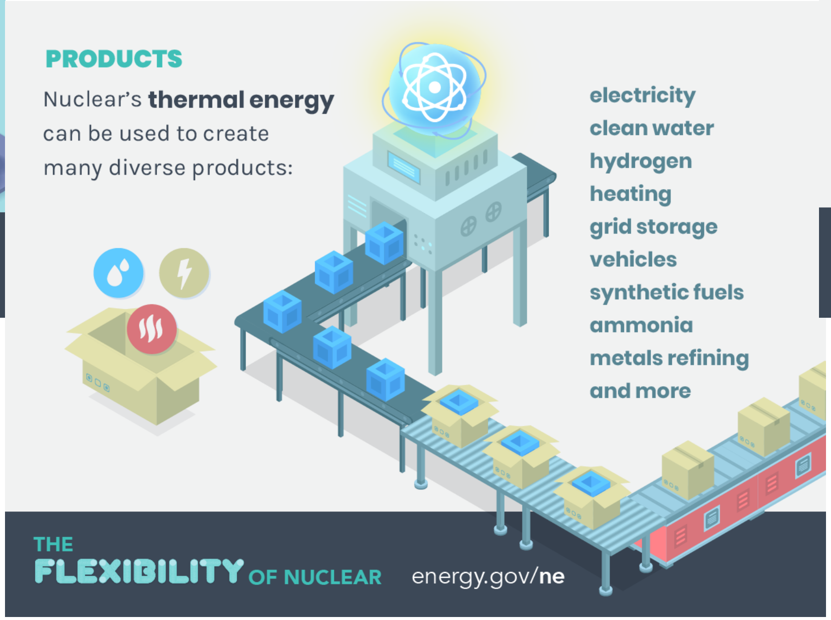
INL Idaho National Laboratory

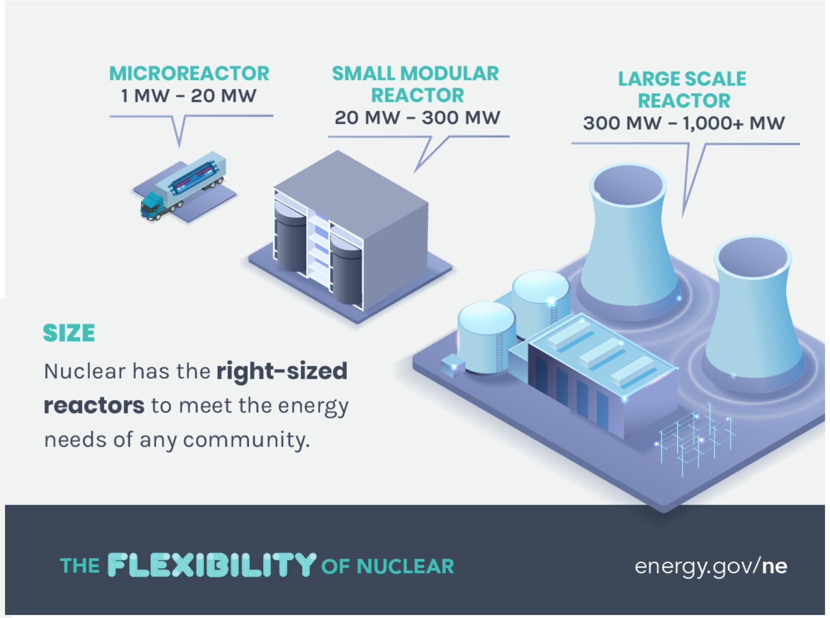
INL/MIS-22-70068

New operational paradigms—nuclear energy flexibility



Nuclear flexibility can be key to enabling deployment of other clean energy generators.





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

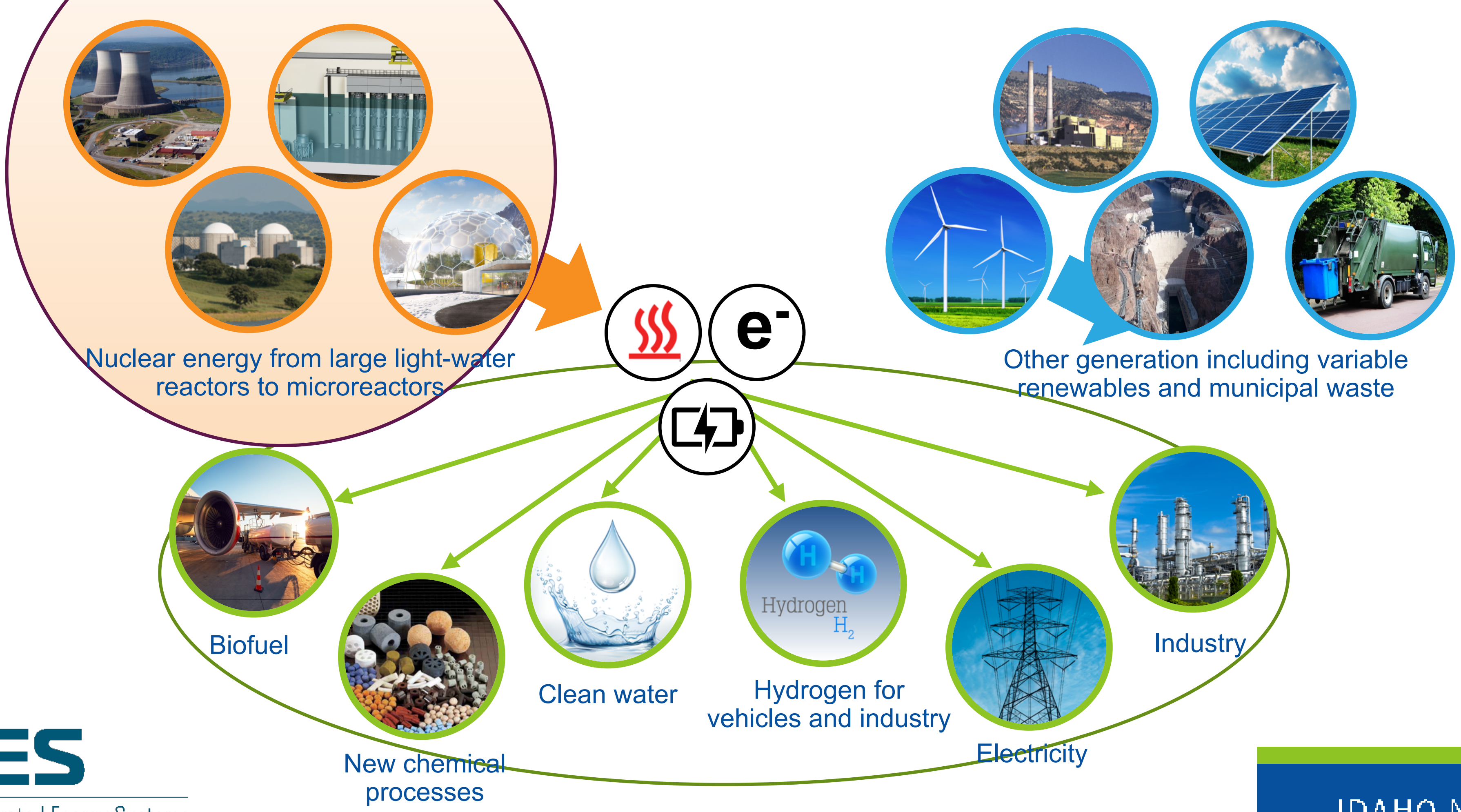
U.S. DEPARTMENT OF ENERGY | *Office of* NUCLEAR ENERGY

