Workshop: Purpose, Inputs, and Outputs

An Overview of HERON basics and examples

FORCE Workshop

March 2022, Virtual

INL/MIS-22-66302

Outline

- Motivations
- What is HERON?
- Why HERON?
- Inputs and Outputs
- Example Studies
- Current Efforts Overview
- Q&A

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Acknowledgements

HERON development: cross-lab, university-included, industry-informed

Idaho National Laboratory

Argonne NATIONAL LABORATORY

OAK RIDGE National Laboratory

PURDUE UNIVERSITY

COLORADO SCHOOL OF MINES

THE GEORGE WASHINGTON UNIVERSITY WASHINGTON, DC

UNIVERSITY OF MICHIGAN

Motivations

- Changing Energy Landscape
  - Main characteristics:
    - Increase in inflexible intermittent energy sources (VREs)
    - Larger gap between daily max, min electricity prices
    - Less baseload, more flexibility required
    - Battery storage is prohibitively expensive
  - How can Nuclear respond?
    - Flexible operation
      - Curtail production during low-demand hours
      - Minimal savings: most of nuclear cost is fixed, so not operating means losses
    - Integrated Energy Systems
      - Switch production during low-demand hours
      - Viability depends on regional markets for secondary commodities
      - Also depends on uncertainty of VREs

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What is HERON?

… and what isn't it?

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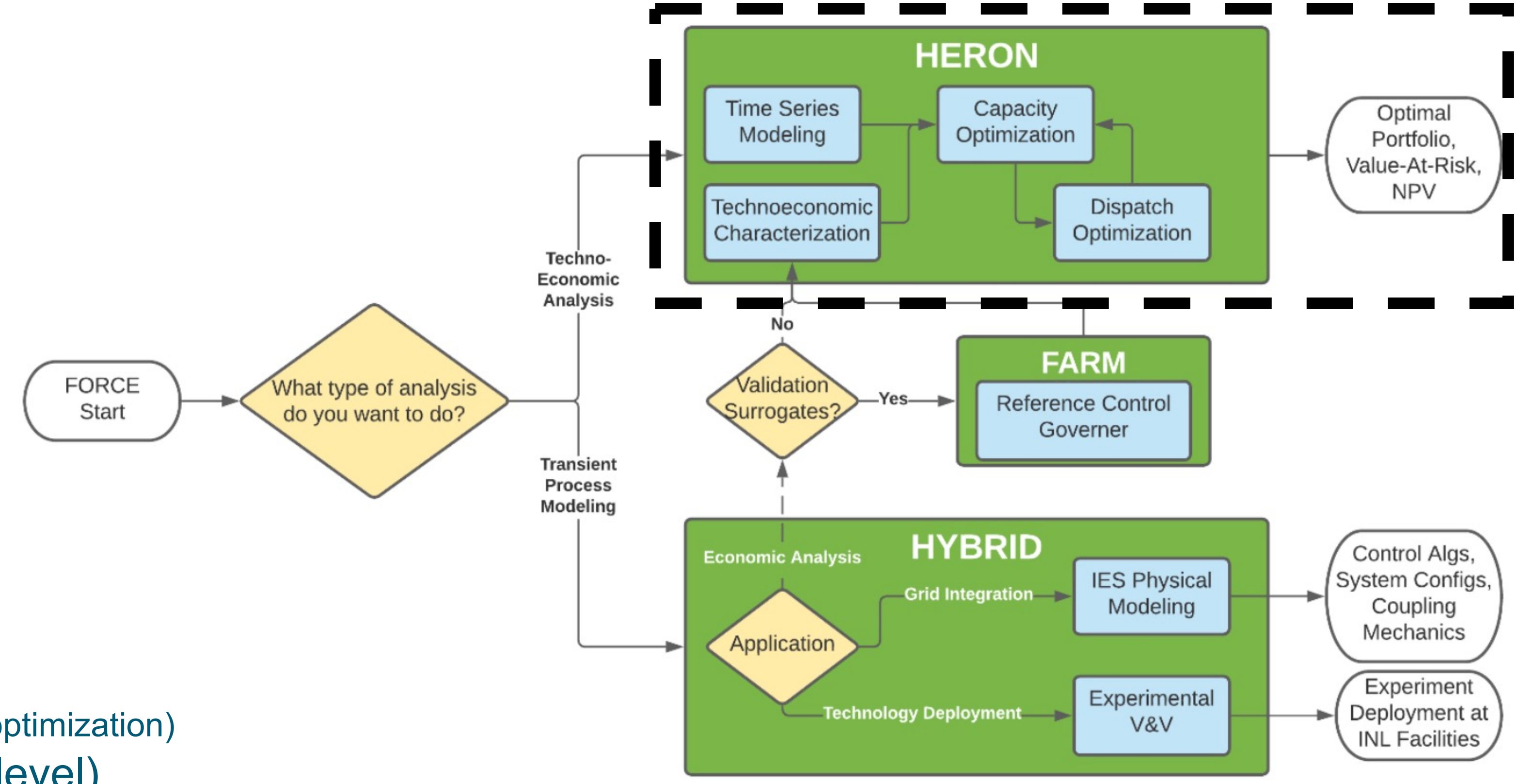
- Portfolio optimization
- Dispatch optimization
- Stochastic analysis
- Workflow automation
- Economic analysis
  - Multiyear, Multi-history
  - Expected Value, Value at Risk

HYBRID

- Process model simulation
  - Steady state
  - Transient
- Control simulation
- Economic analysis
  - (Component-level daily/weekly optimization)
- Supervisory control (system-level)
- Validation and verification
- Digital twinning



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What is HERON?

- Software for stochastic macro technoeconomic analysis of mixed-energy systems
- Command-line software tool
- Optimizes portfolio mixes to maximize statistical benefit
  - Expected NPV
  - Value at Risk (coming soon)
- Free, open source, openly available (https://github.com/idaholab/HERON)

HERON

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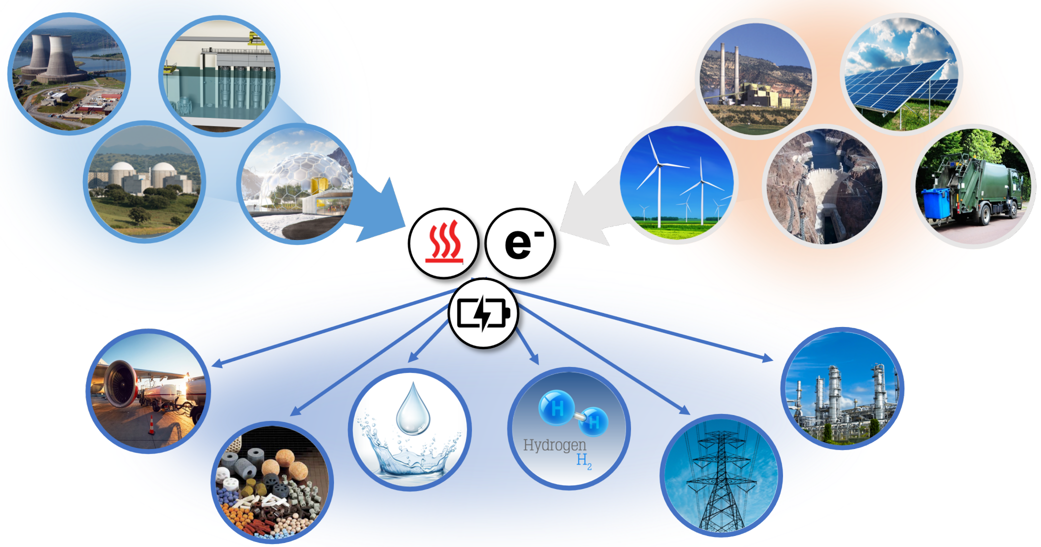
What is HERON?

