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Modeling the evolution of transforming power system: methods and tools

Presentation for the DOE Electricity Advisory Committee (EAC)

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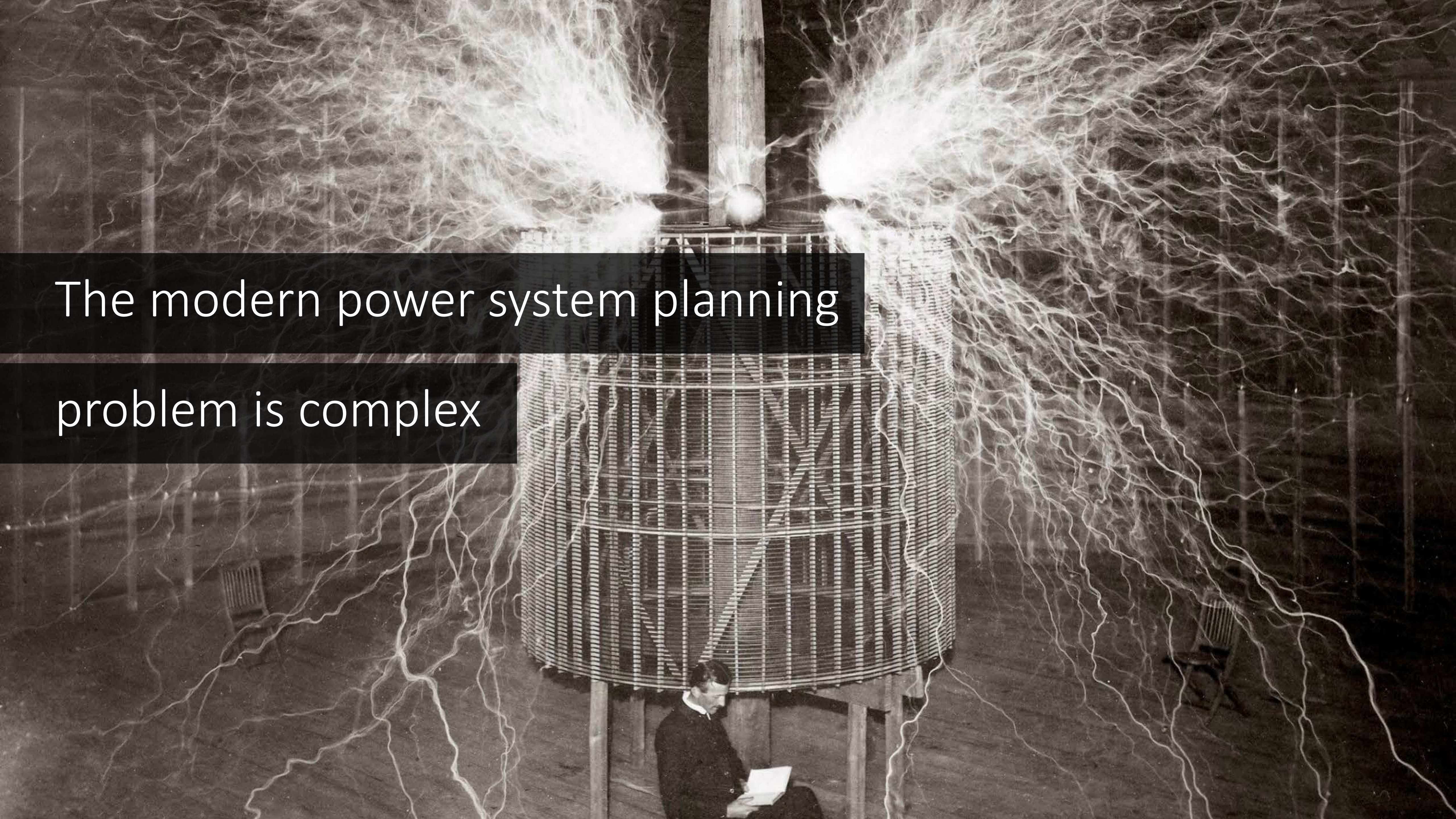
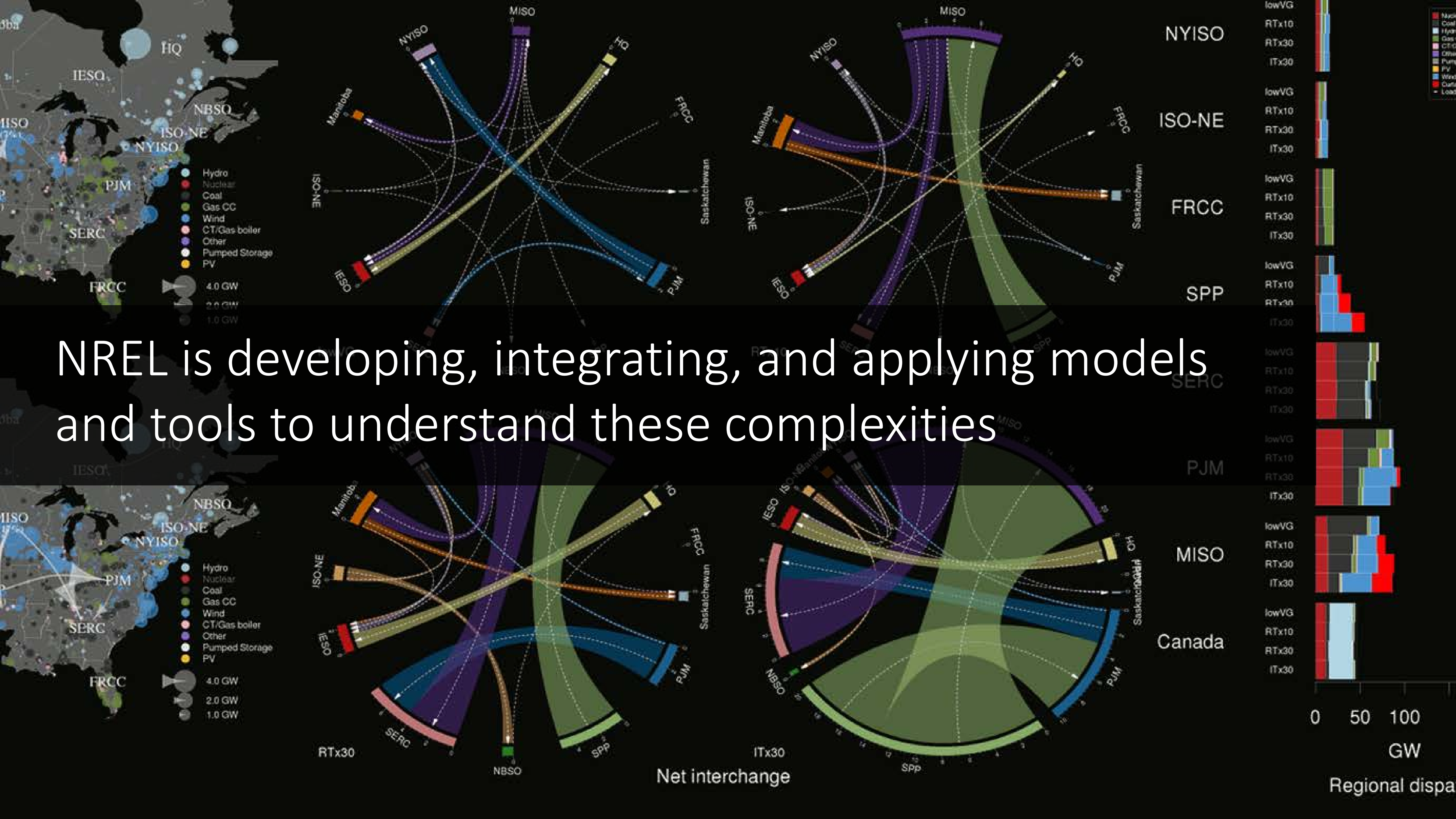
Key Power System Trends