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

Cross-sectoral energy solutions for a resilient net-zero future

Future Energy System: Transforming the Paradigm

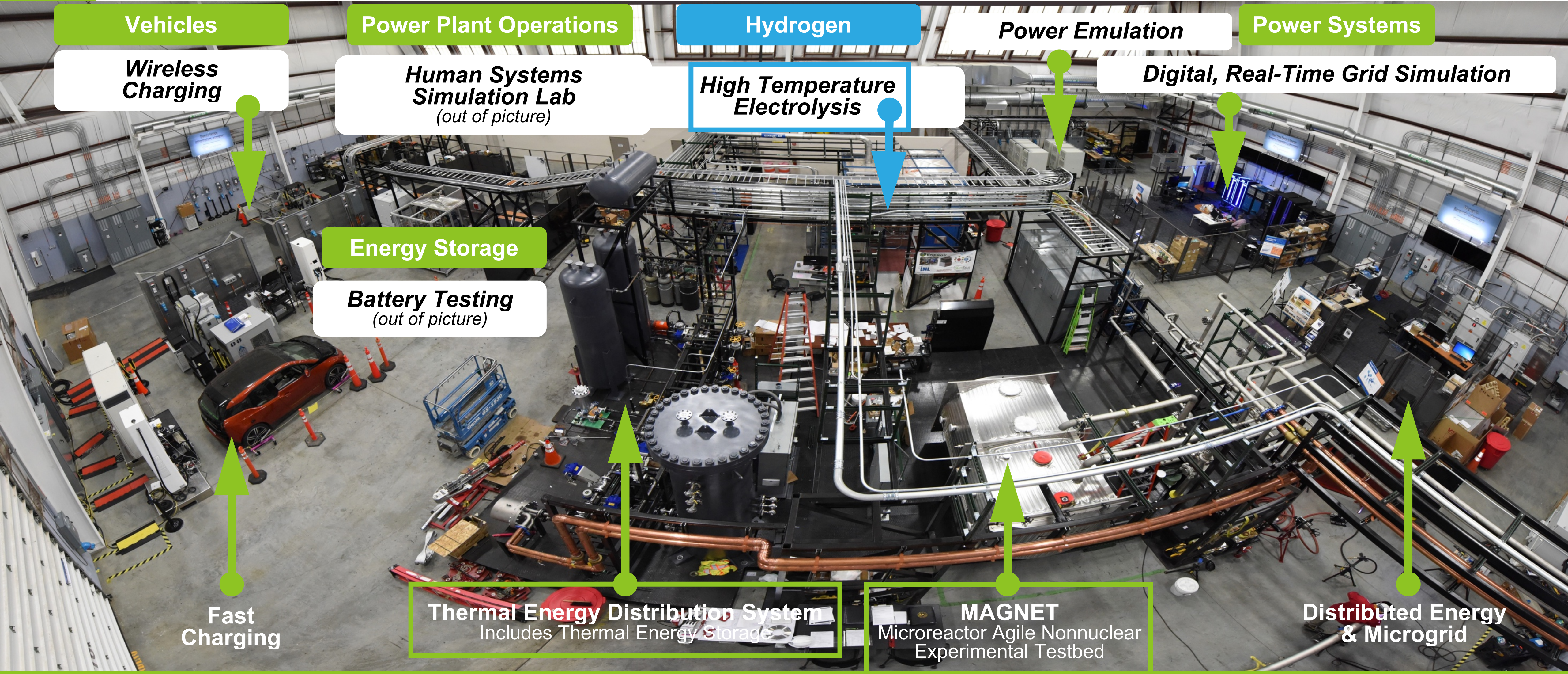
Integrated systems leverage contributions from all low emission energy generation options to support decarbonization of electricity, industry, and transportation



Goals

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

DETAIL – Dynamic Energy Transport and Integration Laboratory



IES Optimization at INL

- HERON
  - https://github.com/idaholab/HERON
  - RAVEN plugin
    - https://github.com/idaholab/RAVEN
  - Optimize capacity/component sizing
    - Dispatch optimization
- ORCA
  - Optimization of Real-time Capacity Allocation
  - Under development
  - Real-time economic optimization

