NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Modeling Market Interactions

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Why model wholesale electricity markets?

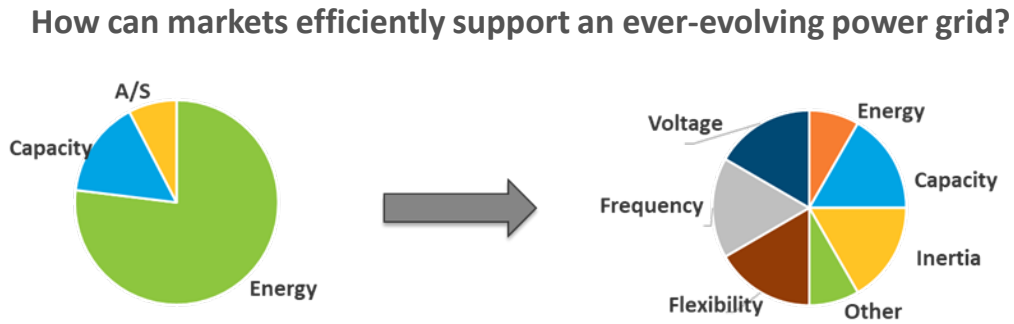
- Markets cover a large portion of the U.S. grid (2/3 of load), as well as many other areas in the world

- Markets (and any associated out-of-market transactions) determine incentives for investment decisions and operational outcomes
  - Current rapid pace of investment in low- or zero-marginal-cost technologies increases the importance of understanding market structure impacts on investment and resource adequacy
  - Uncertainty of future market structure and power system evolution further stress the need to understand market-investment dynamics

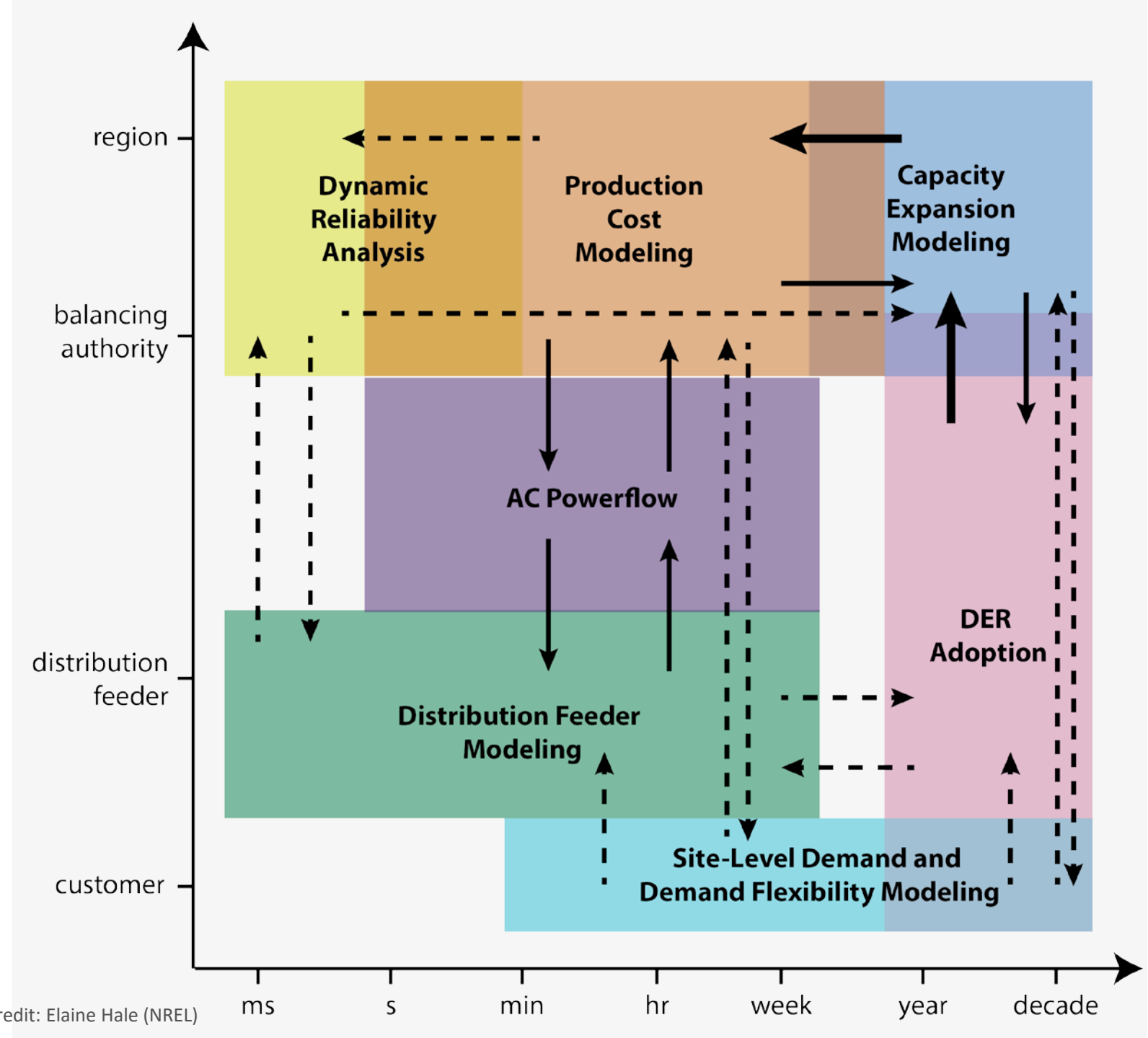
- Current leading models do not sufficiently capture the impacts of market structure on both investment and operation outcomes
  - For example, traditional linear programming capacity expansion models (CEMs) assume central planner minimizing system cost and inherently guarantee cost recovery