1. Increasing shares of variable renewable energy (VRE) and storage, and lower levels of synchronous generation capacity:
    - Improvements in the costs and performance of VRE and storage technologies, and
    - State, city, local, and corporate targets for clean energy could result in high penetrations of variable renewable energy generation
2. Expanding electricity markets and evolving market structures
    - Energy Only; Energy + Capacity; Energy + Capacity + Ancillary Services
3. Increasing customer adoption of distributed generation and storage, and self provision of energy by large customers
4. Evolving electricity demand due to electrification, efficiency improvements, and developing communication techs; increased demand-side participation in markets and non-market regions
5. Growing risks of system damage from severe weather and fires, as well as physical and cyber-security threats

The modern power system planning problem is complex

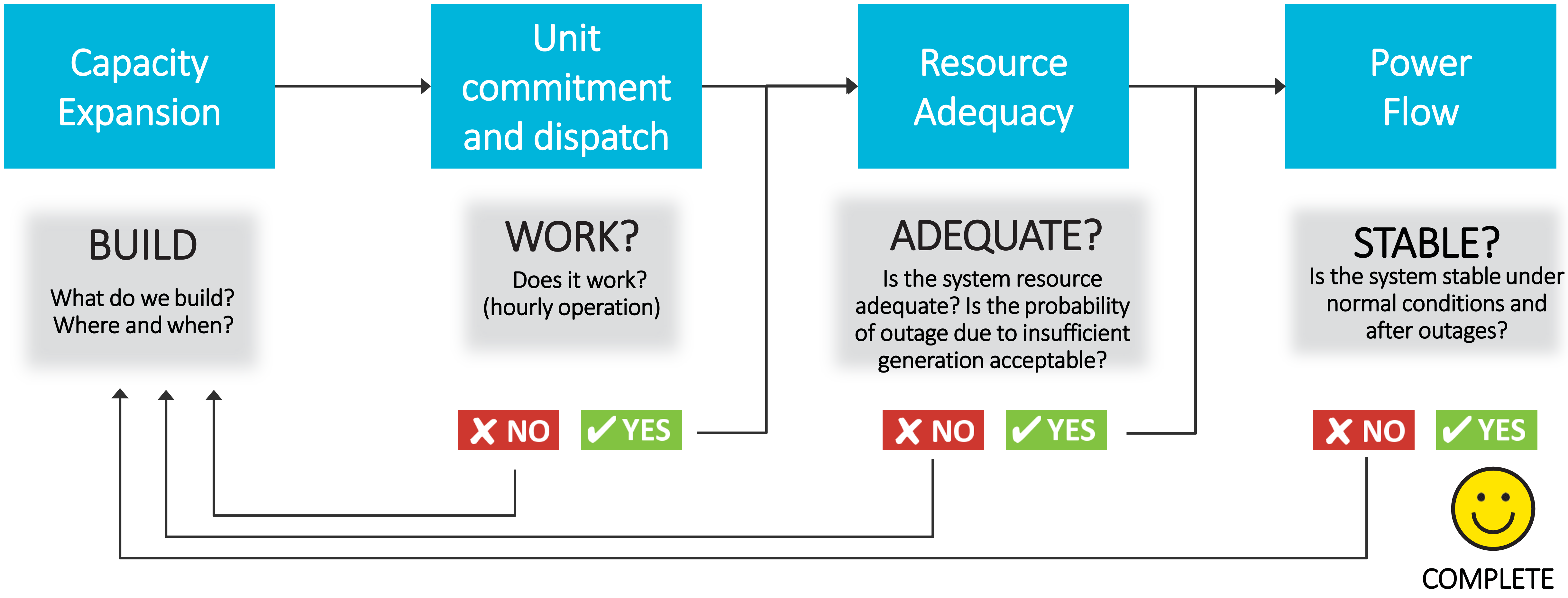


NREL is developing, integrating, and applying models and tools to understand these complexities