HERON

- Bringing FORCE together for Technoeconomic Analyses

RAVEN
- Stochastic Analysis
- Synthetic Histories

TEAL
- Economic Metrics
- Cash Flows

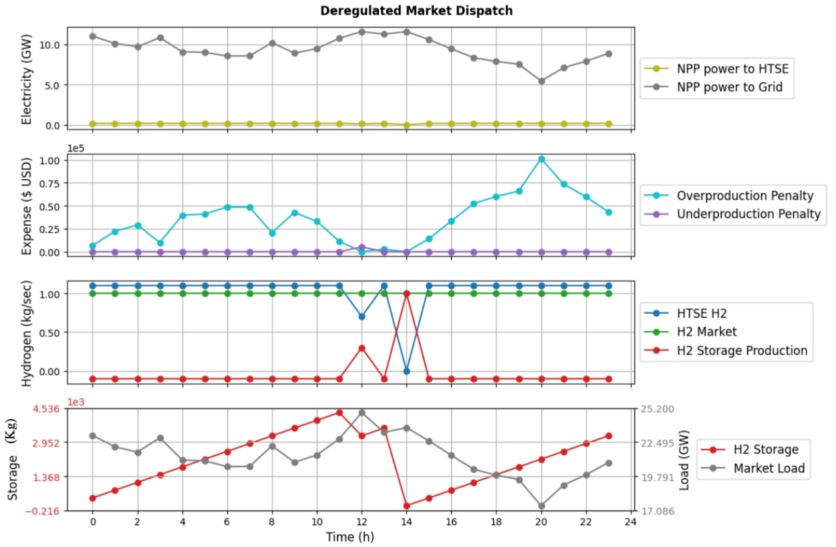
FARM
- Process Analysis
- AI Training, Control

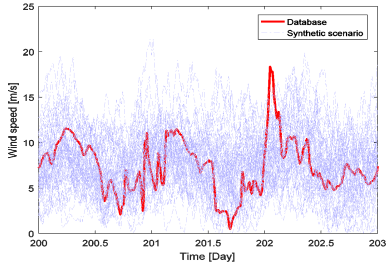
HYBRID
- Process Models
- API Framework

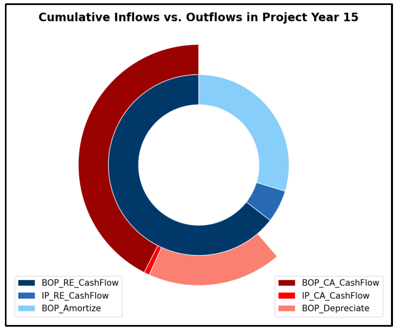
HERON
- Stochastic Technoeconomic Analysis
- Component Sizing Optimization
- Dispatch Optimization

Macro
Technoeconomic Analysis

- Holistic Energy Resource Optimization Network
- Solve:
  - Optimal size for IES systems (generators, storage, industrial processes)
- Such that:
  - Respect technical limitations
  - Evaluate continuous-time responses
  - Optimize component dispatch
  - Maximize expected profitability
    - Requires uncertainty quantification
  - Weight expected profit by risk
    - Value at Risk, risk assessment



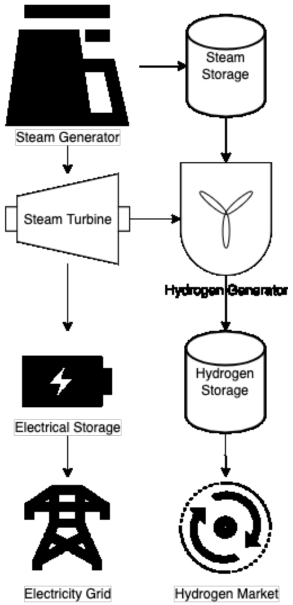




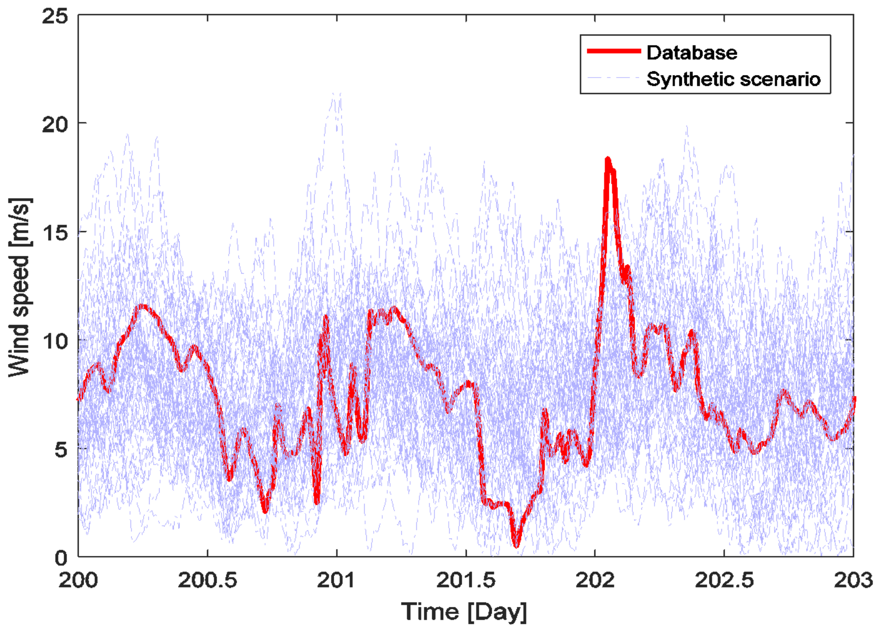
Risk-Informed Optimization

- Stochasticity
  - Consider more than one projected future
  - Statistically consider hundreds or thousands
- Optimize system size for expected benefit
  - Expected NPV
  - Value at Risk