- Features:
  - Mixed-Energy
    - electricity, hydrogen, water, heat, arbitrary commodities
  - Stochasticity
    - uncertain wind, solar, demand, prices
    - portfolio to maximize <u>average</u> benefit
  - Flexible Economics
    - arbitrary economic drivers
    - Capital costs
    - Fixed Operations, Maintenance costs
    - Variable Operations, Maintenance costs
    - Fuel consumption costs
    - Market sales for commodities
    - Policy-driven incentives



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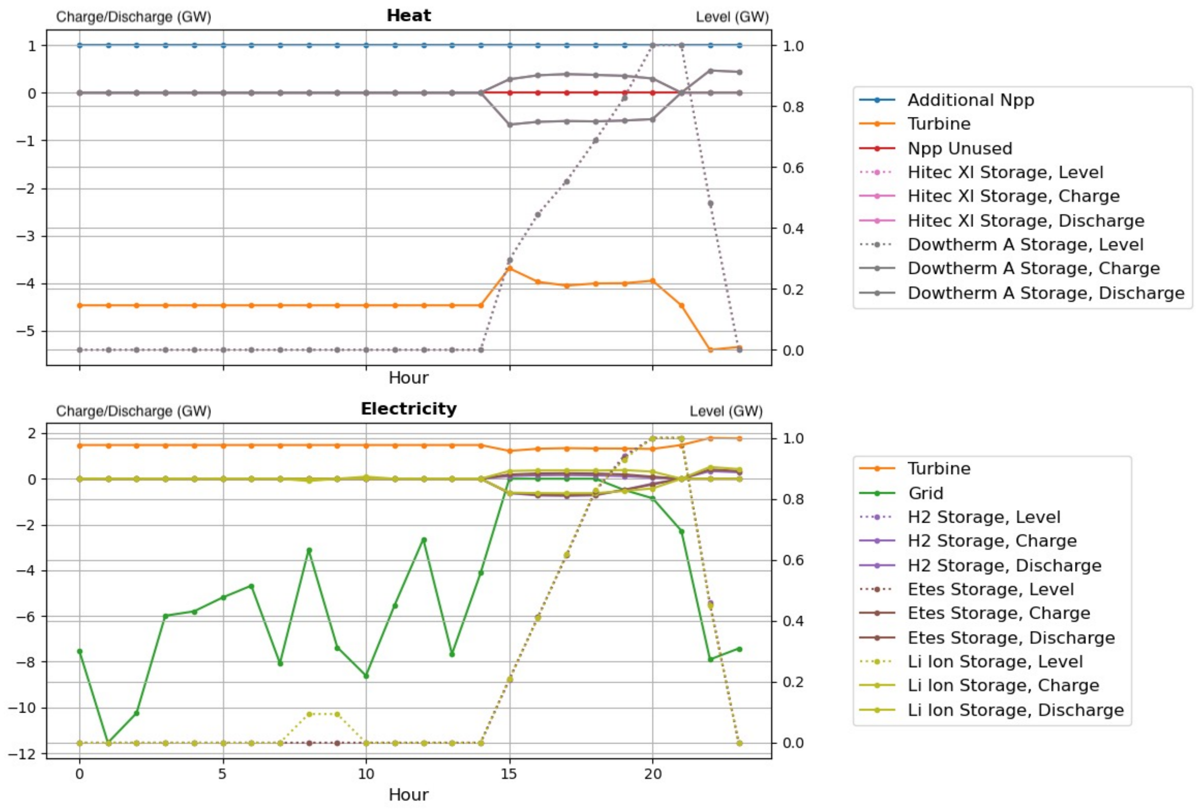
What is HERON?

- Features (ct'd):
  - Stochasticity
    - uncertain wind, solar, demand, prices
    - portfolio across many scenarios
      - optimize expected profit or Value at Risk
  - Contiguous Time
    - No time "slices"
      - Time "windows" capture connected time
    - Include inertial terms
      - Production ramp limitations
      - Commodity storage level tracking
      - Step-by-step volatility



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What is HERON not?

- Not Capacity Expansion
  - HERON solves for optimal portfolios, not evolution (yet)
- Not Market Constructor
  - Market information is an input to HERON
- Not Regional Database
  - HERON process user inputs, no pre-defined models
    - May be able to use some existing data from published analysis
- No Graphical User Input
  - … yet

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Why HERON?

How did we get here?

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Why HERON?

- Limitations in existing portfolio optimizers
  - Statistical analysis is afterthought or not present
  - Limited representation of Wind, Solar, Nuclear
  - Rarely include multiple markets, commodities
  - Often not openly available, easily extensible
  - Many designed on mostly-baseload pre-VRE expectations
- Integration with FORCE tools
  - Open-source models from HYBRID, IDAES
  - Validation through FARM
  - Stochastic engine through RAVEN
  - Economic analysis through TEAL
  - Part of open-source solutions for Lab, University, Industry collaboration

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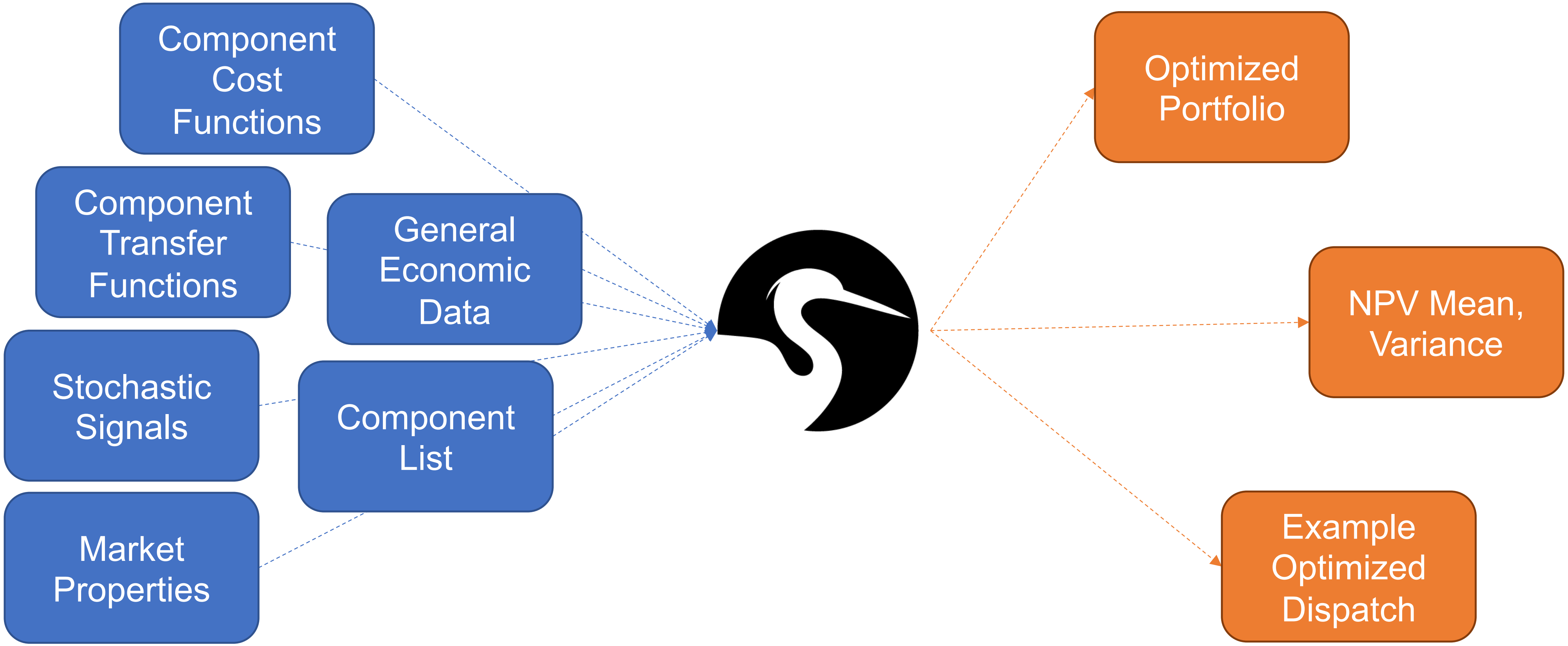
Why HERON?

