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Agent-Based Capacity Expansion

FORCE Overview and Training

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Agenda

- Introduction and motivation
- ABCE overview
- FORCE / ABCE interface
- Example results and next steps

Introduction and Motivation

- New project initiated FY23
- Objective:
  - Bring a market-wide capacity-expansion solver into FORCE
  - “Capacity expansion”: change in installed base of system energy resources over time
- Anticipated benefits:
  - Simulate some market dynamics impacting energy systems of interest to IES, which FORCE does not currently have a method to solve

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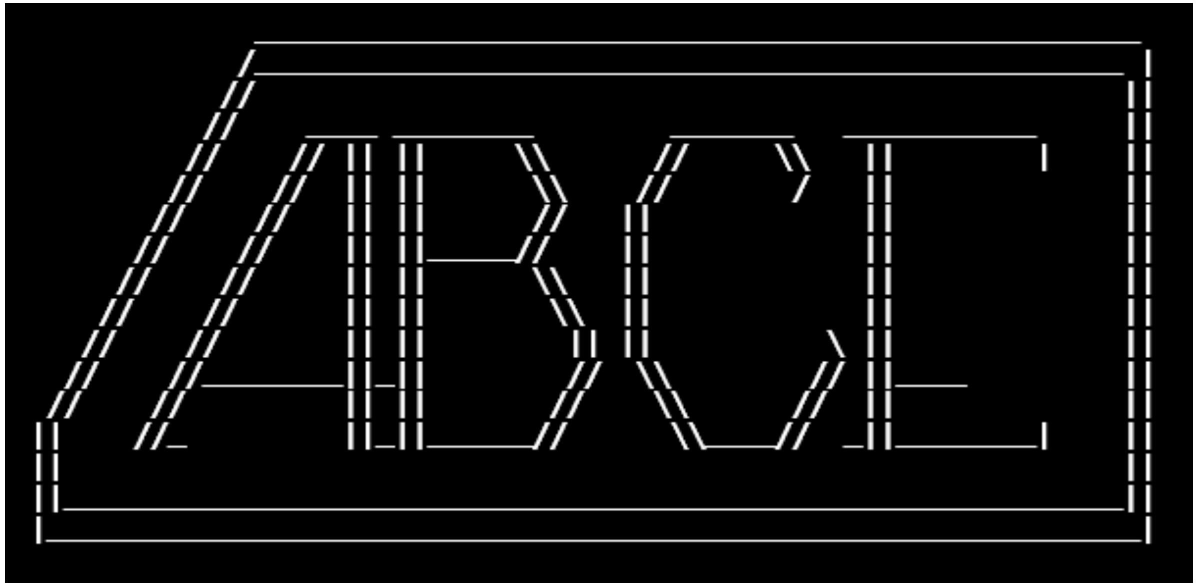
ABCE:
Agent-Based Capacity Expansion

ABCE: Agent-Based Capacity Expansion

- Purpose: explore capacity investment decisions made by multiple decentralized, profit-maximizing utility companies ("agents") competing in a shared wholesale energy market



- Developed for K. Biegel's PhD project, with support from DOE-NE/Systems Analysis & Integration Campaign

Capacity expansion modeling: optimization

- Many market simulation/capacity expansion codes rely on optimization techniques
  - Optimization partially replicates market forces for “regulated” utilities
  - Determine system portfolio by minimizing cost of delivering electricity to the consumer
  - Useful to model “what *should* happen” / best possible outcomes
  - Examples: TIMES/MARKAL, ReEDS
- Downside: optimization cannot represent firm-specific decision drivers which govern behavior in competitive wholesale markets

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Nuclear energy and agent-based modeling

- Market factors are key for nuclear:
  - if nuclear plants are unprofitable/too risky, utilities won't build them
  - true EVEN if more nuclear would be "better" for the overall energy system: reliability, cost, carbon, etc.
  - firms optimize on returns, not on benefit to system/society
- Benefits of agent-based approach:
  - directly simulates actions of multiple independent companies ("agents")
  - agents behave according to realistic decision methods and drivers
- This brings us to ABCE: the agent-based capacity expansion code