Optimize Size



Many Potential 30-year Outlooks



Synthetic Histories

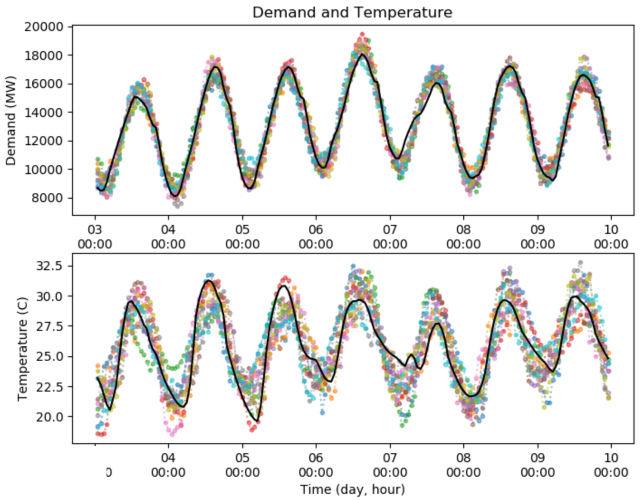
IES Integrated Energy Systems

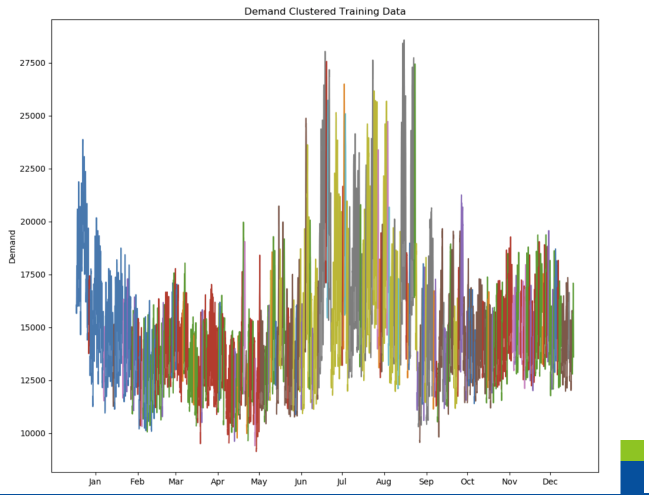
COLORADO SCHOOL OF MINES

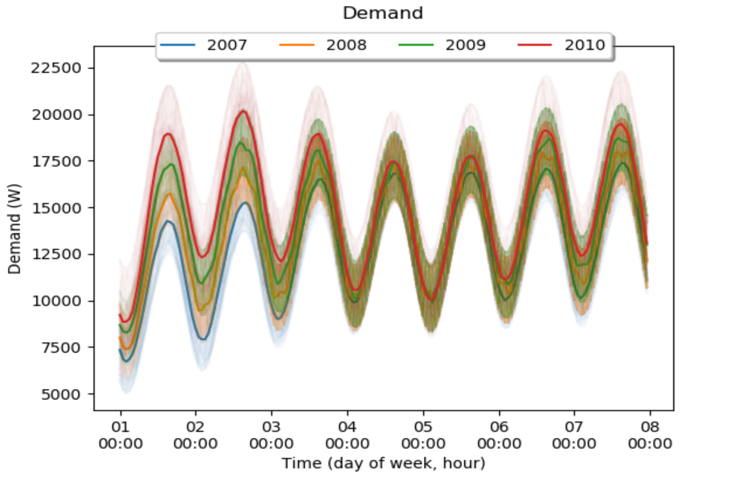
THE GEORGE WASHINGTON UNIVERSITY

WASHINGTON, DC

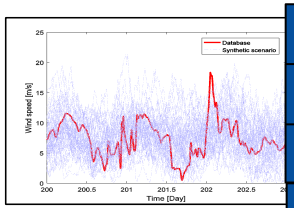
- Synthetic Histories allow exploring many possible futures
- Train on historical or projected data
  - Capture short, long-term deterministic effects
  - Characterize residual uncertainty
- Sample new histories
  - Each independent, identically-distributed
  - Same characteristics as training, new behavior
  - Clustering, correlation, multiyear evolution