- Why stochastic sampling?
  - Why not just analyze historical or forecast data?
- “Golden Year Problem”
  - Common practice: solve optimal portfolio for single history
  - Fails to capture range of possible outcomes
  - Driving economics is in outlier scenarios
    - High demand/low VRE
    - Low demand/high VRE
    - Sudden ramping demand
    - Stressed storage usage
  - Historic or Forecasted single scenarios can’t reliably capture outliers

Inputs and Outputs

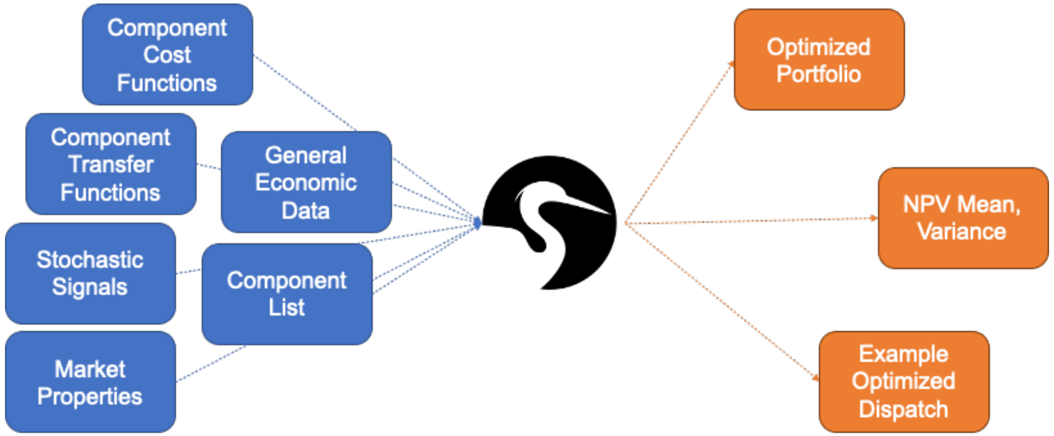
How does this stuff work anyway?

HERON I/O


Component Cost Functions
Component Transfer Functions
General Economic Data
Stochastic Signals
Component List
Market Properties
Optimized Portfolio
NPV Mean, Variance
Example Optimized Dispatch

HERON Inputs

- Component List
  - All components you want in your simulation
  - Sources
    - Generators
    - Producers
  - Sinks
    - Demand sources
    - Markets
  - Storage



- Where do I find these?
  - Problem Definition
  - Determining what questions you want to answer
  - Previous Examples (HERON Github)

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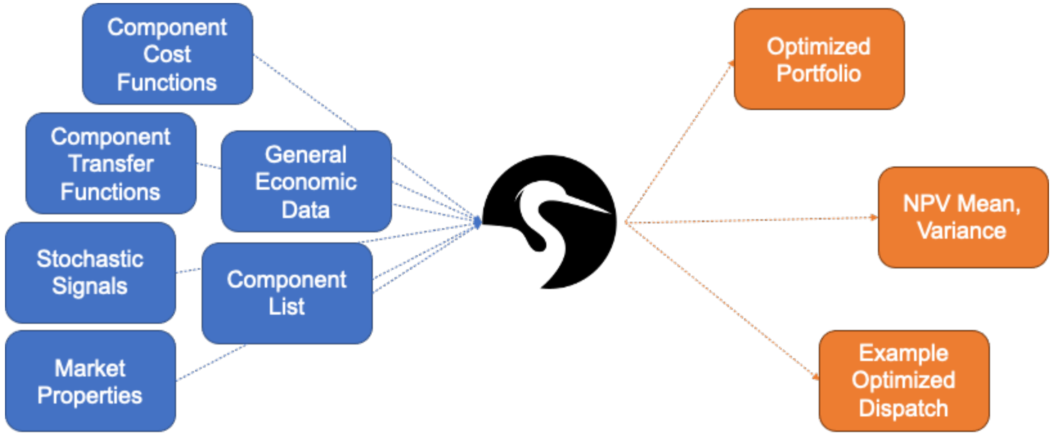
HERON Inputs

- Component Cost Functions
  - Capital construction costs
  - Fixed OM costs
  - Variable OM costs
  - Fuel costs
  - Economy of scale
  - Policy Incentives



- Where do I find these?
  - Literature (EIA, industry reports)
  - Previous studies (OSTI, HERON github)

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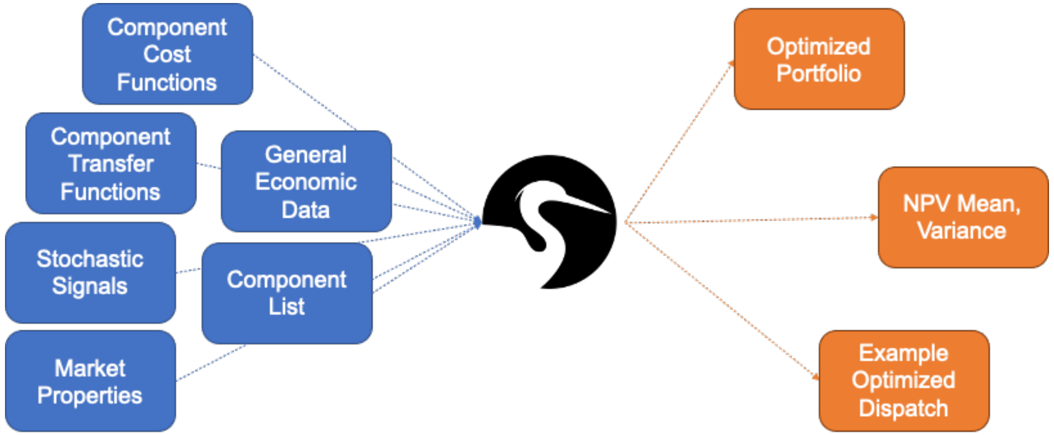
HERON Inputs

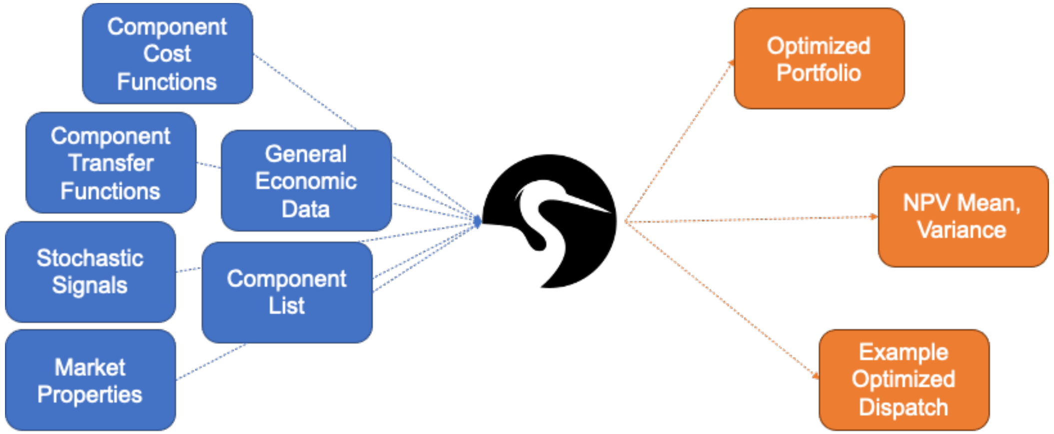
- Component Transfer Functions
  - Commodities consumed
  - Commodities produced
  - Reasonable sizing
  - Transfer function
    - Currently linear, but extensible



- Where do I find these?
  - Previous studies (OSTI, HERON github)
  - HYBRID simulations

HERON Inputs

- Stochastic Signals
  - Wind
  - Solar
  - Market prices
  - Commodity demand



- Where do I find these?
  - Public databases (NREL solar, wind, ERCOT, PJM, etc)
  - Capacity Expansion Models
  - Stay tuned for session on synthetic history training!