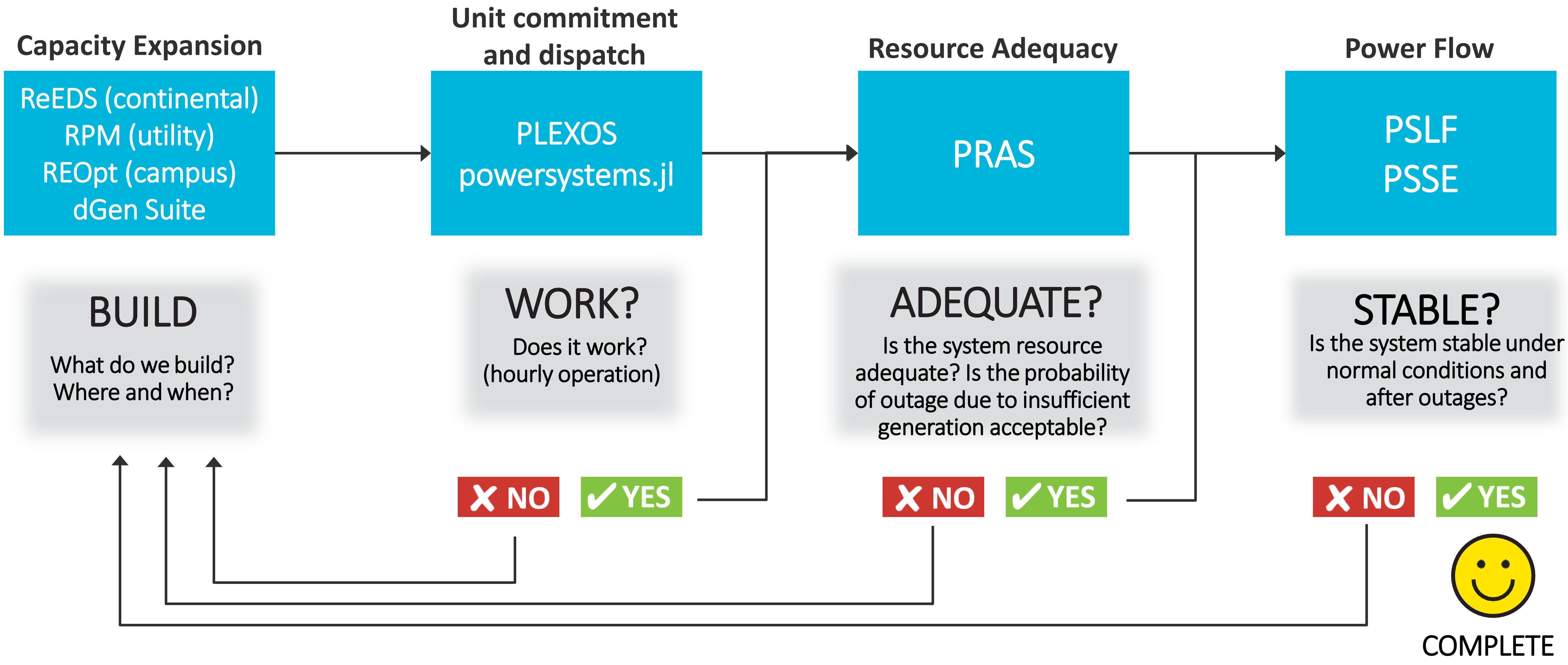
Current state of the art: integrated and coordinated workflow between models

Identifying and evaluating pathways to a high VRE systems requires a robust and integrated set of modeling tools