HERON Two-Loop Optimization



solar

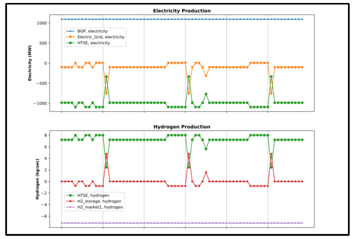
demand

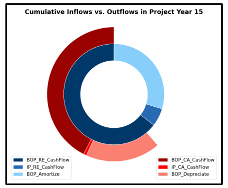
wind

markets

Repeat for
Many Histories

Statistical
Economic
Metrics





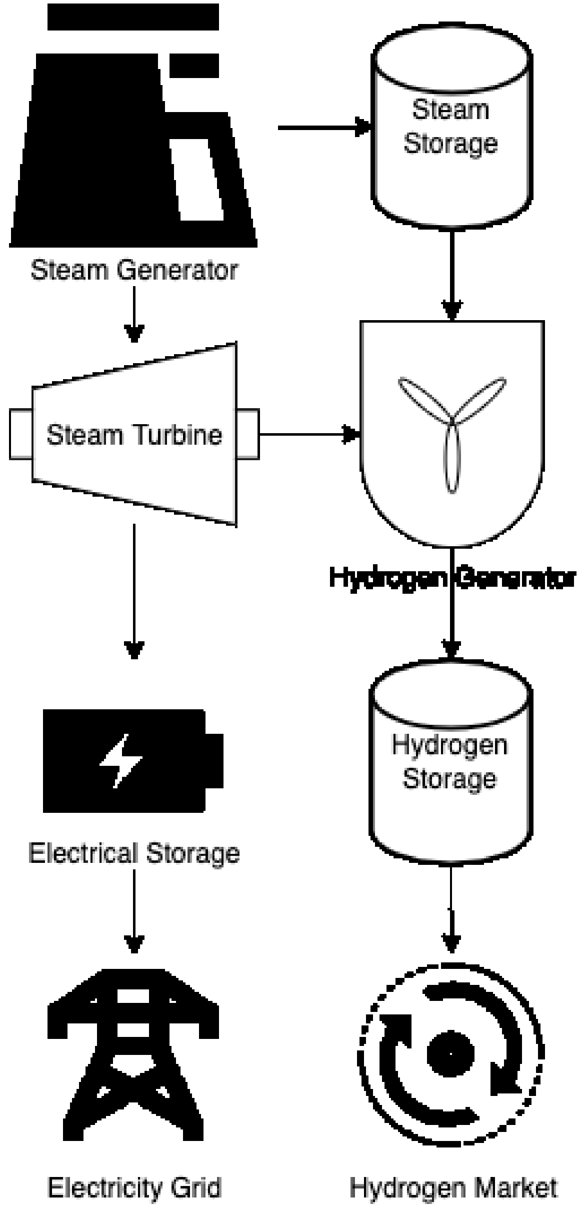
New
System

Component
Sizing

“Outer” Optimization Components and Markets

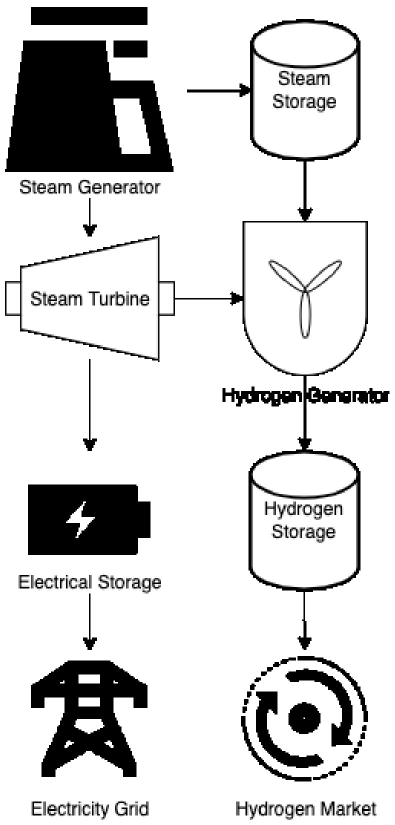
- Nuclear Power Plant
  - Core (Steam Generator)
  - Turbine (Steam to Electricity)
- Hydrogen Generator
- Hydrogen Storage
- Battery Storage
- Thermal Energy Storage
- Electricity Market
  - Real Time, Day Ahead
- Hydrogen Market
- See https://github.com/idaholab/FORCE for examples

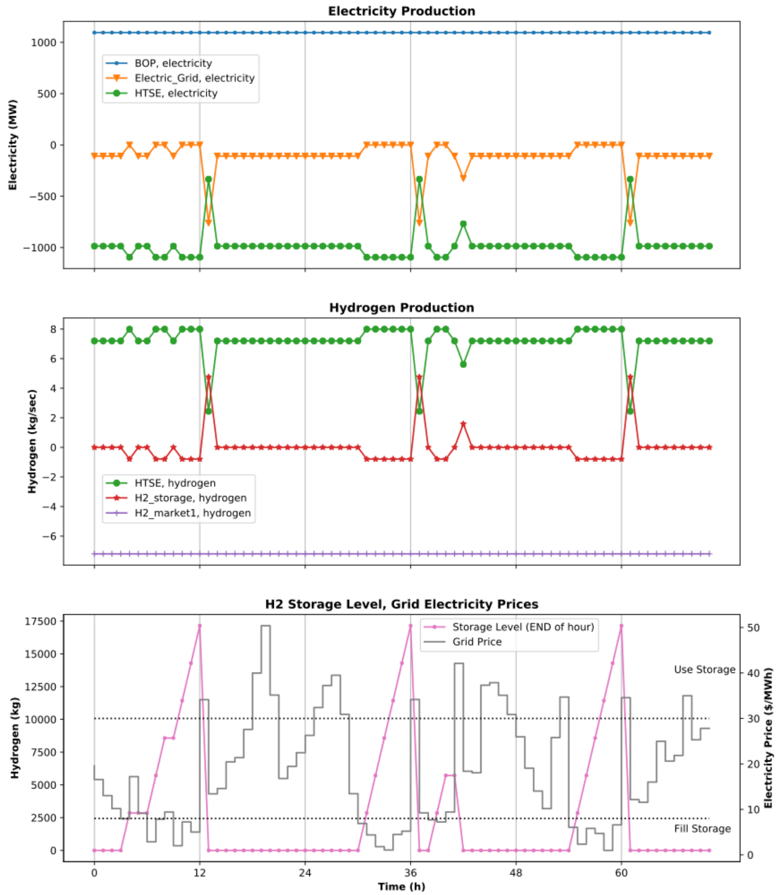
Optimize
- **Size**
- **Dispatch**



“Inner” Optimization – Dispatch

Optimize Size





Optimize Dispatch, Commitment
30-year projection

Continuous Time

Flexible Economic Drivers

Multiple Commodities

Arbitrary Policies

Signal Response

Storage Flex

ORCA – IES Real-Time Economic Optimization

- IES optimization occurs at multiple time scales
  - “Real-Time” = days, hours, minutes, etc.
- Operation optimization of IES
  - Integration of IES with digital twin
    - RTO sits between M&S and operations
  - How do we operate optimally?
    - Maximize profits
    - Production scheduling
    - Arbitrage
- Why RTO?
  - $$$