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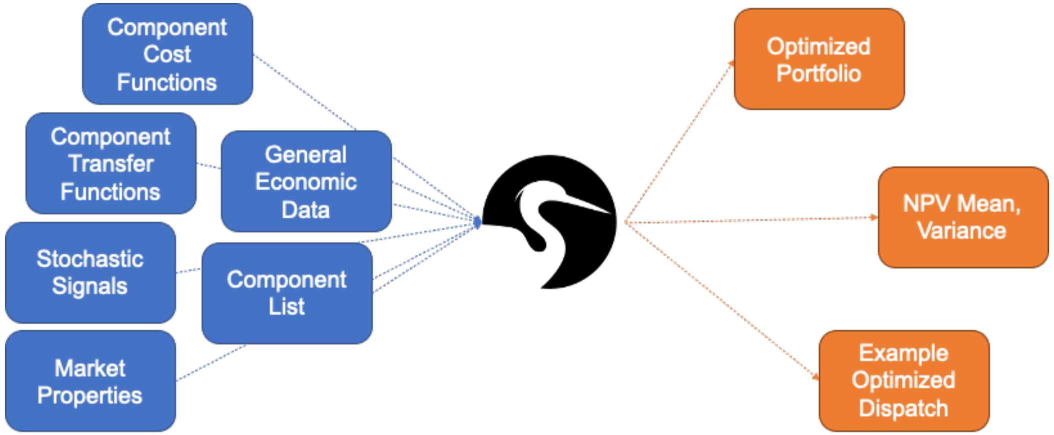
HERON Inputs

- Market Properties, General Economic Data
  - Ancillary market depth, prices, limitations
    - Capacity market
    - Frequency control



- Where do I find these?
  - Specific to each ISO
  - Industry Reports
  - Proposed Policy

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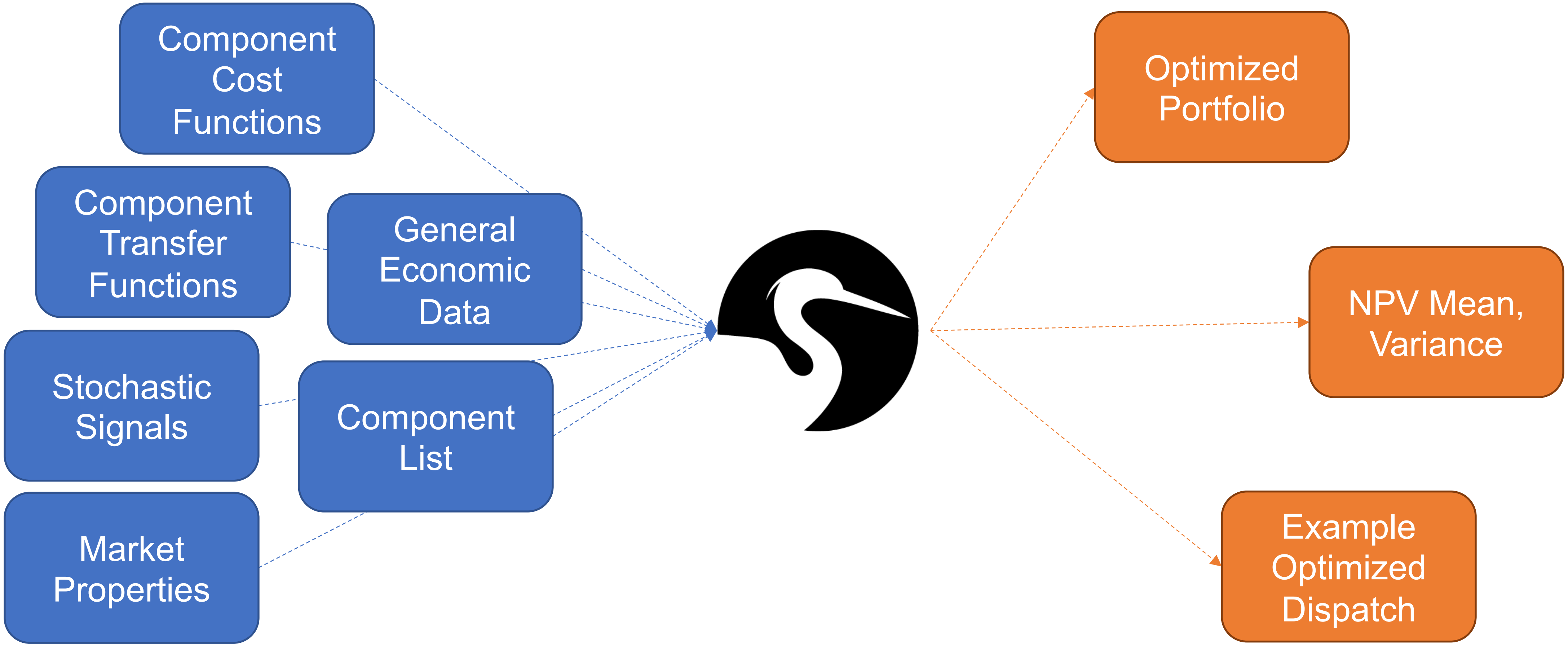
HERON I/O


Component Cost Functions
Component Transfer Functions
General Economic Data
Stochastic Signals
Component List
Market Properties
Optimized Portfolio
NPV Mean, Variance
Example Optimized Dispatch

HERON Outputs

- Optimized Portfolio
  - Optimal size of each optimized component

- What does this look like?
  - CSV output

	A	B	C	D	E
1	iteration	accepted	ngcc_capacit	import_capa	mean_NPV
2	1	accepted	17.5	100	-8.77E+09
3	2	accepted	23.5	100	-7.44E+09
4	5	accepted	31.5	100	-7.23E+09
5	6	accepted	36.833333	100	-7.21E+09
6	13	accepted	39.993827	100	-7.2E+09
7	44	accepted	39.989016	100	-7.2E+09
8	171	accepted	39.989016	100	-7.2E+09
9	172	accepted	39.989016	100	-7.2E+09
10	0	first	[illegible]	100	-1.42E+10
11	3	rejected	11.5	100	-1.42E+10

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HERON Outputs

- NPV Statistics
  - Mean, variance, percentile of NPV
  - Value at Risk (soon)
- What does this look like?
  - CSV output