ABCE: decision logic

- Agent decision logic:
  - Objective: maximize a weighted sum of portfolio NPV valuation and "financial flexibility" metrics
  - Constraints: avoid credit rating downgrade to "speculative", avoid causing foreseeable energy shortages
  - Agent forecasting: demand, future dispatch results, issuance of financial instruments
- ABCE is currently electricity-only
- Planned expansion to multi-commodity simulation in upcoming FYs

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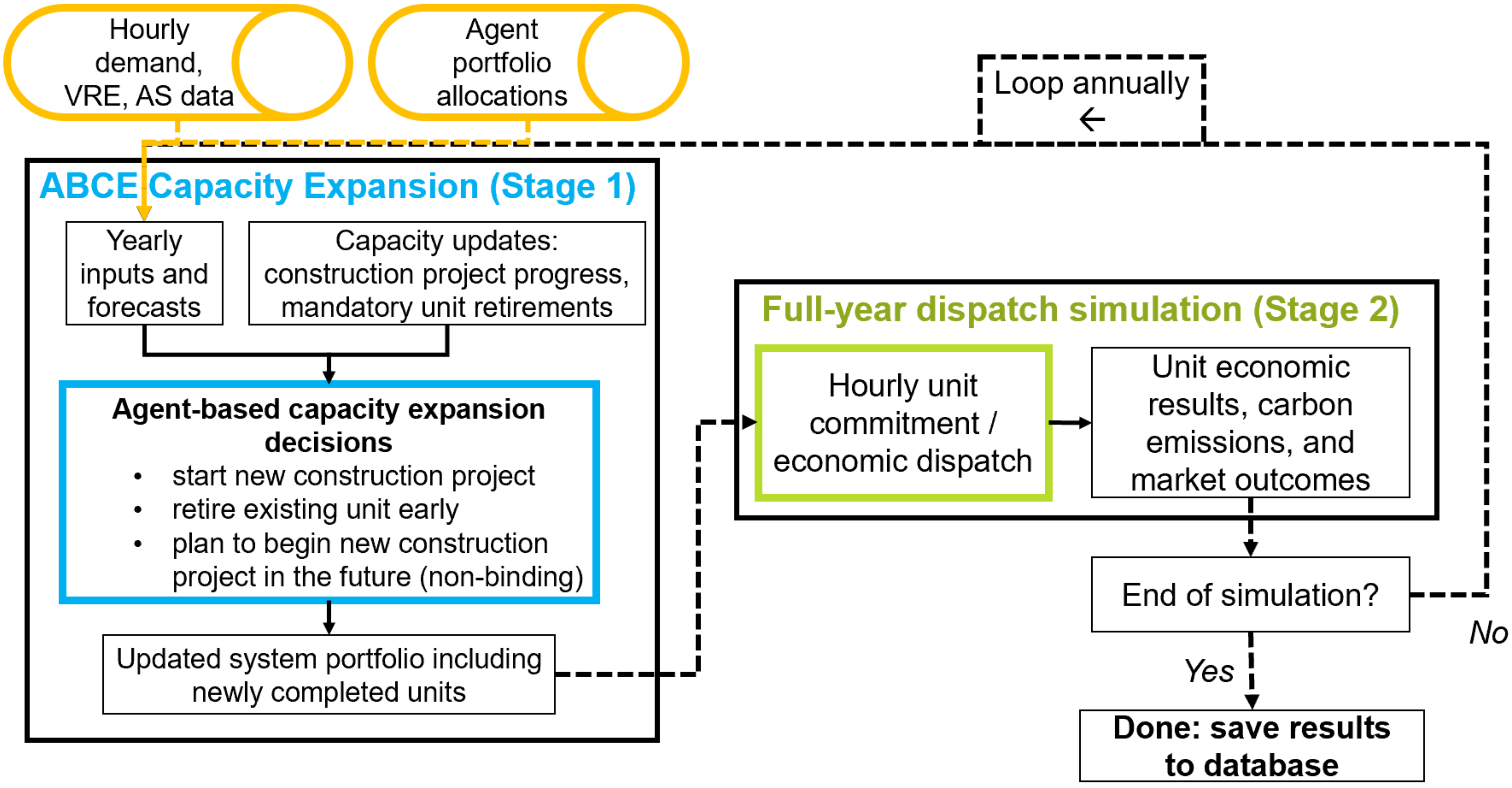
ABCE: execution and logic flow