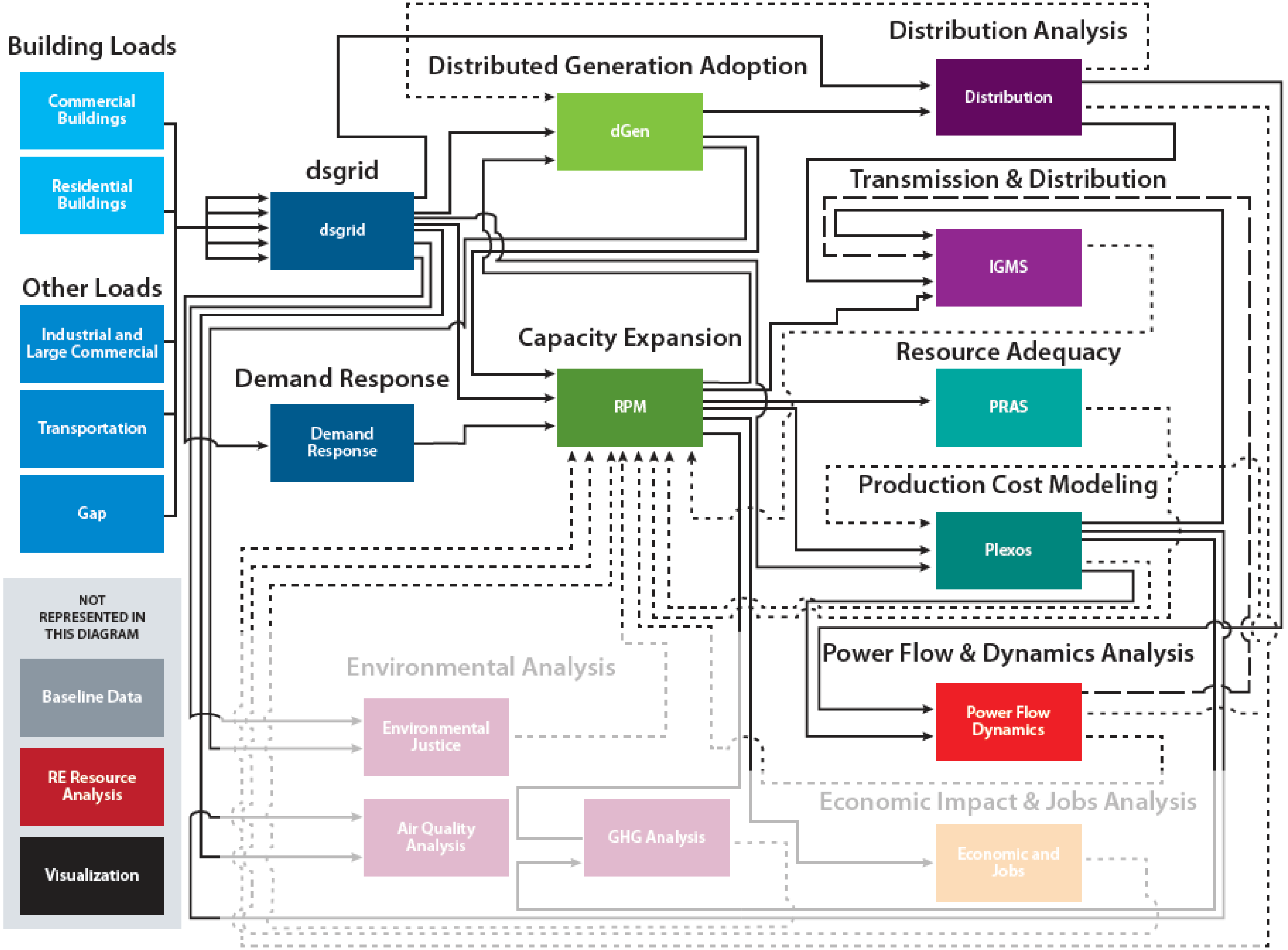
Integrating multiple best-in-class (independently developed) power system models to identify and evaluate potential pathways that ensure reliability and achieve all policy objectives

Modeling flow at NREL



Integrating multiple best-in-class (independently developed) power system models to identify and evaluate potential pathways that ensure reliability and achieve all policy objectives