What is NREL doing about this?

- Develop a capacity expansion model for evaluating the impact of market design and investor heterogeneity on investment decisions and reliability: ***Electricity Markets and Investment Suite (EMIS)***
  - Represent individual investor firms with heterogenous beliefs about the future and risk representations
  - Explore how different market designs perform under uncertainty and imperfect information
  - Allow non-optimal investment (i.e., over- or under-investment) by firms with imperfect information
  - Leverage and integrate with the Scalable Integrated Infrastructure Planning (SIIP) modeling framework that include NREL's next generation of *integrated* modeling tools

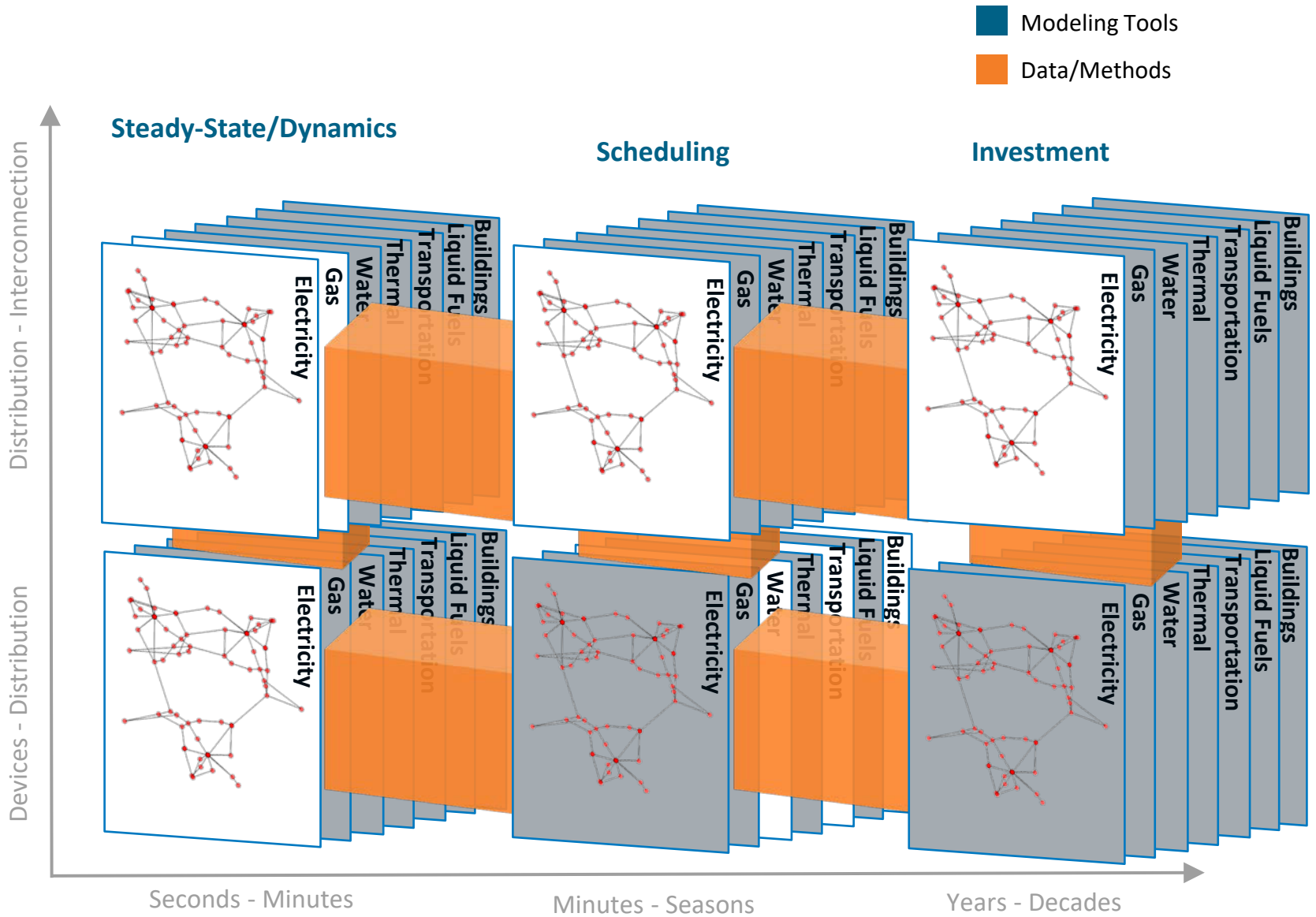


How does this fit into NREL's existing power system modeling capabilities?



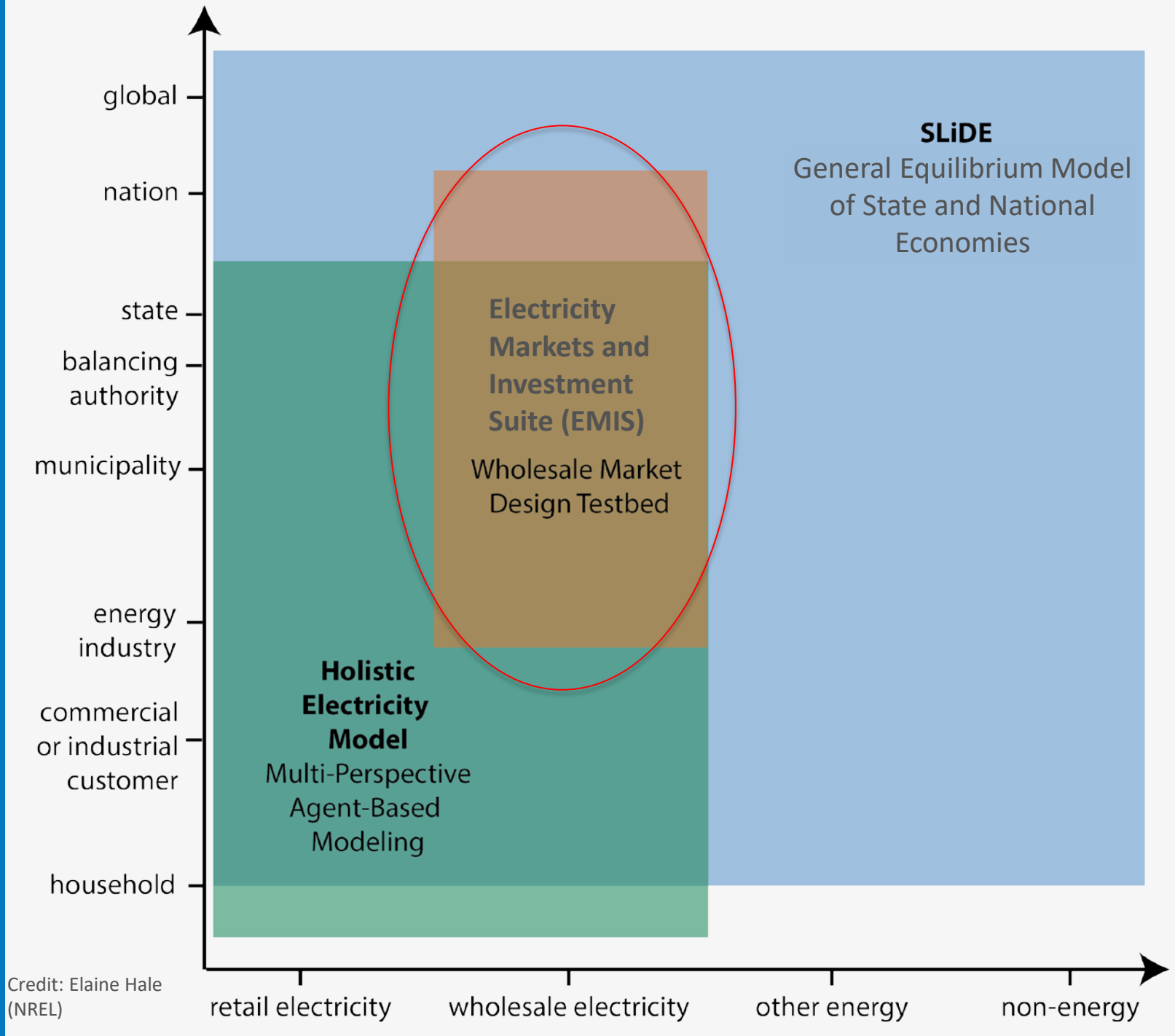
Credit: Elaine Hale (NREL)

