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Long-Term Energy Storage Planning for Reliability and Affordability

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ENERGY STORAGE DIVISION

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Project Overview

- **Project Goal**: Develop advanced storage planning to improve system reliability, affordability, and flexibility by addressing evolving system needs under uncertainty.
- **Current Practice**: Storage planning often relies on oversimplified models, treats storage with limited consideration of its interactions with transmission and generation, and represents uncertainties through a limited set of deterministic scenarios.
- **Why PNNL**: PNNL combines modeling expertise, real-world data, and industry partnerships to develop adaptable storage planning capabilities.
- **Innovation**: Advanced modeling framework for co-optimizing storage with transmission and generation across regions and timescales, incorporating uncertainty through stochastic planning, cost-recovery analysis, and high-resolution nodal modeling.
- **Duration**: FY25–FY26.
- **Impact**: Provides enhanced system-level storage modeling and planning to better address growing electricity demand, system complexity, and long-term uncertainties.
- **Vertical/Investment Area**: Analytics.
- **Alignment**: Supports OE priorities to stabilize grid operations through storage planning that addresses uncertain and extreme system conditions, optimize storage sizing, duration, and operation to minimize long-term system costs, and grow grid capacity through coordinated expansion planning of storage, generation, and transmission.

Project Team and Industry Partners

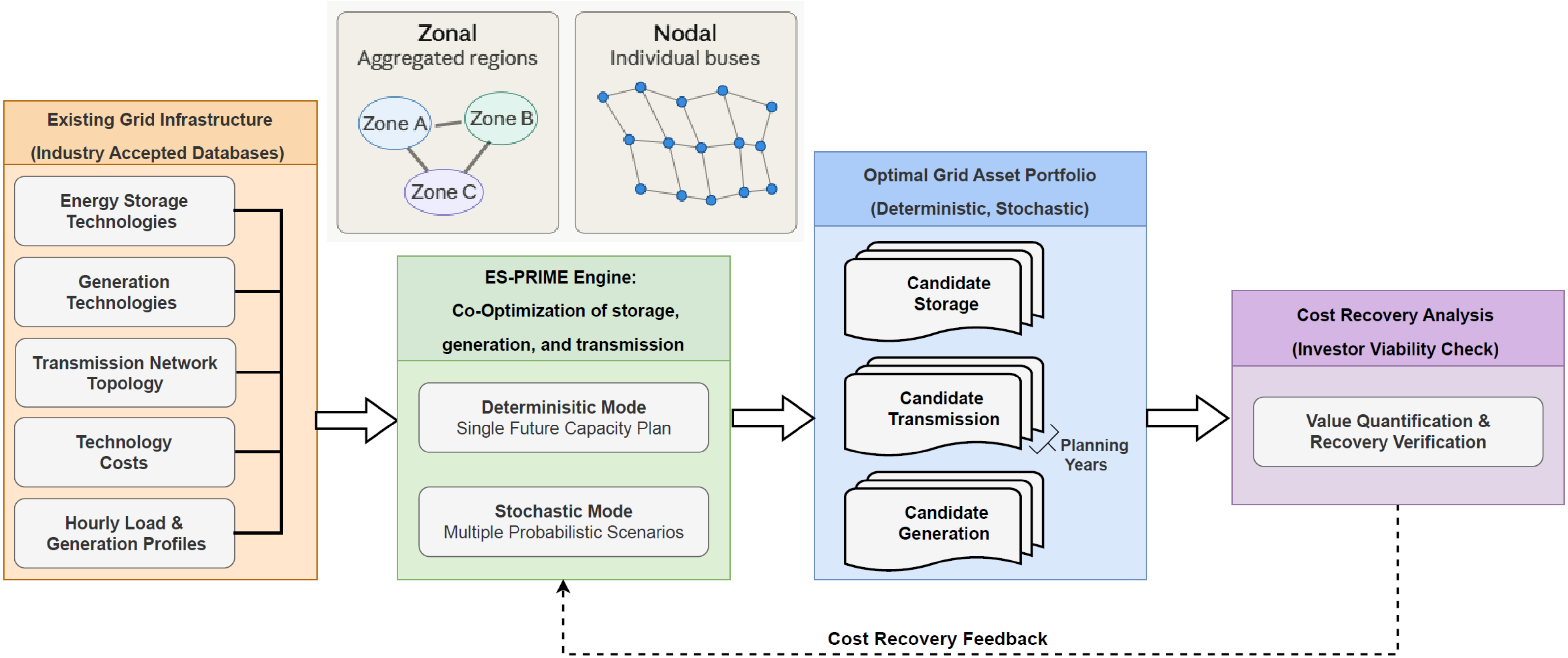
- Dr. Kostas Oikonomou, Electrical Engineer
- Dr. Di Wu, Electrical Engineer
- Dr. Patrick Maloney, Electrical Engineer
- Dr. Jesse T. Holzer, Mathematician
- Dr. Osten P. Anderson, Electrical Engineer
- Dr. Saptarshi Bhattacharya, Mechanical Engineer
- Dr. Jeremy B. Twitchell, Energy Analyst
- Dr. Meng Zhao, Electrical Engineer
- Dr. Wei Wang, Electrical Engineer
- Dr. Casey D. Burleyson, Earth Scientist
- Dr. Cameron W. Brecken, Earth Scientist