	A	B	C	D	E
1	iteration	accepted	ngcc_capacit	import_capa	mean_NPV
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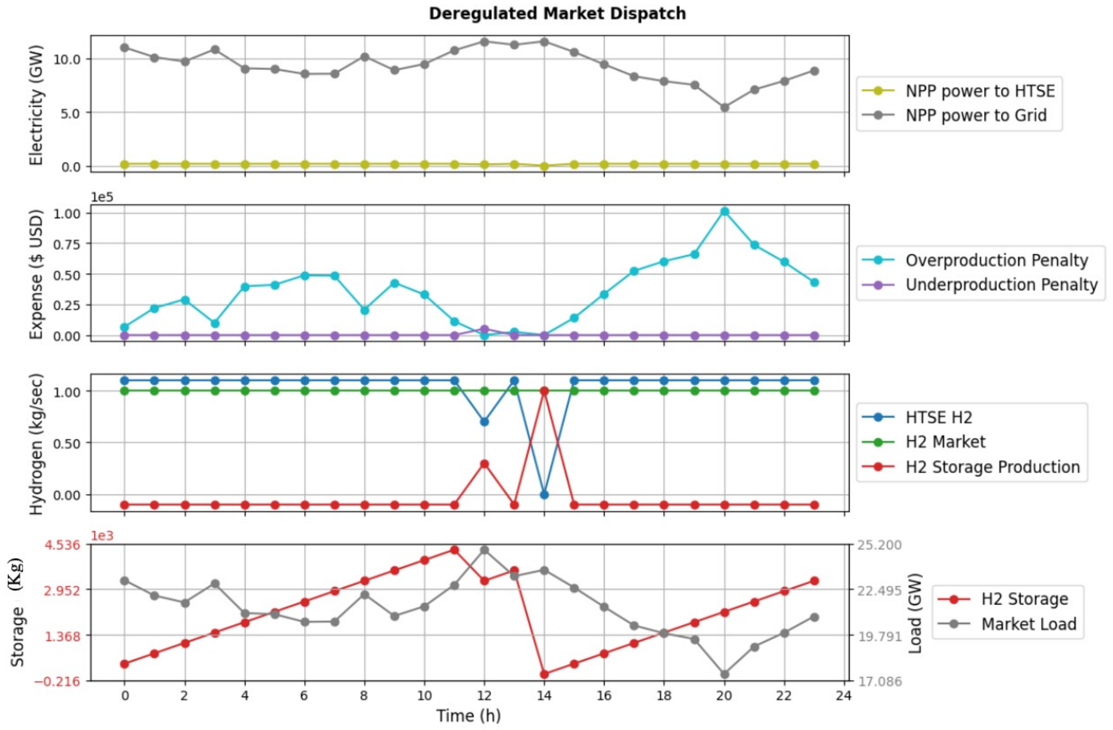
HERON Outputs

- Example Optimized Dispatch
  - Produce in "debug" mode
  - Dispatch of each component in one window
    - HERON solves ~millions of these per run; "debug" just shows a few

- What does this look like?
  - Automated plots
  - CSV



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Example Studies

TEA is as TEA does

Example Studies

- A sampling of what has been done, and can be done

- 2017: Nuclear-Hydrogen
- 2018: Nuclear-Water Desalination (APS)
- 2019: Nuclear-Hydrogen in Midwest (Exelon)
- 2020: Nuclear-Hydrogen in Regulated, Deregulated Markets (EPRI)
- 2021: Nuclear-Thermal Energy Storage in NYISO (EPRI)

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2017: Nuclear-Industrial Coupling

- What are potentially profitable configurations of nuclear-industrial coupling given stochastic wind?
  - First use of RAVEN for IES analysis
  - Nuclear, Natural Gas (SES), Battery (ES), Hydrogen Generator (IP)
  - Parametric on:
    - Unit sizes (SES, ES, IP)
    - Average demand
    - H_2 price
    - Wind turbine installation as percent of demand

https://www.osti.gov/biblio/1593858-economic-analysis-nuclear-hybrid-energy-system-stochastic-environment-including-wind-turbines-electricity-grid

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2017: Nuclear-Industrial Coupling

- Features Introduced
  - Multiple unit sizing response surface
  - Synthetic histories for statistical analysis
  - Electrical storage treatment

- Limitations
  - One week to represent year
  - Predefined unit commitment model

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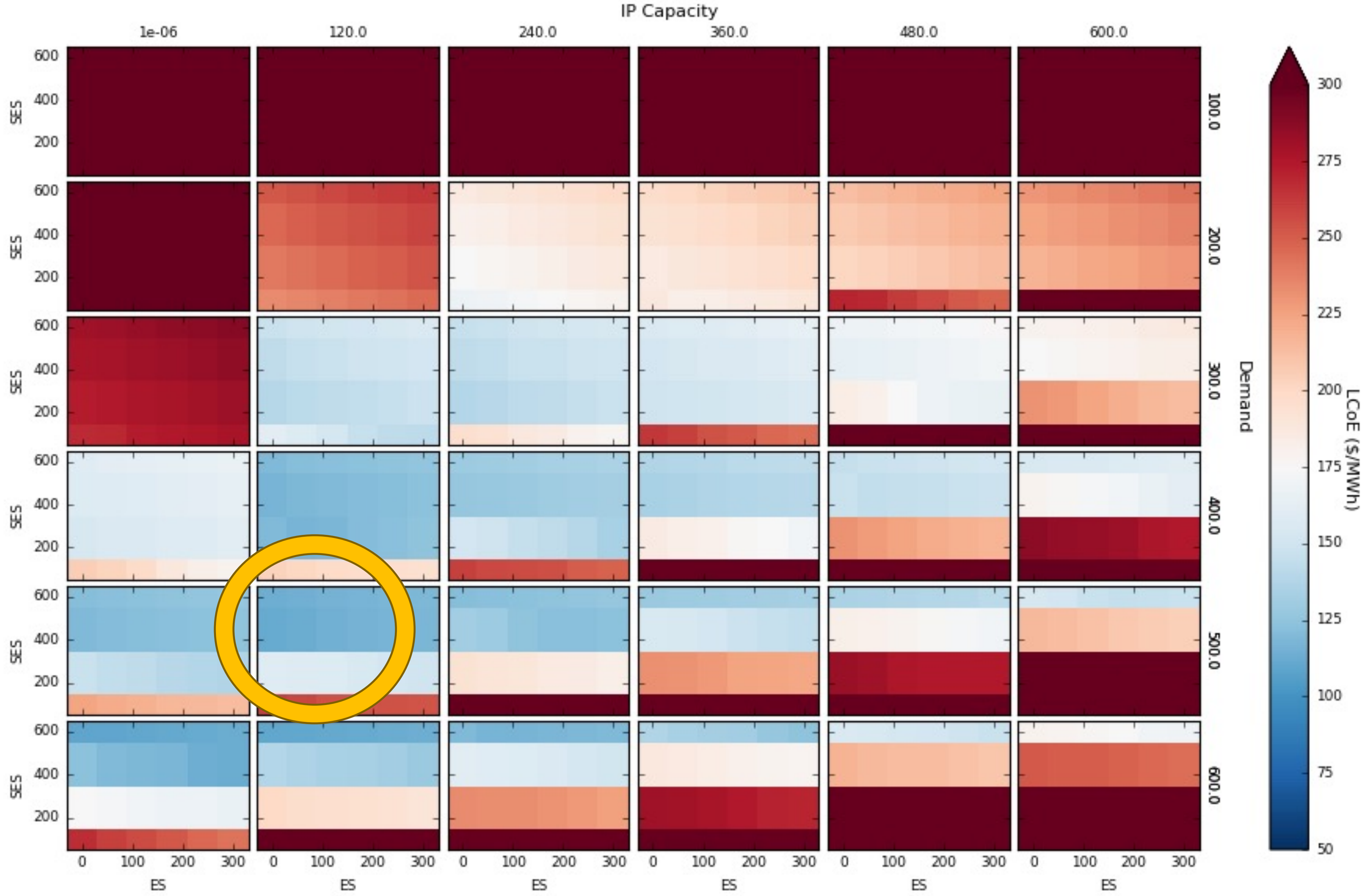
2017: Nuclear-Industrial Coupling