FORCE-ABCE integration

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FORCE-ABCE: initial integration concept

- User:
  - is interested in exploring market viability of certain energy technologies
  - specifies parameters and ranges of interest
- HERON (via ABCE plugin):
  - generates ABCE input files covering the desired parametric ranges
  - spawns individual ABCE instances running each set of inputs
  - collects and processes results
- ABCE:
  - behaves like a black-box module

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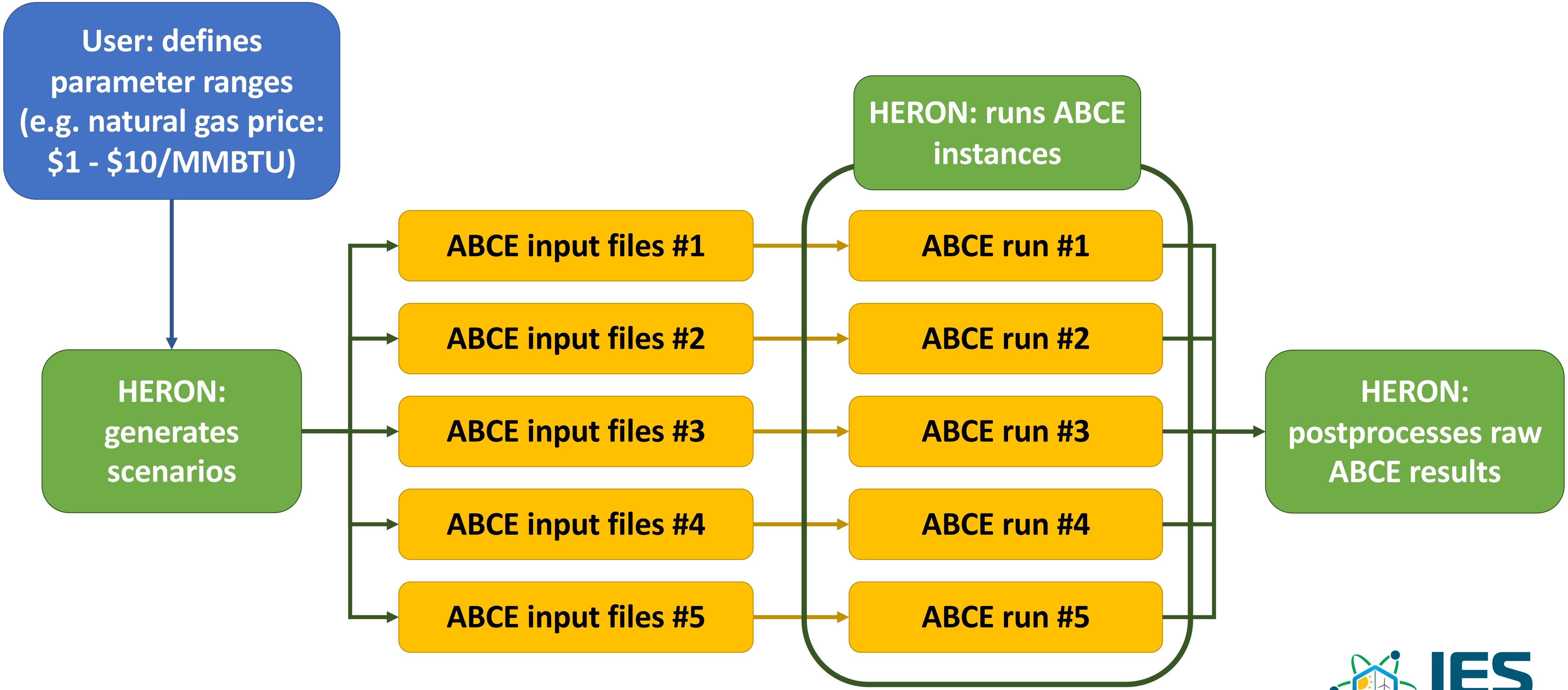
FORCE-ABCE integration workflow