Objectives

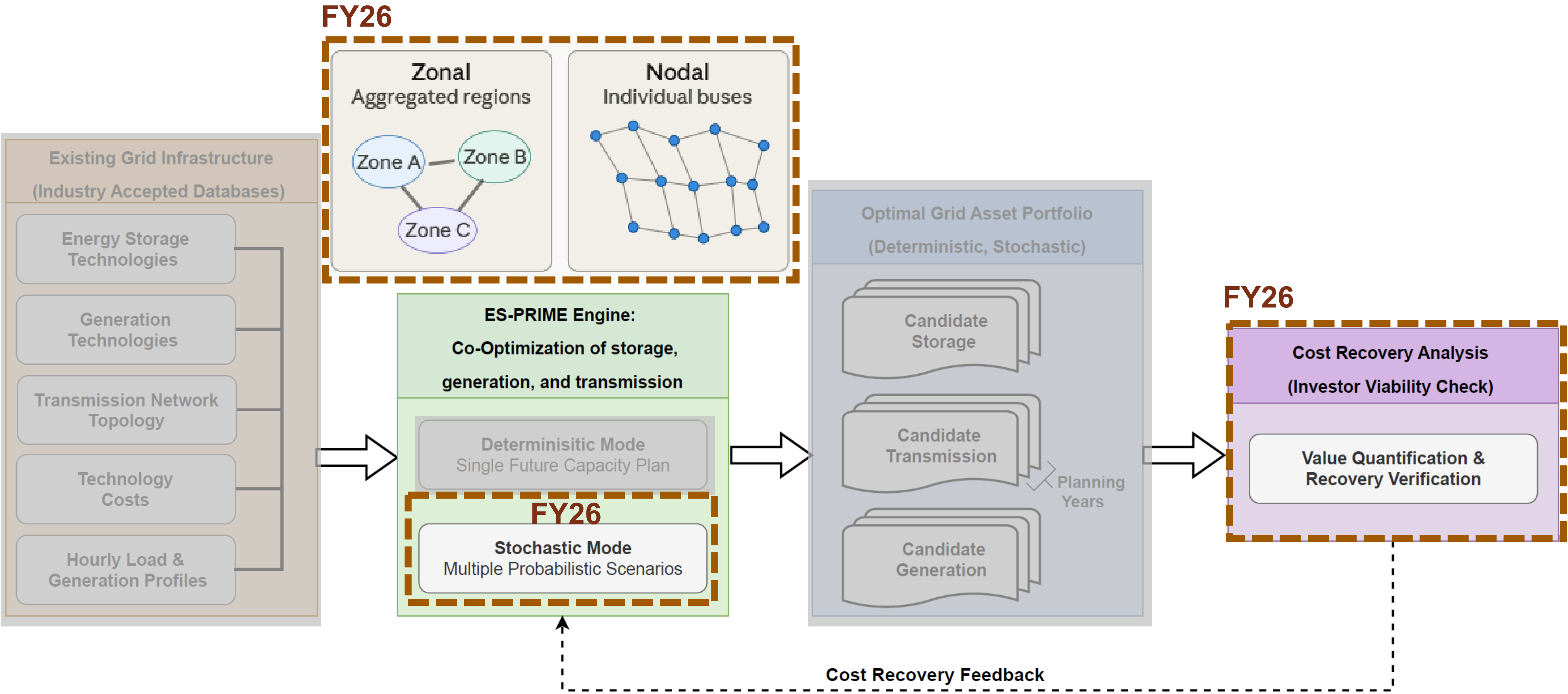
Develop advanced models, framework, tools, and benchmarks to:

- Represent storage technologies with sufficient fidelity while balancing computational complexity and accuracy to capture key techno-economic and physical characteristics
- Co-optimize storage, transmission, and generation planning by capturing key couplings, constraints, and trade-offs
- Assess storage’s role in meeting capacity, flexibility, and transmission needs while reducing costs and improving system reliability
- Analyze planning sensitivities to factors such as technology advancement, load growth, and evolving system needs
- Better capture uncertainties through scenario-based and stochastic methods to support robust long-term planning

Enhanced Storage Planning Framework



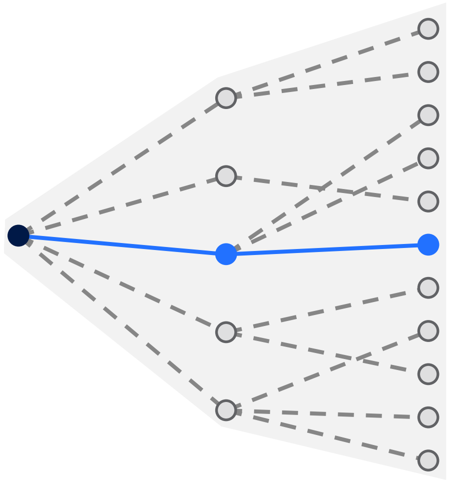
Enhanced Storage Expansion Planning Framework