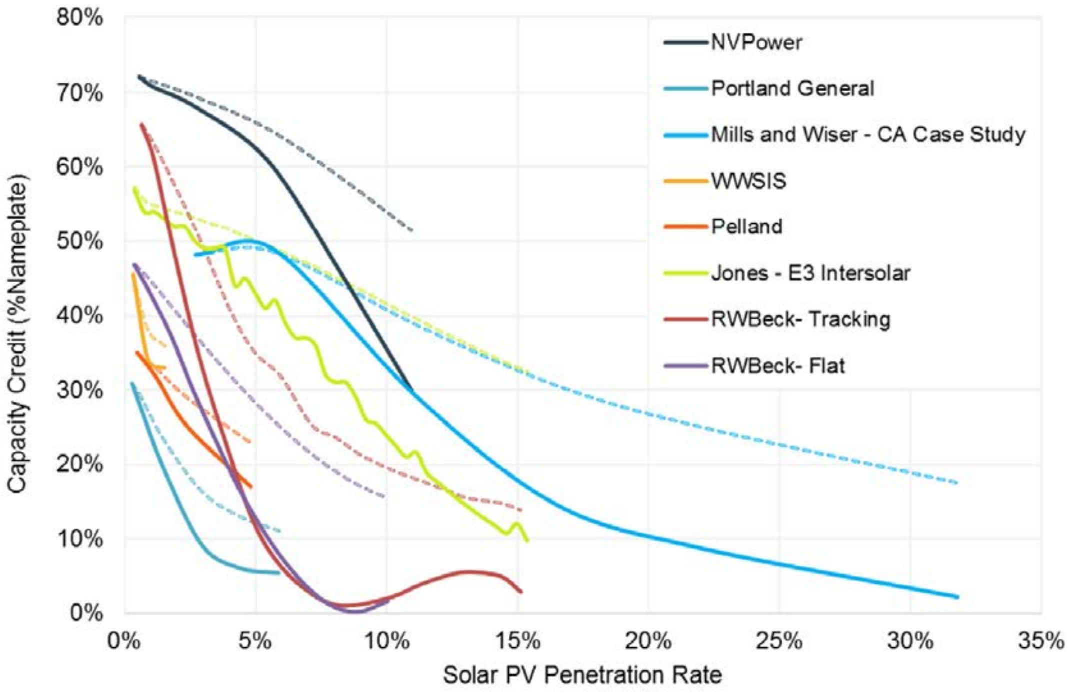
Endogenously incorporating load and distribution system expansion and operations becomes more complex



Models must be robust to evolving systems

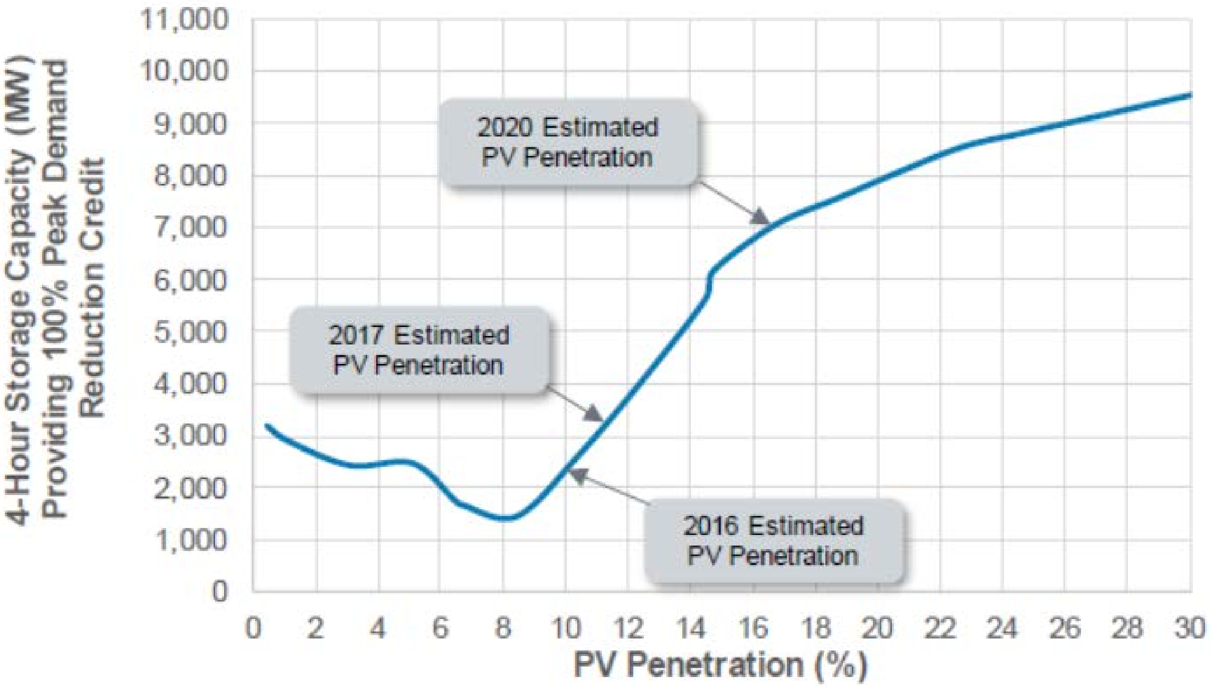
e.g, within capacity expansion models, it is crucial to account for the endogeneity of the capacity credit of VRE and storage technologies with system composition and load

Solar Photovoltaics



*Dashed lines are average (fleet-wide) capacity credit while solid lines are marginal capacity credit.