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FORCE-ABCE: parameterize anything

- ABCE inputs:
  - 4 structured (yaml) input files, plus time-series data
  - Loaded by the integration plugin as a template
- FORCE-ABCE integration plugin can find-and-replace any ABCE input value in the hierarchy:
  - fuel costs
  - which units qualify for policy incentives
  - agent #201's cost of issuing debt
  - etc.
- Plugin generates parallel sets of input files according to user's desired parameters and ranges

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FORCE-ABCE – Initializing with HERON

Example HERON input:
system economics specification

```
<economics>
  <policies>
    <CTAX>
      <enabled>True</enabled>
      <qty>60</qty>
    </CTAX>
    <PTC>
      <enabled>True</enabled>
      <eligible>ConventionalNuclear, Wind, Solar</eligible>
      <qty>15.0</qty>
    </PTC>
  </policies>
</economics>
```

The HERON input specifies global economic inputs:

- a carbon tax of $60/ton
- Production tax $15/MWh for nuclear, wind and solar

Parameters not set in the HERON inputs are drawn from a set of ABCE defaults pre-specified for this market system.

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FORCE-ABCE: input/parameter translation

Example HERON input:
system economics specification

```xml
<economics>
  <policies>
    <CTAX>
      <enabled>True</enabled>
      <qty>60</qty>
    </CTAX>
    <allowed_xtr_types>Wind, Solar, NGCC,
      NGCT, AdvancedNuclear</allowed_xtr_types>
  </policies>
</economics>
```

ABCE defaults

HERON-created ABCE input:
system economics specification

```yaml
simulation:
  ALEAF_scenario_name: "ABCE_ERCOT"
  solver: "CPLEX"
  num_steps: 15

scenario:
  peak_demand: 78000
  policies:
    CTAX:
      enabled: True
      qty: 60  # $/t CO2
  allowed_investment_types:
    - wind
    - solar
    - ngcc
    - ngct
    - conventional_nuclear
    - advanced_nuclear
```

FORCE-ABCE – Initializing with HERON

Example HERON input:
generator type ("component") specification

```
<Component name="NGCC">

  <produces resource="electricity" dispatch="independent">
    <capacity resource="electricity" />
  </produces>

  <economics>
    <lifetime>30</lifetime>
    <!-- construction cost -->
    <CashFlow name="capex" type="one-time" taxable="True" inflat
    </CashFlow>

    <CashFlow name="fixed_OM" type="repeating" period="year" tax
    </CashFlow>

    <CashFlow name="var_OM" type="repeating" period="hour" taxab
    </CashFlow>

    <CashFlow name="Fuel" type="repeating" period="hour" taxable
    </CashFlow>
  </economics>
```

For each generator type, HERON specifies the economic data for:

- **Capex:** one-time cash flow based on capacity
- **Fixed O&M Costs:** repeating annual cashflow based on generator capacity
- **Variable O&M Costs:** repeating hourly cashflow based on generation
- **Fuel:** repeating hourly cashflow based on the heat rate and fuel used

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FORCE-ABCE: input/parameter translation