Stochastic Capacity Expansion Planning

Deterministic

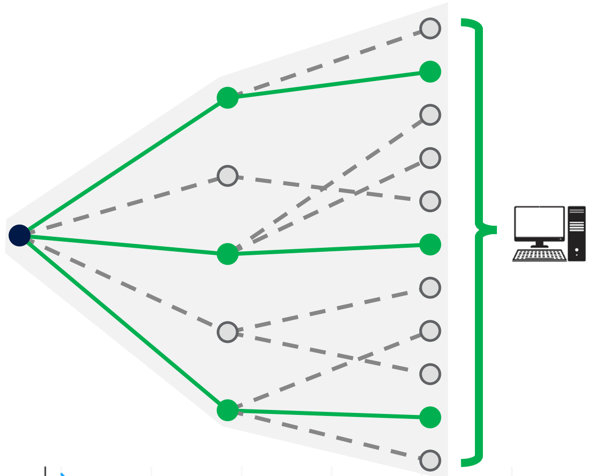
Uncertainties: single nominal scenario

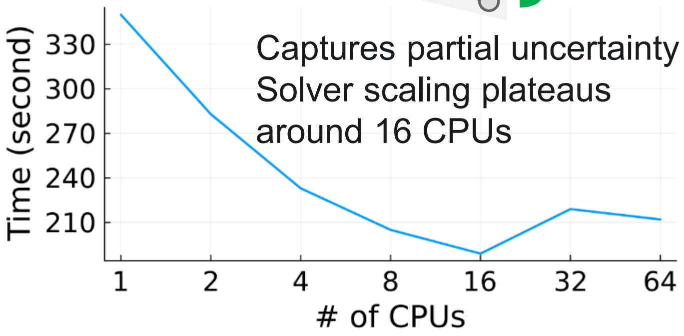


No uncertainty captured
No compute scaling needed

Stochastic with Scenario Reduction (FY25)

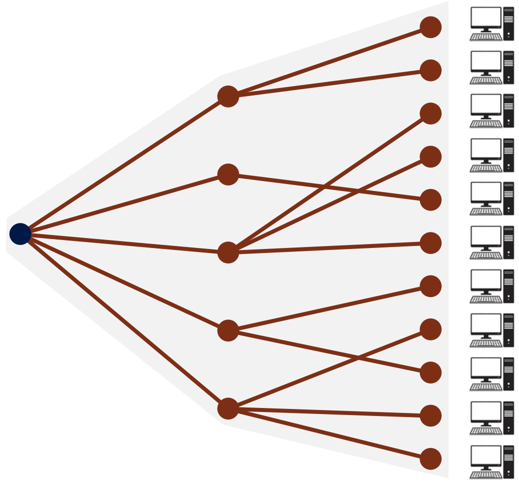
Uncertainties: a finite set of representative scenarios





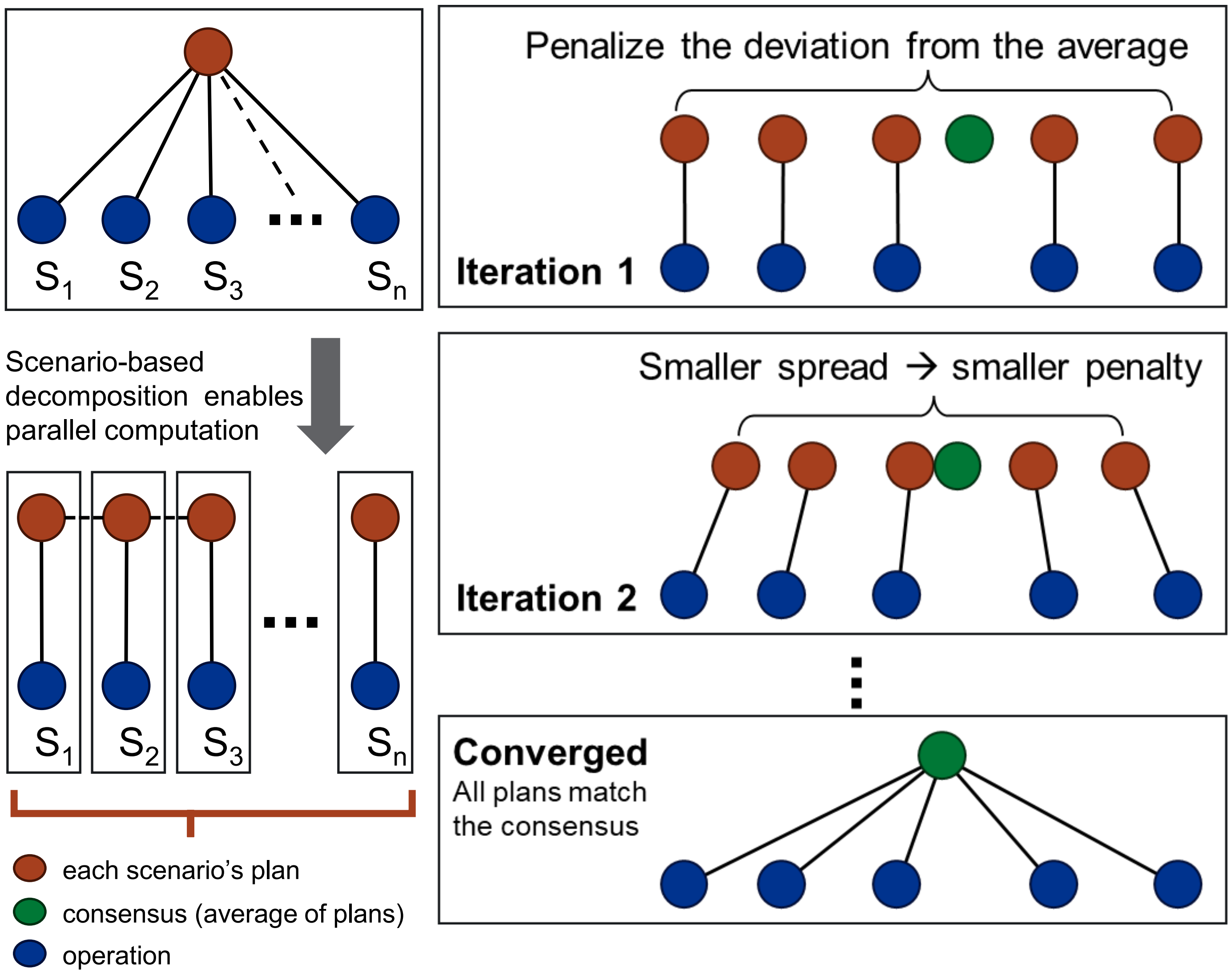
Stochastic with Progressive Hedging (FY26)