Co-Modeling: Scalable Integrated Infrastructure Planning (SIIP) modeling framework



Credit:
Doug Arent (NREL)

Emerging Economic Modeling Capabilities within SIIP



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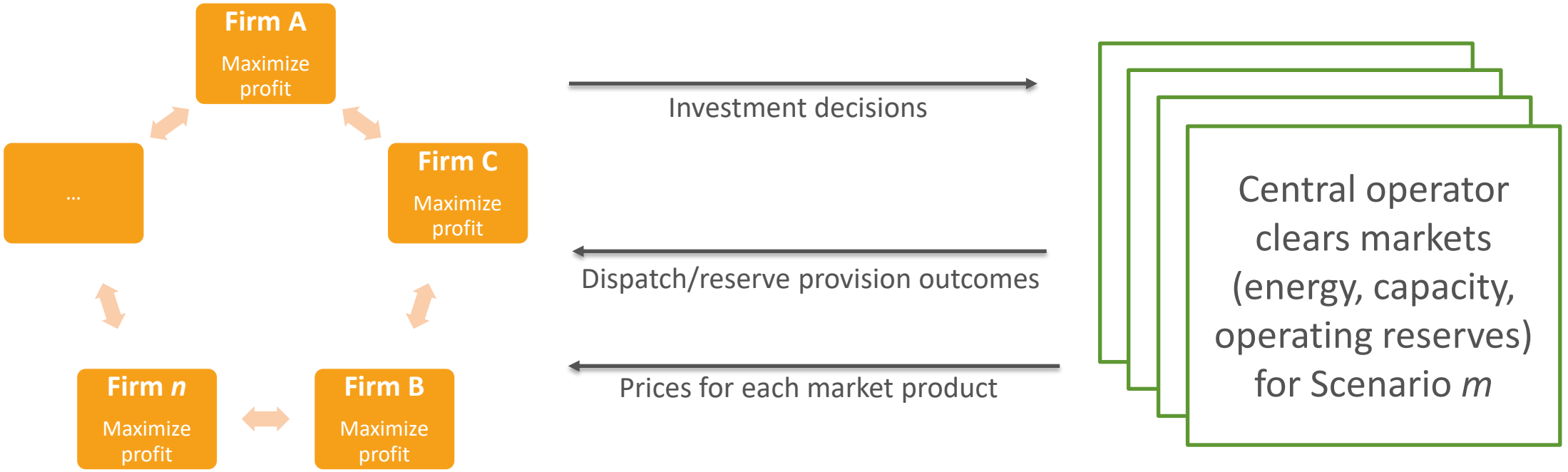
EMIS Vision:

Multiple firms, technologies, products/timescales, project build phases, and economic/policy scenarios



We currently do not have one model structure that can incorporate all these features, hence the need for a suite of tools

Model Versions: 3 Tracks ("Tools")

1. **Idealized Competitive Equilibrium**
2. **Agent-Based Simulation**
3. **Approximate Strategic Equilibrium**