Example HERON input:
generator type ("component") specification

```
<CashFlow name="capex" type="one-time" taxable="T
  <driver>
    <variable>ngcc_capacity</variable>
  </driver>
  <reference_price>
    <!-- 1000 $/kW * 1e6 kW/GW = 1e9 est cost for
    <fixed_value>-1e8</fixed_value>
  </reference_price>
</CashFlow>
<CashFlow name="var_OM" type="repeating" period="
mult_target='False'>
  <driver>
    <activity>electricity</activity>
  </driver>
  <reference_price>
    <!--  $2.16/MWh -->
    <fixed_value>-2160</fixed_value>
  </reference_price>
</CashFlow>
```

ABCE defaults

HERON-created ABCE input:
generator type specification

```
ngcc:
  capacity: 200    # MW
  max_PL: 0.9
  min_PL: 0.5
  overnight_capital_cost: 1000 # $/kW
  retirement_cost: 0.0
  FOM: 12.86     # $/kW-yr
  VOM: 2.16     # $/MWh
  fuel_type: natural_gas
  FC_per_MMBTU: 3.25
  no_load_cost: 0.0
  start_up_cost: 0.0
  shut_down_cost: 0.0
  heat_rate: 6.401     # MWh/MMBTU
```

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FORCE-ABCE: managing outputs

- Each ABCE run outputs a SQLite database, containing:
  - most input data
  - the results of all agents' decisions throughout the run
  - nearly all interim data generated during the simulation
- HERON postprocessing (WIP):
  - assemble individual run databases into a single master database
  - perform postprocessing on a wide variety of generated data

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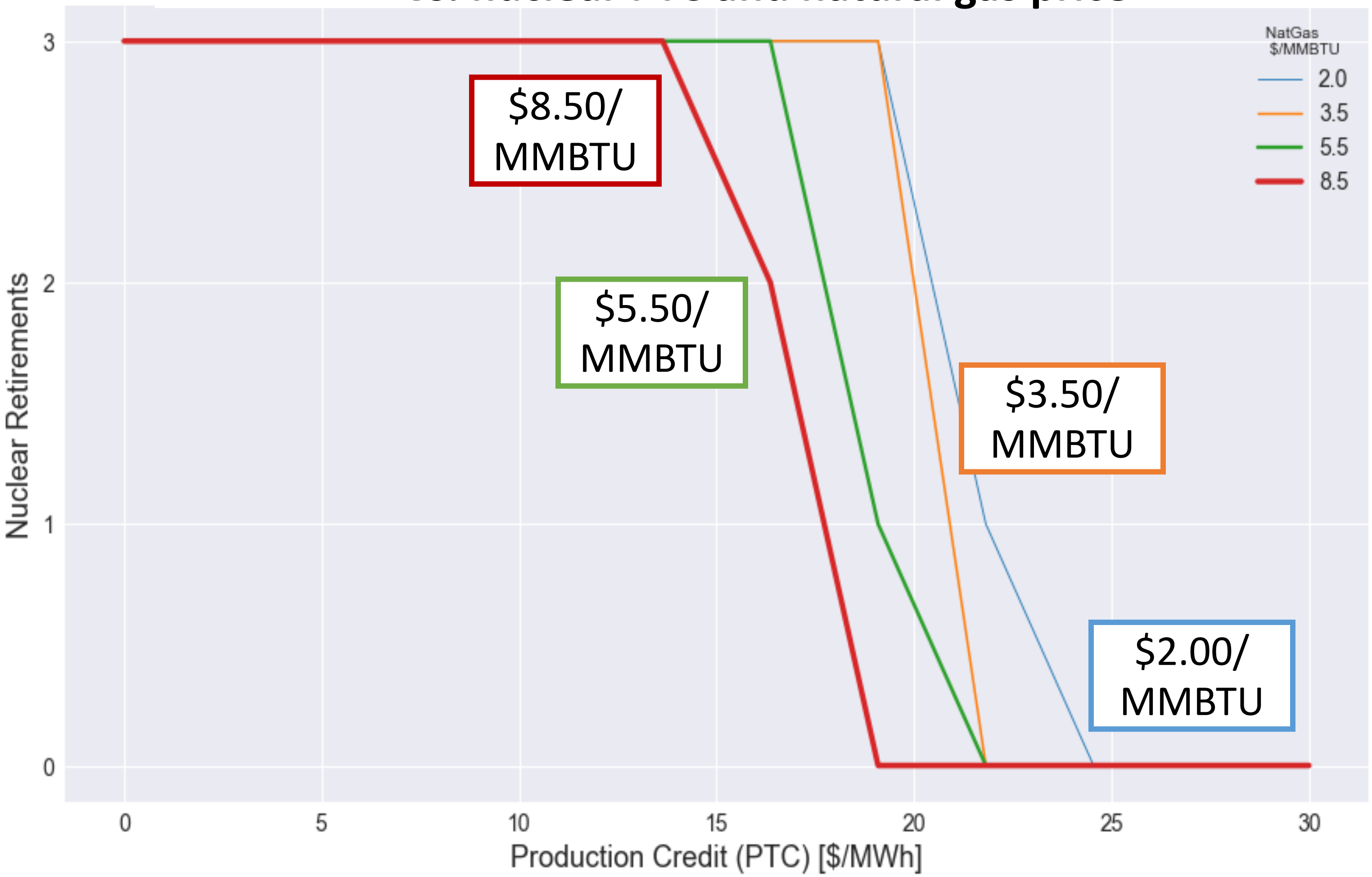
Example results and next steps