Uncertainties: full scenario set

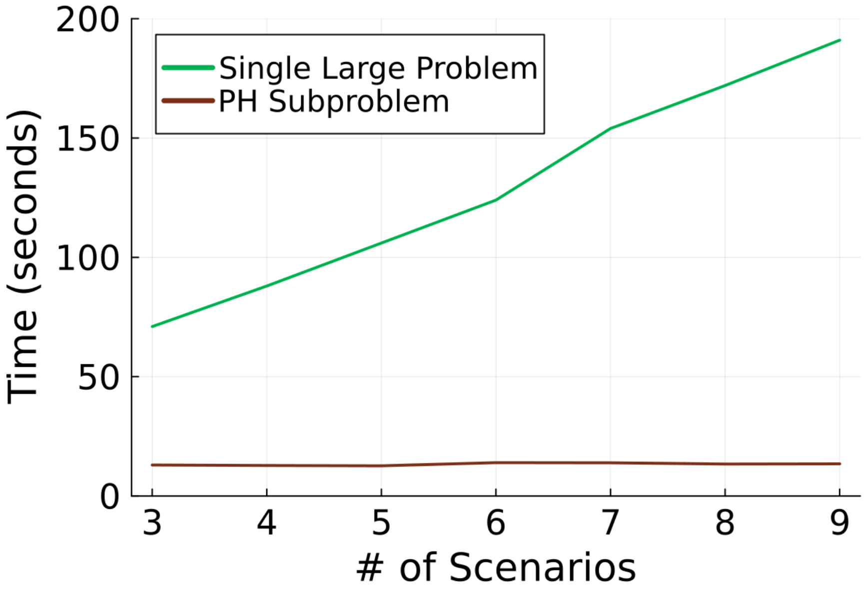


Captures full uncertainty
Scales with available HPC cores

Progressive Hedging Algorithm



- PH decomposition unlocks parallel HPC; runtime no longer scales with the number of scenarios.
  - Single problem → +150% runtime (3 to 6 scenarios)
  - PH → essentially constant



Energy Storage Cost Recovery

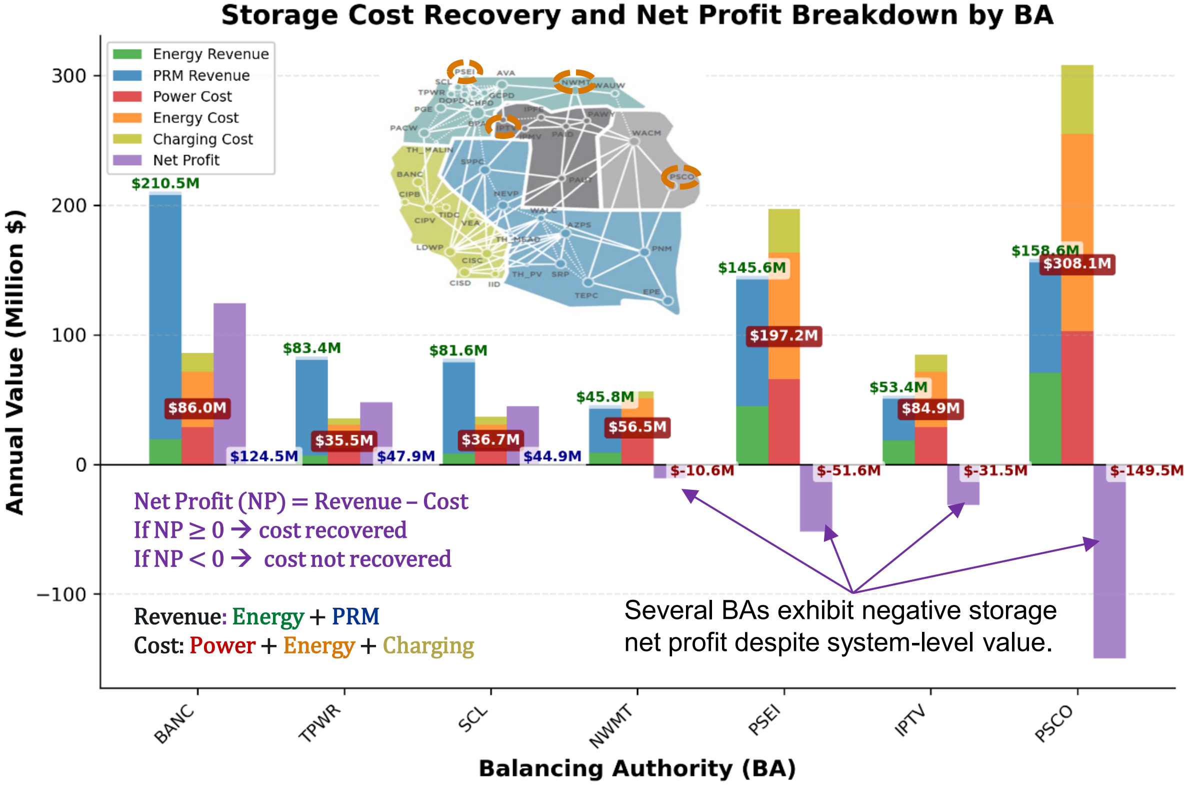
Motivation:

- System-level planning focuses on global cost minimization
- Investor viability is not considered
- Practical deployment requires aligning system benefits with investor returns

Objective:

- Enhance the storage planning to incorporate cost-recovery modules to capture investor viability considerations

Example of BAs with Non-recovered Costs: NWMT, PSEI, IPTV, PSCO



Marginal-Contribution-Based Cost Recovery

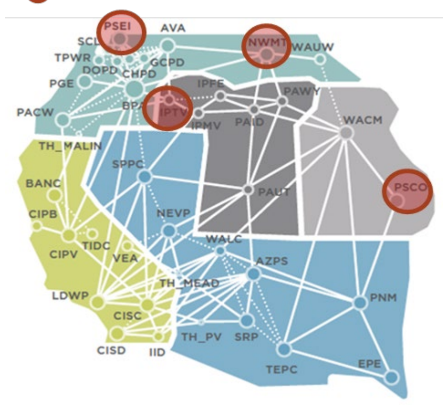
- Each storage system earns a subsidy proportional to its contribution to system savings.

Step 1

Run baseline plan and identify non-recovered energy storage (NRES).

→ Baseline system cost

Non-recovered BAs

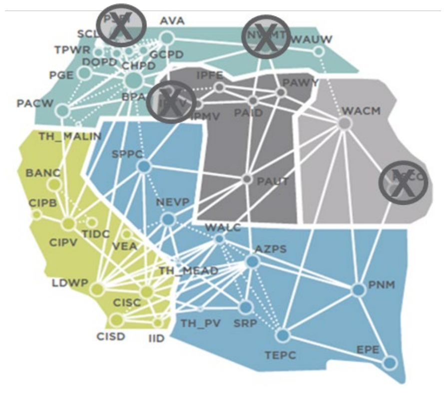


Step 2

Remove all NRES from the system, re-run the plan, and compare system cost (CAPEX + OPEX) vs Step 1.

→ Total value of all NRES

All removed

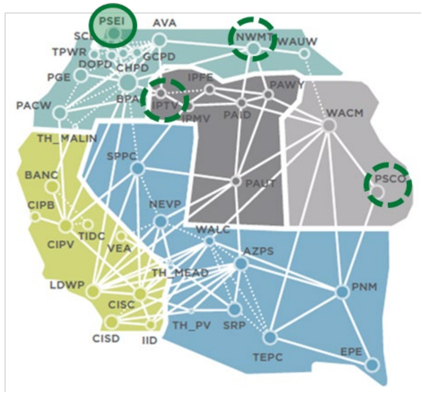


Step 3

Re-run with each NRES excluded one at a time; measure each one's contribution to total system savings.

→ Contribution share per NRES

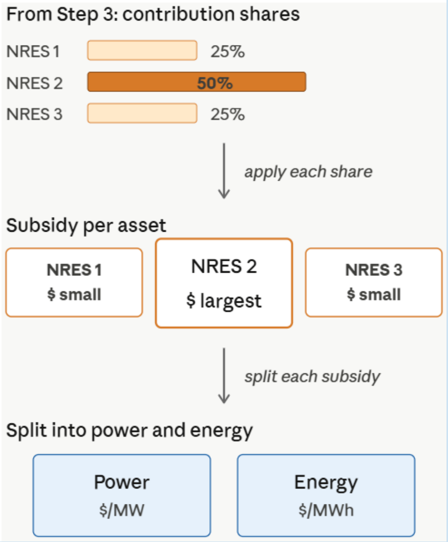
Exclude each at one time



Step 4

Compute each NRES's subsidy from its share of total savings, then split it into power and energy components.