Battery Storage (4-hr duration)



Sources: Mills and Wiser (2012) and Denholm and Margolis (2018)

Selected NREL Renewable Integration Studies

Title	Year of pub	~Max VRE Penetration Achieved	Modeling included
Wester Wind and Solar Integration Study (WWSIS)	2010	35% VRE	Production cost (GE-MAPS) – 5 min
WWSIS – Phases 2 and 3	2013, 2014	33% VRE - annual 60% Total RE – annual 65% VRE – instantaneous	Capacity Expansion (ReEDS) Production Cost (PLEXOS) – 5 min AC Power flow/Stability (PSLF)
Renewable Electricity Future (REF) Study	2012-2014	50% VRE – annual 85% Total RE – Annual	Capacity Expansion (ReEDS) Production Cost (GridView) - Hrly
REF: Operational analysis of the WI Interconnection at Very High Renewable Penetrations	2015	45% VRE – annual 85% Total RE – annual	Production Cost (PLEXOS) – 5 min
Eastern Renewable Generation Integration Study (ERGIS)	2016	30% VRE – annual 60% VRE – instantaneous	Capacity Expansion (ReEDS) Production Cost (PLEXOS) – 5 min
Low Carbon Grid Study: Analysis of a 50% Emission Reduction in CA	2016	44% VRE – annual 56% Total RE – annual	Production Cost (PLEXOS) – 5 min
REF: Operational Analysis of the EI at Very High Renewable Penetrations	2018	73% VRE – annual 90% VRE - instantaneous	Capacity Expansion (ReEDS) Production Cost (PLEXOS) – 5 min
North American Renewable Integration Study	Ongoing	---------	Capacity Expansion (ReEDS) Production Cost (PLEXOS) – 5 min
Los Angeles 100% Renewable Energy Study	Ongoing	---------	Capacity Expansion (ReEDS) Production Cost (PLEXOS) – subhourly Probablistic Resource Adequacy (PRAS) AC Power Flow/Stability (PSLF)

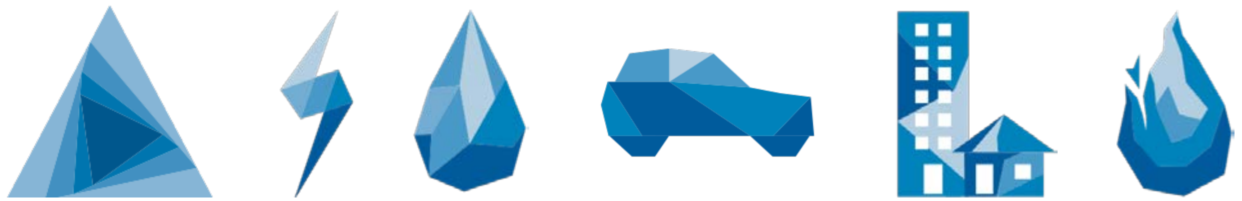
Methods: Where we are going

An integrated modeling framework:

Integrating independently developed models is cumbersome and has both analytical and computational limits;

An integrated and harmonized modeling framework would enable formulations that more fundamentally capture linkages and feedbacks (at multiple time-scales), as well as computational advantages