Case 1
H2: 0 $/kg
Wind: 100%

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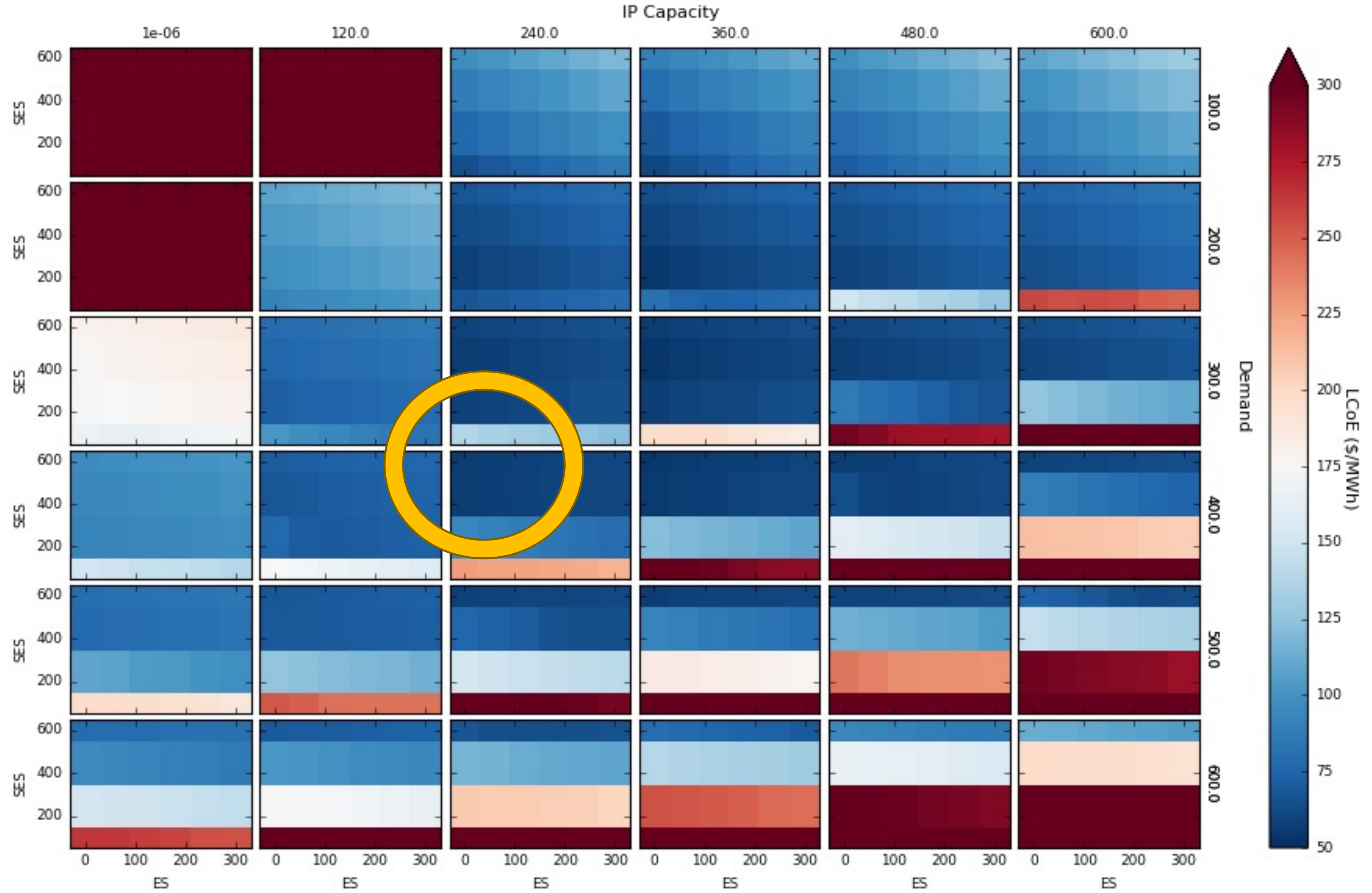
2017: Nuclear-Industrial Coupling



Case 1
H2: 3.5 $/kg
Wind: 50%

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2018: Water Desalination in Arizona

- Can water desalination be a profitable IES for the Palo Verde nuclear plant?
  - Partnership with Arizona Public Service (APS)
  - Multiple desalination coupling opportunities
  - Public, Private reports

https://www.osti.gov/biblio/1634115-economic-assessment-nuclear-hybrid-energy-systems-nuclear-renewable-water-integration-arizona

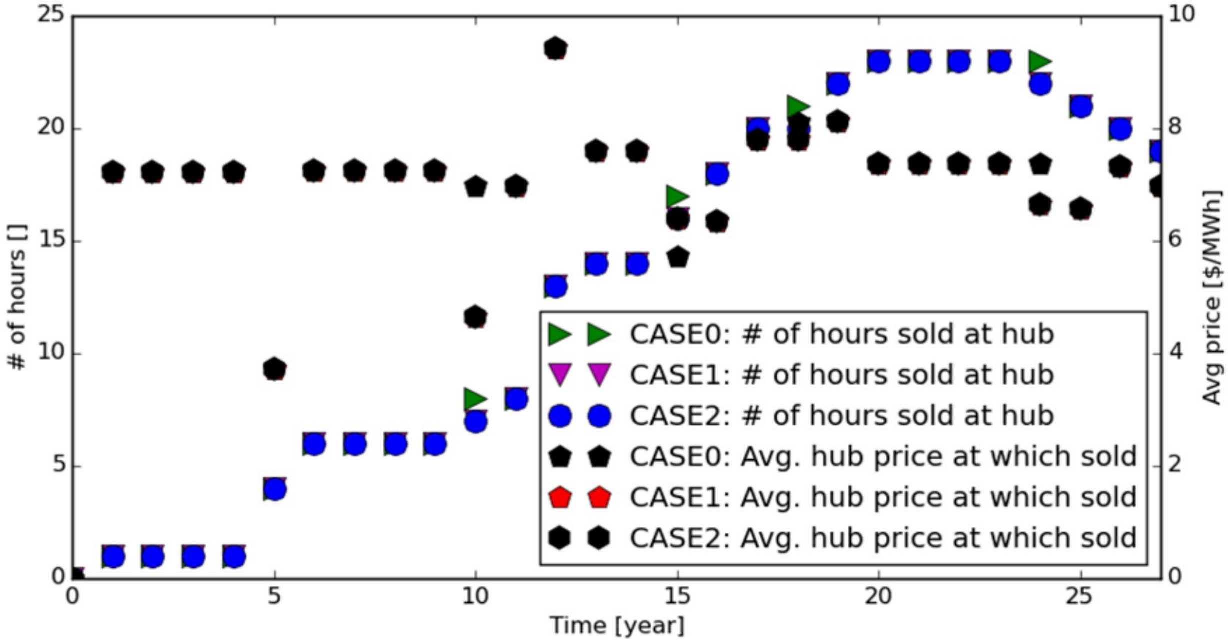
2018: Water Desalination in Arizona

- Features Introduced
  - Desalination Characterization
  - Direct industry engagement
  - Multi-year synthetic histories

- Limitations
  - Predefined unit commitment model
  - Required advanced RAVEN workflows

2018: Water Desalination in Arizona

- Results
  - Projected demand growth outpaces VRE installation
  - Few IES-enabled hours
  - Limited desal IES options
  - Desalination is profitable
    - Flexibility through IES is not



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2019: Hydrogen in Midwest

- How does introducing hydrogen IES for a Midwest reactor impact its economic viability?
  - HERON before HERON was HERON
  - Projected price histories with PLEXOS and NREL's ReEDS
  - Scenario design with Exelon
  - Hydrogen market characterization with ANL
  - Response surface study
    - Parametric study of HTSE size, H_2 Storage size, H_2 Market size, Discount Rate

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https://www.osti.gov/biblio/1569271-evaluation-hydrogen-production-feasibility-light-water-reactor-midwest