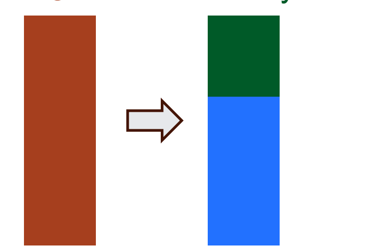
→ Subsidy per NRES



Step 5

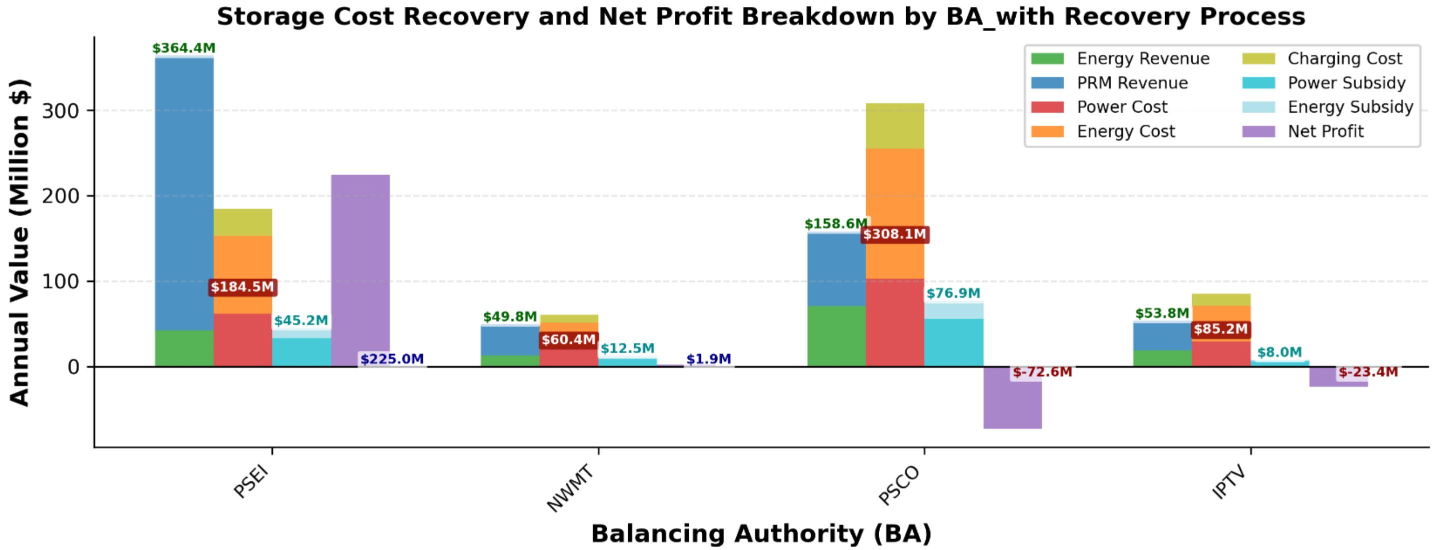
Subtract subsidies from CAPEX, re-run capacity expansion plan, and check recovery. If gaps remain, iterate from Step 1.

→ Revised CAPEX



Iterate until all assets recover their costs

Preliminary Evaluation of the Cost Recovery



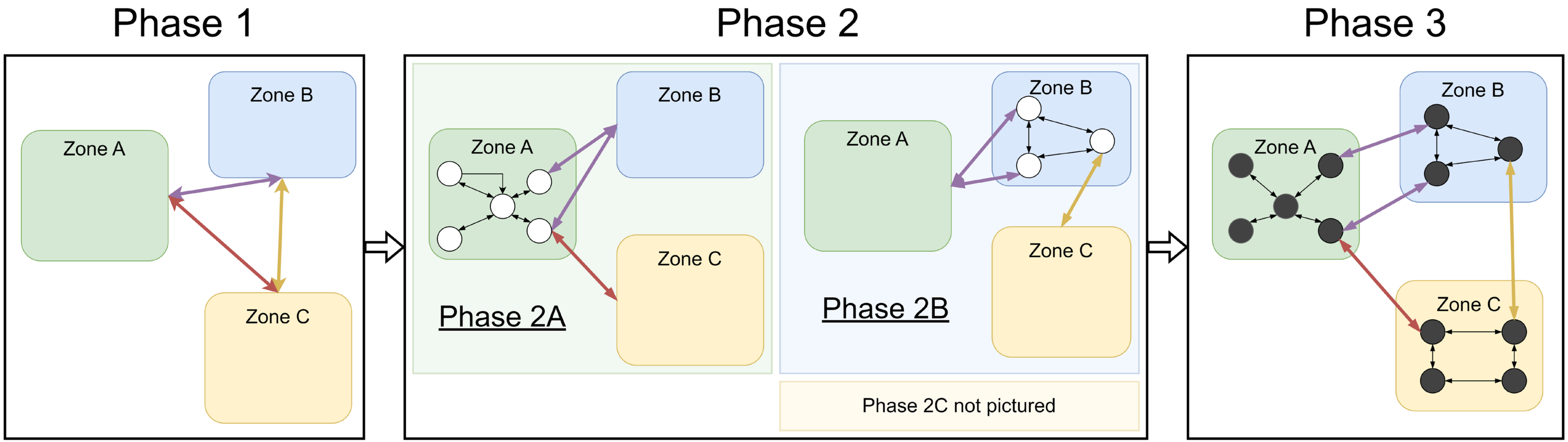
BA	Net Profit M$ (Without Recovery Process)	Net Profit M$ (With Recovery Process)	Status
PSEI	−$51.6M	+$225.0M	✓ Recovered
NWMT	−$10.6M	+$1.9M	✓ Recovered
PSCO	−$149.5M	−$72.6M	51% gap closed
IPTV	−$31.5M	−$23.4M	26% gap closed