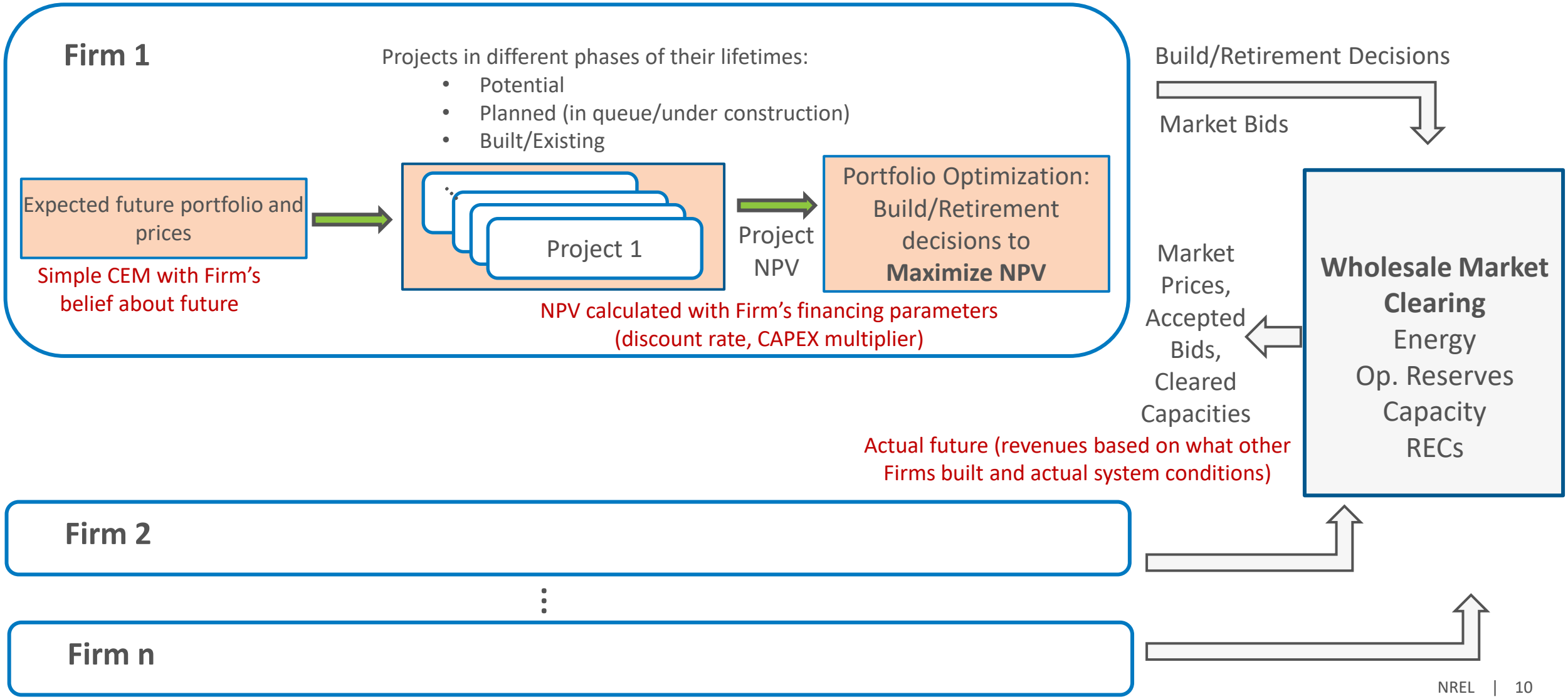
These tools cover the "spectrum" of market and behavior dynamics, with perfect competition on one end and imperfect competition (strategic behavior) on the other. We cannot have an exact strategic equilibrium, so our Approximate Strategic Equilibrium and Agent-Based Simulation tools are a means to approximate the desired heterogenous firm interactions.

Model formulation #1: Idealized Competitive Equilibrium

	Traditional Least-Cost Planning Model	Market Equilibrium Model under Perfect Competition
Objective function	Cost minimization	Social welfare maximization*
Constraints	• Unit- and system-level physical constraints • Any other desired outcomes	• Investor-level constraints • Market rules and supply-demand balance
Decision interpretation	Central planner's least-cost solution	Efficient market outcome given the available price signals

*Reduces to cost minimization under inelastic demand conditions

Model formulation #2: Agent-Based Simulation



Model formulation #3: Approximate Strategic Equilibrium

- We are using a surrogate model approach to approximate the theoretically-optimal strategic behavior of an exact strategic equilibrium problem
- Main steps
  1. Simulate the market clearing for many system buildouts
  2. Use machine learning techniques to derive a set of "surrogate" functions that link investment decisions with the resulting profit
  3. Solve resulting full problem iteratively, optimizing each firm's surrogate sub-problem

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Thank You

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