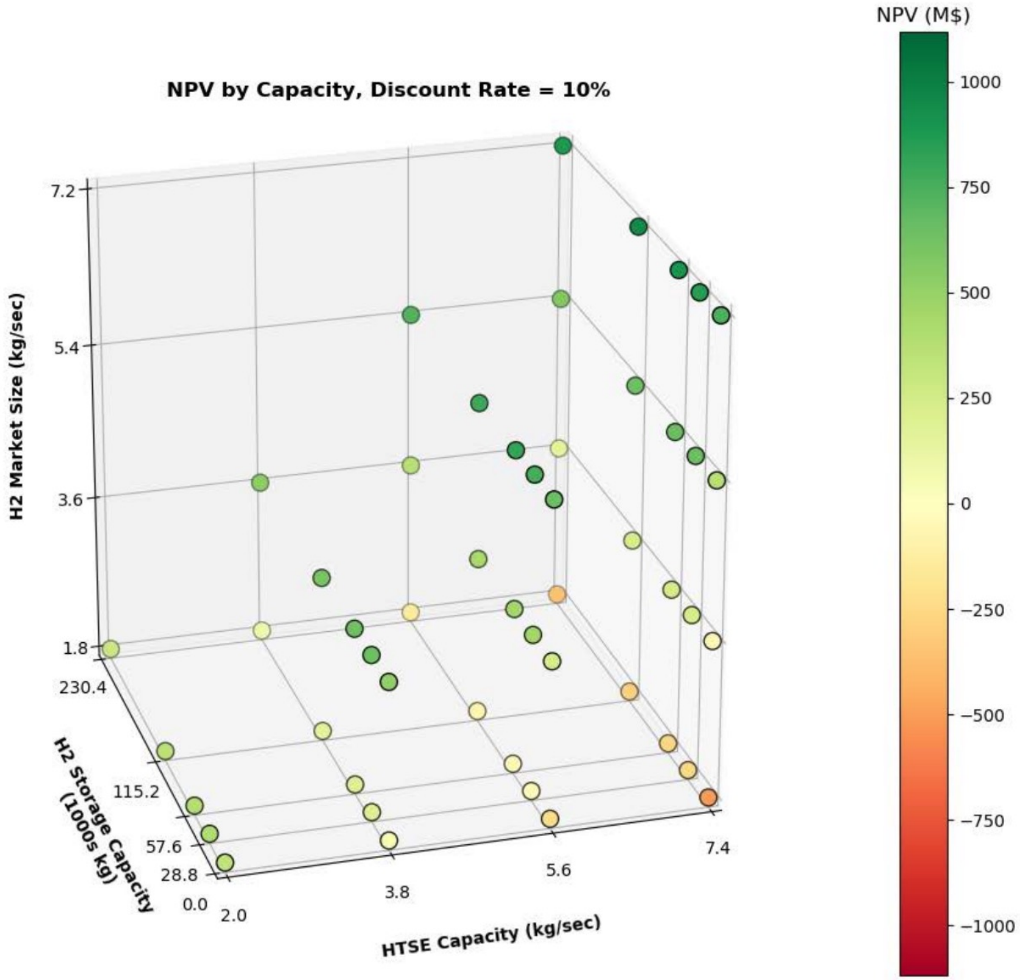
2019: Hydrogen in Midwest

- Features Introduced
  - Templated RAVEN inputs
  - Cross-lab simulation process
  - Preliminary two-layer optimization
  - Complex, peak-focused synthetic histories

- Limitations
  - User-defined dispatching optimization algorithm
  - Still required advanced RAVEN workflows

2019: Hydrogen in Midwest

- Results
  - Ideally HTSE slightly larger than demand
  - Build small H_2 storage
  - High H_2 price leads to larger HTSE
  - Overbuilding is very expensive
  - All simulations led to profitable IES
    - if sized optimally



2020: Hydrogen in Regulated, Deregulated Markets

- How does the impact of introducing hydrogen IES change in regulated versus deregulated markets?
  - Demonstrates modeling of regulated, deregulated markets in HERON
  - Projected futures with EPRI and US-REGEN in Ohio
    - Nominal vs Favorable Nuclear Costs
    - Nominal policy vs Carbon Tax vs Renewable Portfolio Standard
  - Stochastic Net Demand

https://www.osti.gov/biblio/1755894-evaluation-hybrid-fpog-applications-regulated-deregulated-markets-using-heron

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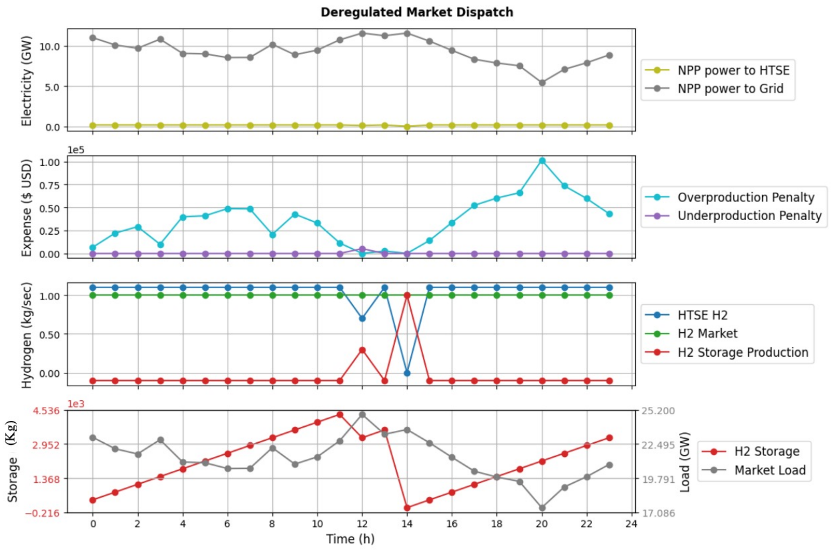
2020: Hydrogen in Regulated, Deregulated Markets

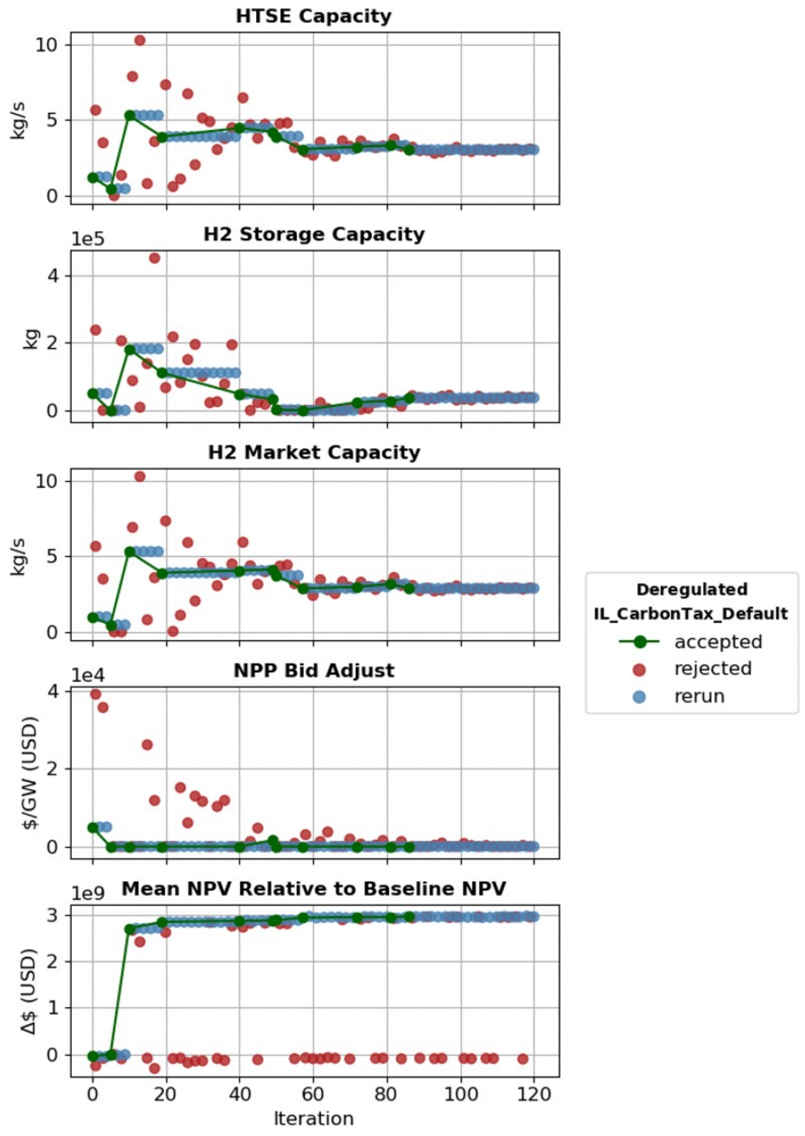
- Features Introduced
  - HERON first release version
  - US-REGEN collaboration
  - Long-term capacity expansion modeling input
  - Automated regulated market simulation for dispatch optimization