Key Takeaways

- ✓ **Two of four BAs fully recovered:**
  - ✓ PSEI and NWMT achieve profitability after 4 iterations.
  - ✓ PSEI's large gain comes from both the direct subsidy and a ~3.5× jump in PRM revenue due to re-optimized prices.
- ✓ **Methodology refinement underway:**
  - ✓ Future runs will fix capacity and prices (LMP, PRM) to baseline values during subsidy application — isolating the pure cost-recovery effect from re-optimization side effects.

Nodal Storage Capacity Expansion Planning

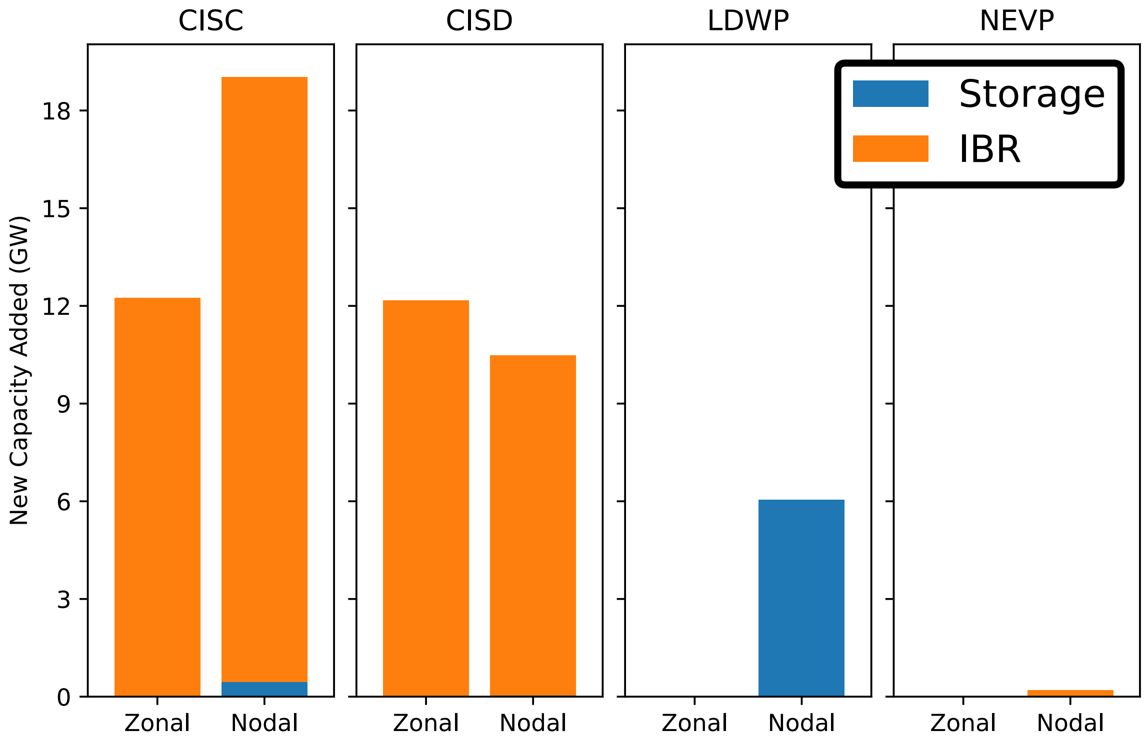
- Nodal CEP captures intra-zone congestion, siting constraints, and other site-specific factors hidden by zonal aggregation, leading to more accurate storage planning decisions.
- Three-phase decomposition that leverages HPC parallelization.
  - **Phase 1**: Solve zonal CEP.
  - **Phase 2**: Solve a nodal model per zone in parallel on HPC (flows fixed from Phase 1).
  - **Phase 3**: Reconcile flows across zones (injections fixed from Phase 2).