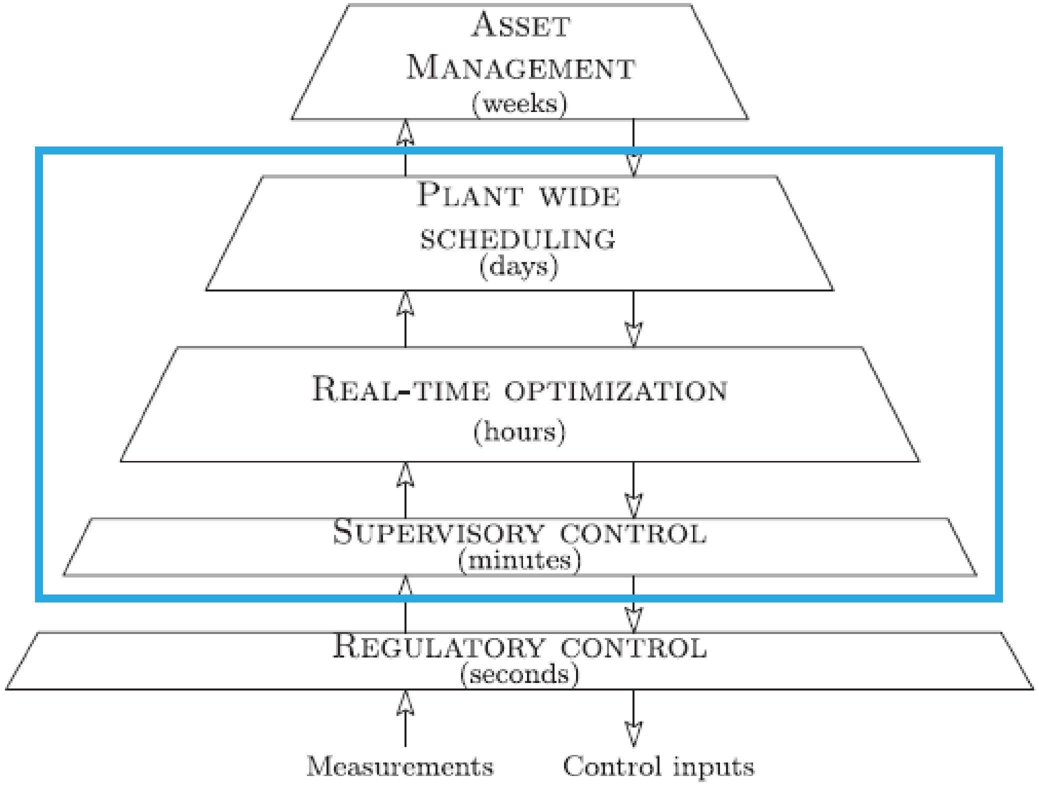
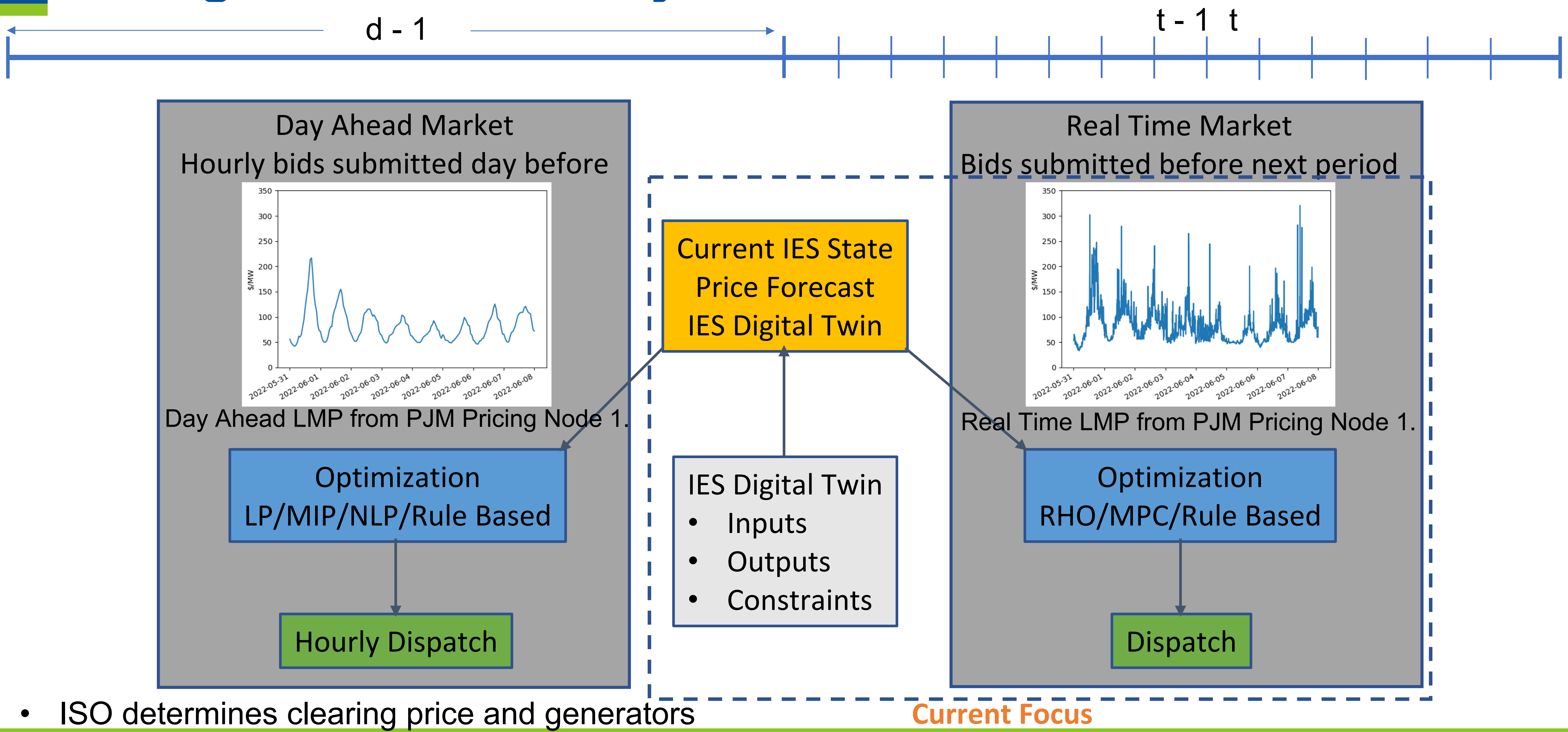