ABCE: parametric study results example

Premature nuclear retirements in IL vs. nuclear PTC and natural gas price



- Parametric study: premature retirements of existing nuclear asset in the state of IL
- Variables:
  - Natural gas price: $2 - $8.50 / MMBTU
  - Nuclear PTC: $0 - $30 / MWh
- PTC efficacy varies depending on prevailing natural gas prices

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Next Steps

- Current work in progress:
  - HERON postprocessing for ABCE outputs
- Future years:
  - Develop ABCE coupling with multi-commodity dispatch codes
  - Multi-commodity optimization in ABCE agent decision algorithm
  - Utilize RAVEN synthetic data in ABCE agent decision algorithm

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Appendix

ABCE: example results: Coal to Nuclear Conversion

- Large, relatively liquid generation utility
- Owned sizeable, unprofitable coal fleet
- Replaced ~1200 MW of coal with 1000 MW SFR-type C2N projects
- "Revenue gap" between coal shutdowns and NPP startups handled by agent's surplus liquidity

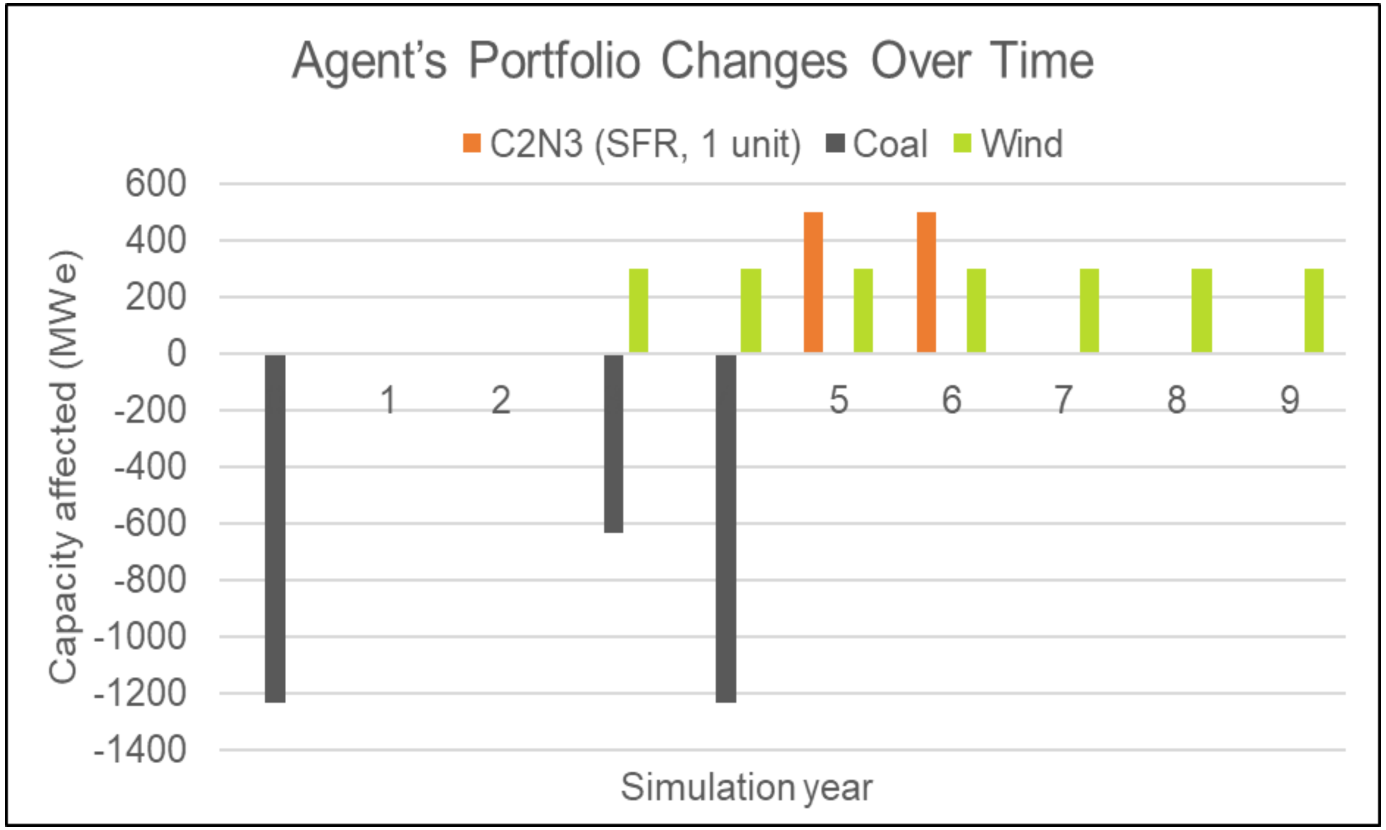

Figure adapted from Hansen et al., "Investigating Benefits and Challenges of Converting Retiring Coal Plants into Nuclear Plants", INL/RPT-22-67964, 2022.

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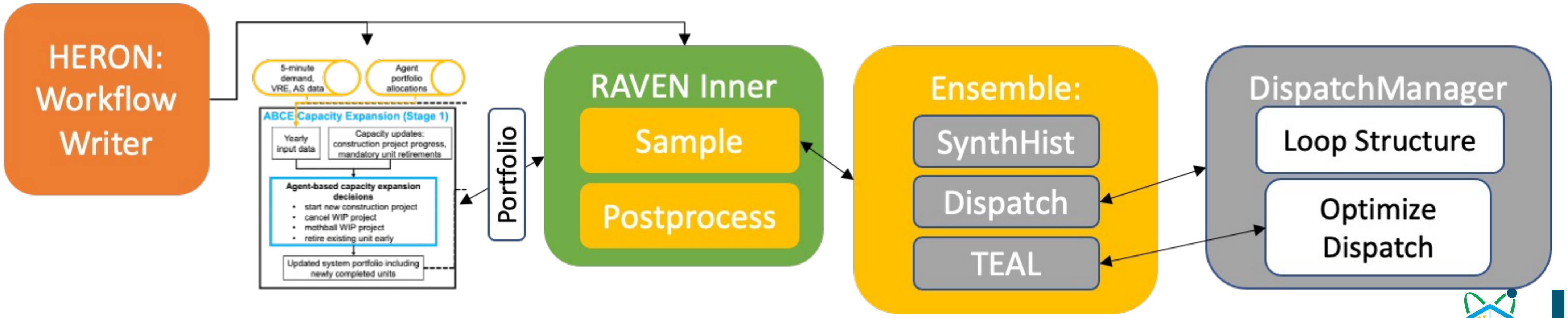

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