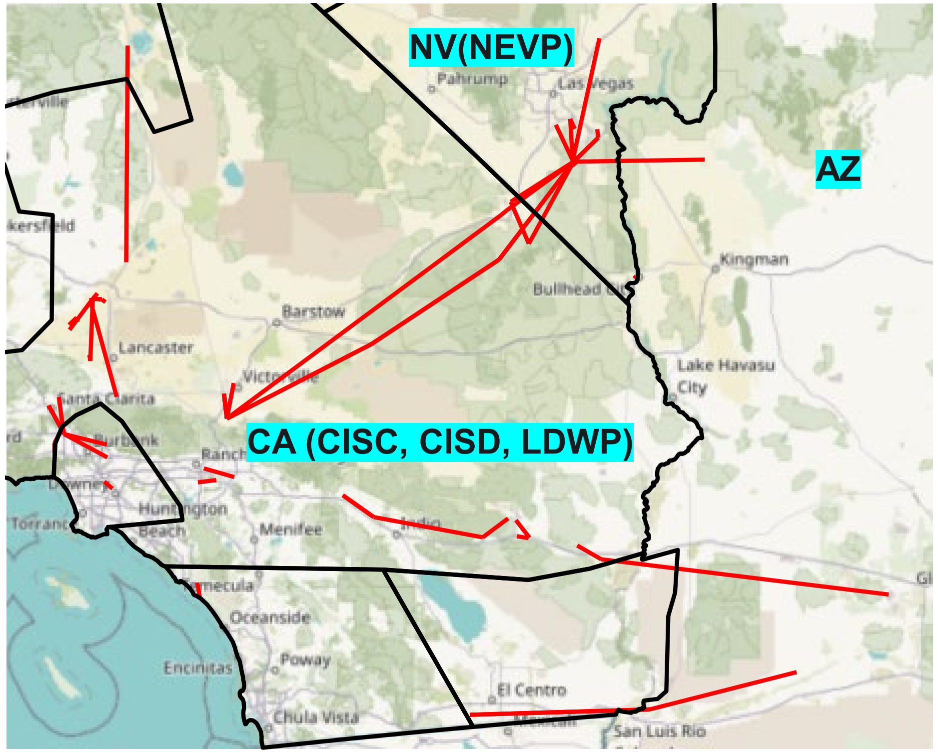
Preliminary Nodal CEP Results: Example from the Southwest (CA, NV, AZ)

- Nodal planning drives different storage, transmission, and generation investments, due to local transmission congestion.

Nodal vs. Zonal Investment Decisions



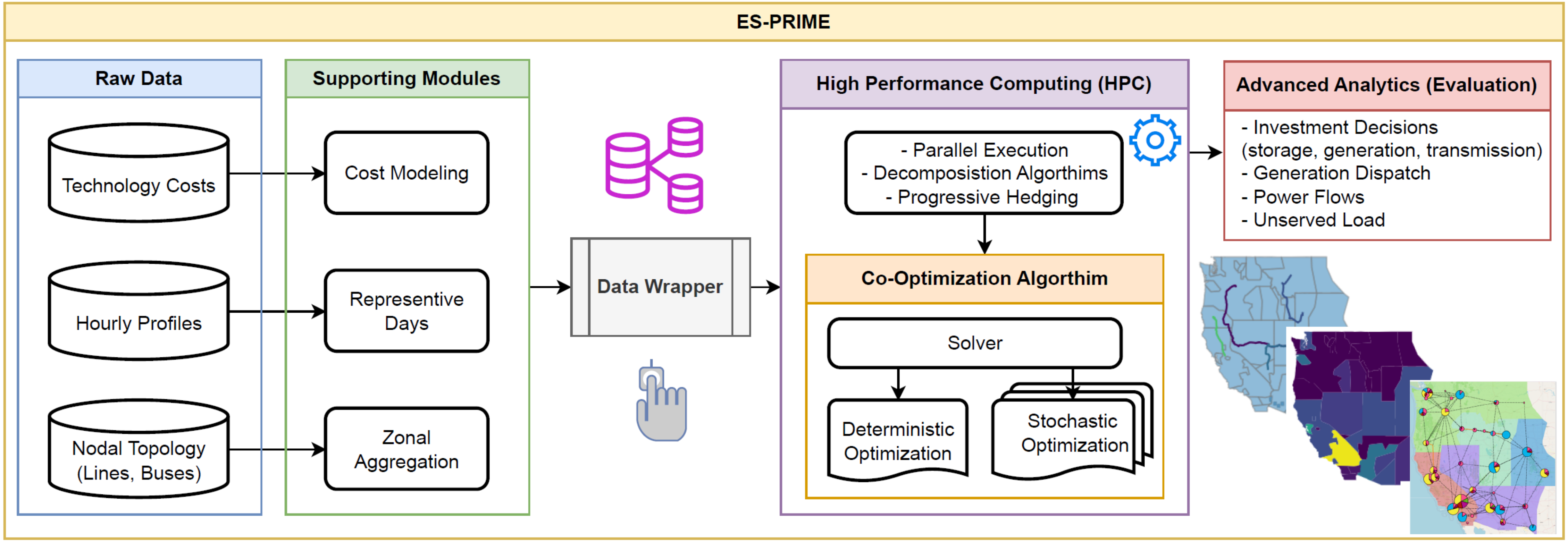
Nodal Line Reconductoring Decisions



*IBR: Inverter Based Resources

Energy Storage Planning, Resource Integration, Modeling, and Expansion (ES-PRIME)

- ES-PRIME: A modeling platform focused on energy storage planning and its co-optimization with generation and transmission investments. It supports automated data integration, high-performance computing, and advanced analytics.



Look Forward

- Complete the energy storage cost recovery workflow and apply it across the Western Interconnection grid.
- Complete nodal CEP modeling framework and apply it across all substations in the Western Interconnection.
- Scale progressive hedging to handle large numbers of uncertainties.
- Refine load modeling to reflect emerging loads, including AI data centers.
- Expand planning analysis to other interconnections to evaluate how storage roles and value vary geographically.
- Continue developing the ES-PRIME platform — user interface, automated data integration, high-performance computing, and advanced analytics.

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Acknowledgment

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https://www.energy.gov/oe/energy-storage