- Limitations
  - Deregulated market simulation requires user input
  - Wind, solar, demand combined into “net demand” synthetic history
  - “Price taker” approach (no market feedback)

2020: Hydrogen in Regulated, Deregulated Markets

- Results
  - Deregulated markets have higher prices
    - Potential for IES flexibility
    - Volatility + High Prices ideal for IES
  - Carbon Tax pushes toward Nuclear IES
    - RPS less motivating





2021: Thermal Energy Storage in NYISO

- What benefits can TES offer NYISO in projected scenarios?
  - Introduces improved storage treatment in HERON
  - Projected futures with EPRI and US-REGEN
    - Local versus National Clean Energy Standard
  - TES Technologies from INL Research
    - Varying Technology Readiness Levels
  - No auxiliary commodities
    - Thermal energy stored for later use in power generation
  - Stochastic wind, solar, demand

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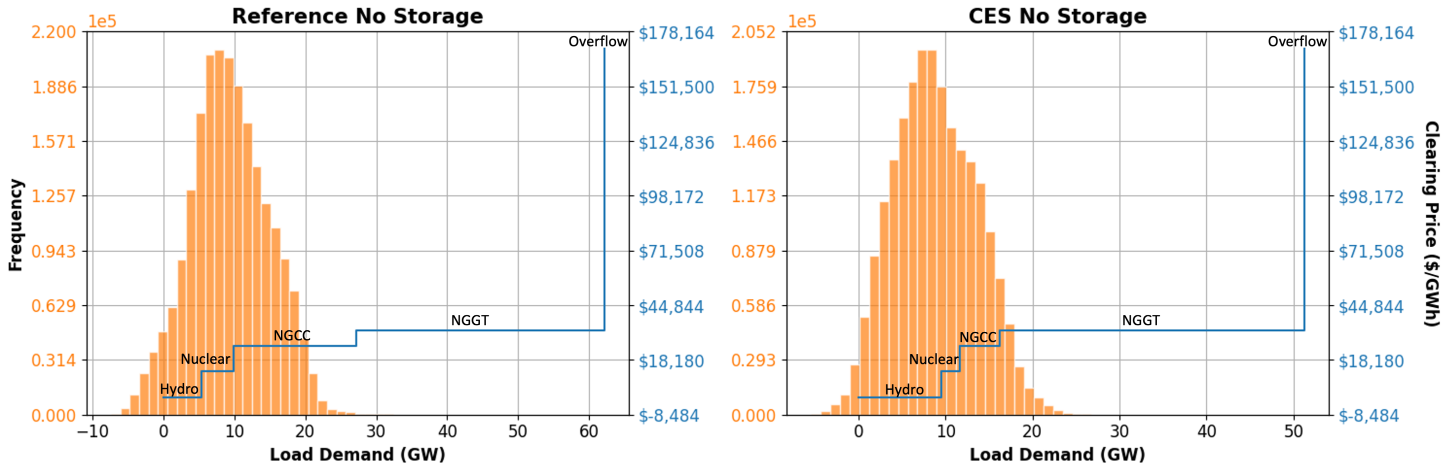
2021: Thermal Energy Storage in NYISO

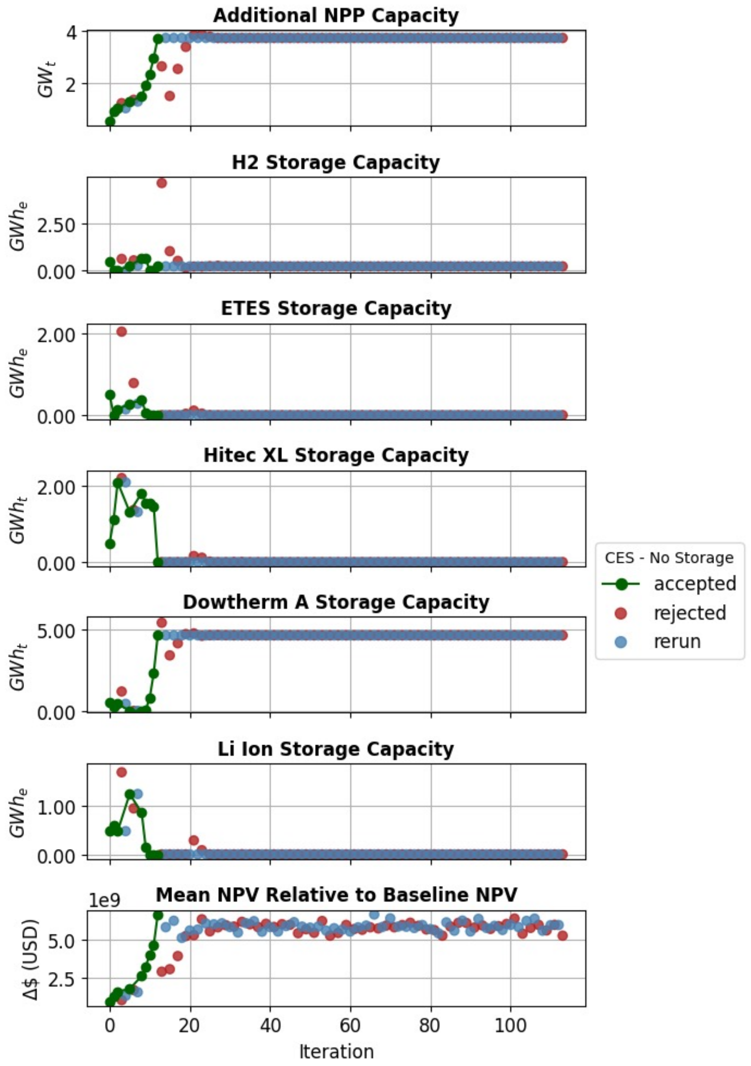
- Features Introduced
  - "Price Maker" approach with market feedback
  - Control algorithms for storage technology
  - Round trip efficiency introduced for storage
  - Automated plots for dispatch, optimization

- Limitations
  - Deregulated market simulation still requires some user input

2021: Thermal Energy Storage in NYISO

- Results
  - TES best for volatile, high prices
  - Amount of TES matters more than which tech
  - TES capital costs drive inclusion
  - Building TES is binary decision
    - If profitable, build fixed amount
    - Not a sliding scale for construction





Ongoing Efforts

Coming soon to a terminal near you

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Usability Improvements

- Interactive Synthetic History Training (Jupyter) *September 2022*
- Value-at-Risk Economic Metric for Optimization *April 2022*
- Automated Levelized Cost workflow *September 2022*
- Loading Components from HYBRID *June 2022*
  - And sending dispatch points to HYBRID
- Real-Time Optimization Demonstration *September 2022*

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Stay connected: https://github.com/idaholab/HERON

2022 TEA Studies

- IES direct studies
  - Thermal Energy Storage — *Konor Frick, konor.frick@inl.gov*
  - Carbon Conversion — *Elizabeth Worsham, elizabeth.worsham@inl.gov*
  - SynFuels Applications — *Konor Frick, konor.frick@inl.gov*
  - FARM Demonstration — *Roberto Ponciroli, rponciroli@anl.gov*

- Externally driven studies
  - APS and Hydrogen — *Andrew Foss, andrew.foss@inl.gov*
  - Exelon-GMI Tri-Lab — *Jason Hansen, jason.hansen@inl.gov*

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Questions?

- Q&A
  - as time permits

- Upcoming training sessions:
  - Synthetic History Training and Generation
  - HERON demonstration

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