Fig. 1. Typical control hierarchy in process control.

Krishnamoorthy et al. 2018

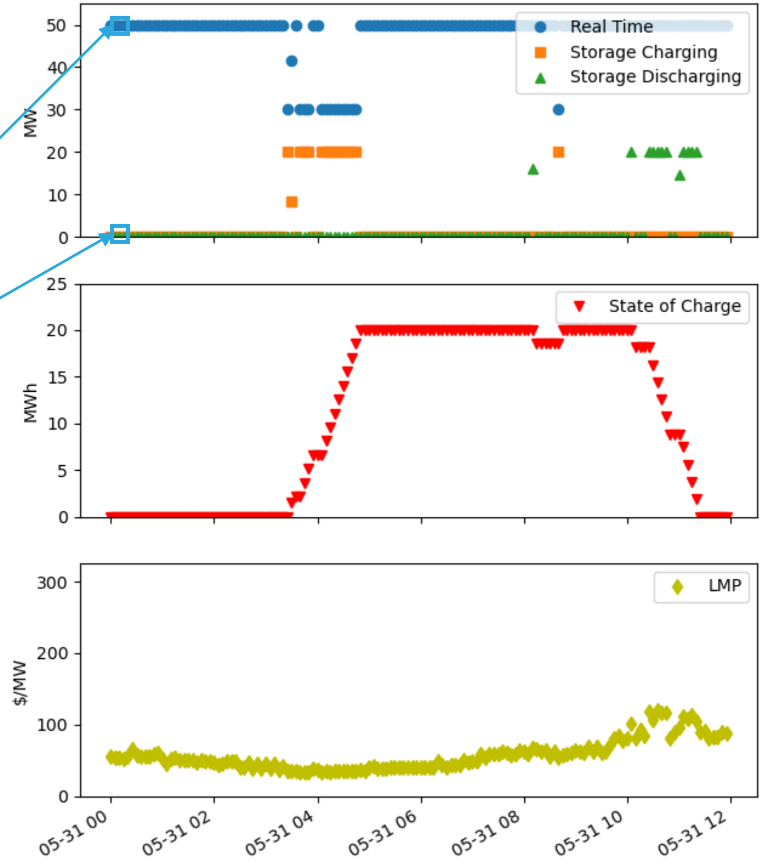
Deregulated Electricity Market RTO



- ISO determines clearing price and generators

ORCA – Dispatch Optimization

- Economic Model Predictive Control/Receding Horizon Optimization
  - Forecast LMP forward in time (i.e., 12 hours)
  - Use model to predict IES performance
  - Optimize dispatch for maximum revenue
  - Use dispatch for next time step only
    - Implement as setpoints/control actions
  - , repeat



IES Mathematical Model Example

- NPP + Electrical Storage

- NPP supplies constant capacity
- Electrical storage for arbitrage

- : state of charge at time (MWh)
- : round trip efficiency (0,1)
- : charging at time (MW)
- : discharging at time (MW)
- : time step (minutes)
- : LMP at time ($/MW)
- : NPP capacity (MW)

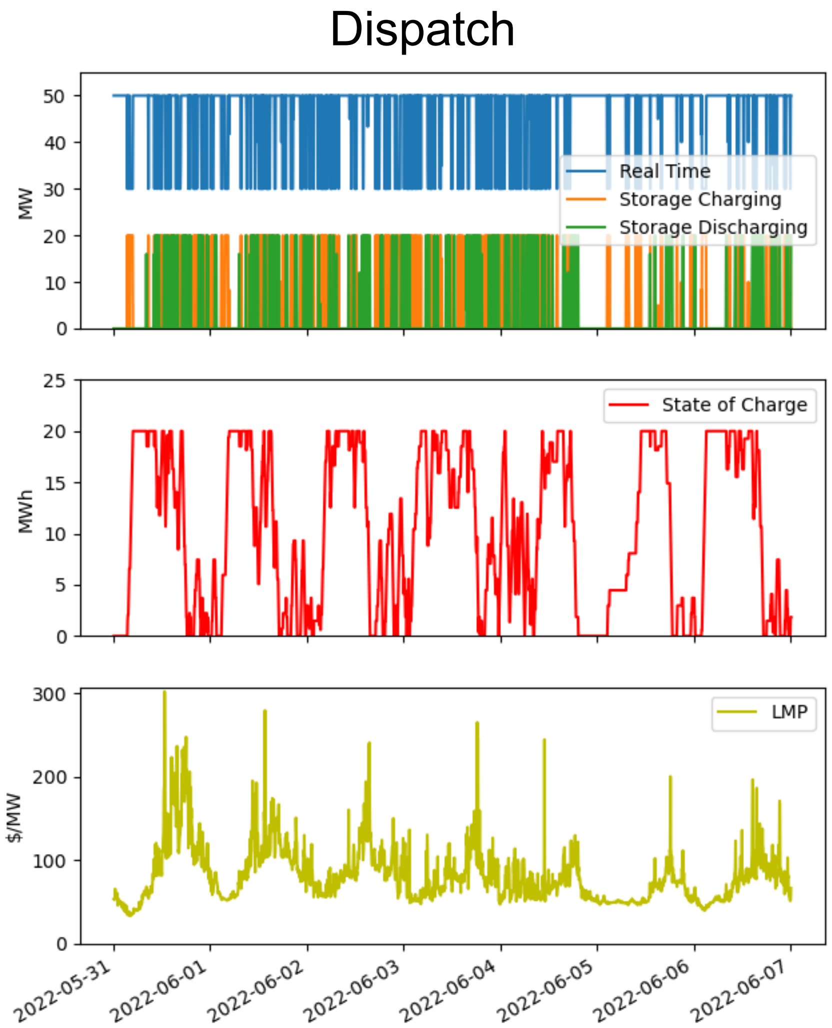
- Objective function: maximize revenue

ORCA Example

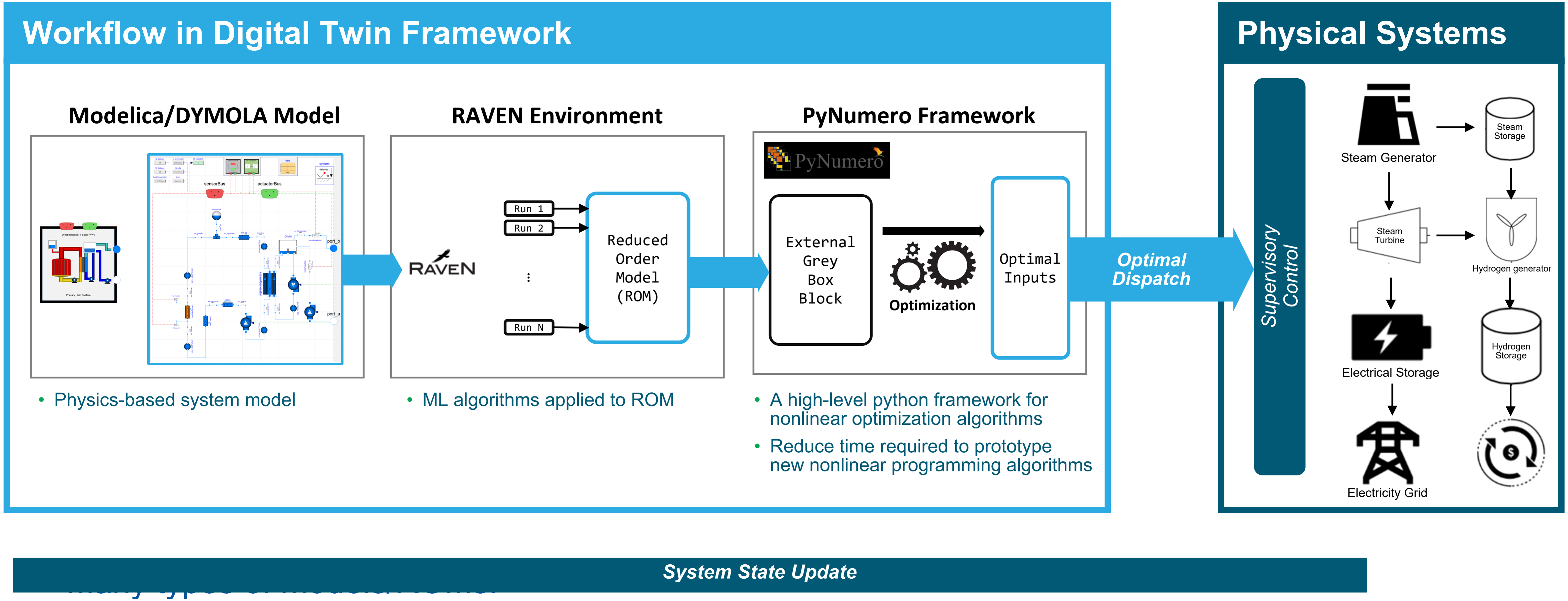
- 05-31-2022 to 06-07-2022
- PJM Pricing Node 1 (5-minute real time market)
- Perfect knowledge LMP forecast

Parameter	Value
	5 minutes
	0.8
	50 MW
	20 MWh
	0 MWh
	20 MW
	20 MW

	1 Week Revenue
IES	$8,511,996.26
NPP only	$8,265,764.33
Revenue Increase	**$246,231.93**



ORCA – Digital Twin □ Physical System Control



– Black box – no information: only inputs □ outputs

– Grey box – some information: inputs □ outputs, derivatives (Jacobians, Hessians, etc.)

–

ORCA – Current Work

- Build Python package to perform dispatch optimization
  - Provide tools for use in building workflows, not THE workflow
  - Given a model, perform optimization
- EMPC-based dispatch optimization
  - Current mathematical model:
  - Automatically generate Pyomo expressions for model, constraints, objective function
- Prepare for virtual demonstration of real-time economic optimization
  - Virtual model in Modelica/Dymola to emulate physical IES
  - Deep Lynx data warehouse to communicate between virtual model and optimization
  - Digital twin development for ORCA to use in economic dispatch

ORCA – Future Work

- Demonstrate real-time economic optimization on physical IES
  - DETAIL IES at INL
  - Deep Lynx data warehouse to communicate between IES and optimization
  - Digital twin development for ORCA to use in economic dispatch
- Open source ORCA
- Expand ORCA package
  - Additional optimization methods beyond EMPC
  - Integrate with other tools at INL or open-source community

Summary

- IES can make nuclear more flexible, economical
- Optimization of IES at INL
  - HERON
    - Optimal sizing for IES components
  - ORCA
    - Real-time economic dispatch optimization

- ies.inl.gov
  - daniel.garrett@inl.gov

INL

Idaho National Laboratory