An Integrated Modeling Vision

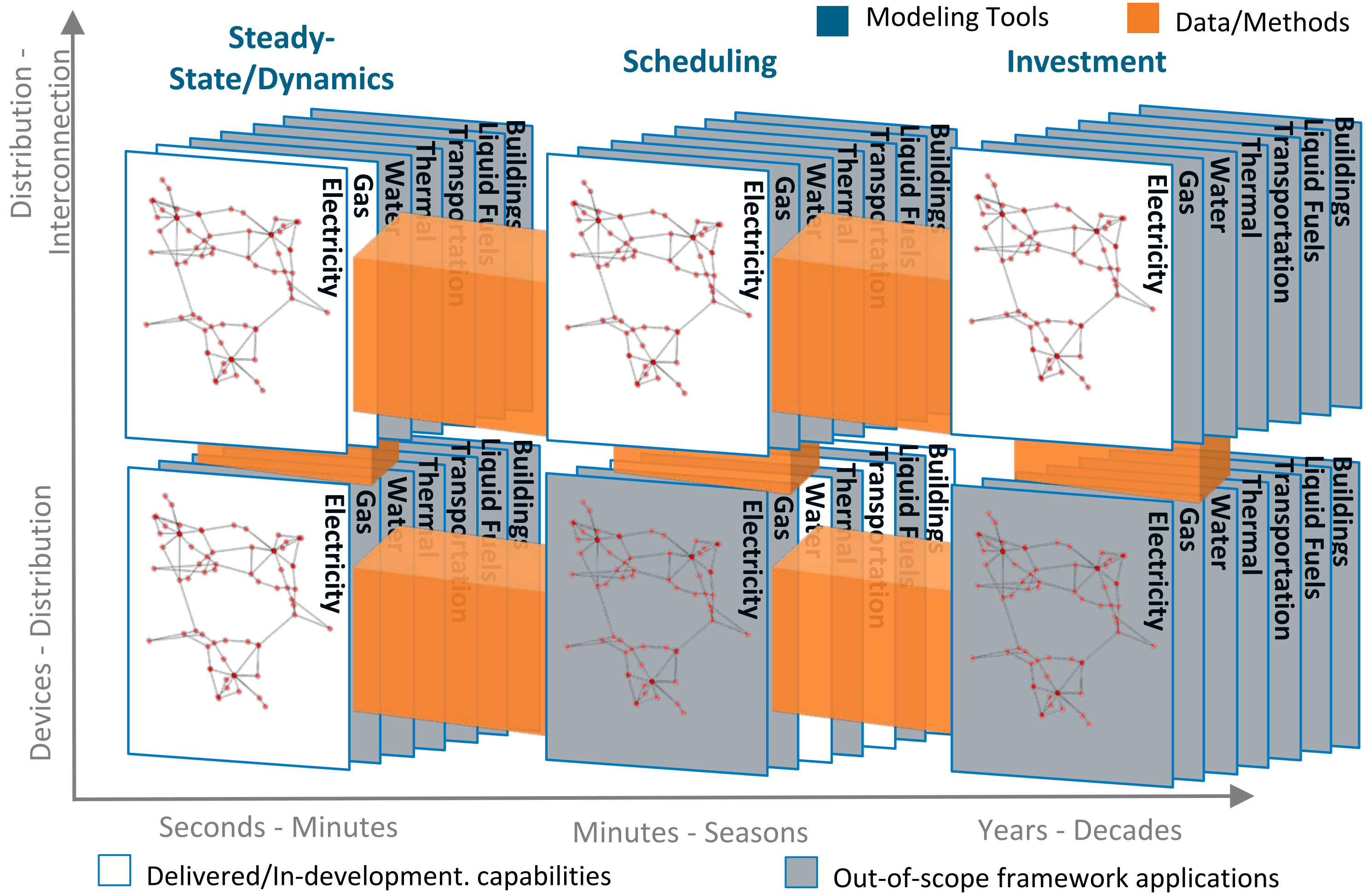


Scalable Integrated Infrastructure Planning (SIIP) Framework Design Objectives

Modularity and Accessibility – flexible and transparent problem creation that is easily extensible

Integration – coherency between models representing distinct phenomena

Scalability – address scales that matter through efficient problem simulation and parallelism



SIIP::POWER
PowerSystems.jl
PowerSimulations.jl

SIIP::WATER
WaterSystems.jl
WaterSimulations.jl

SIIP::Scalability
InfrastructureSystems.jl
ProgressiveHedging.jl

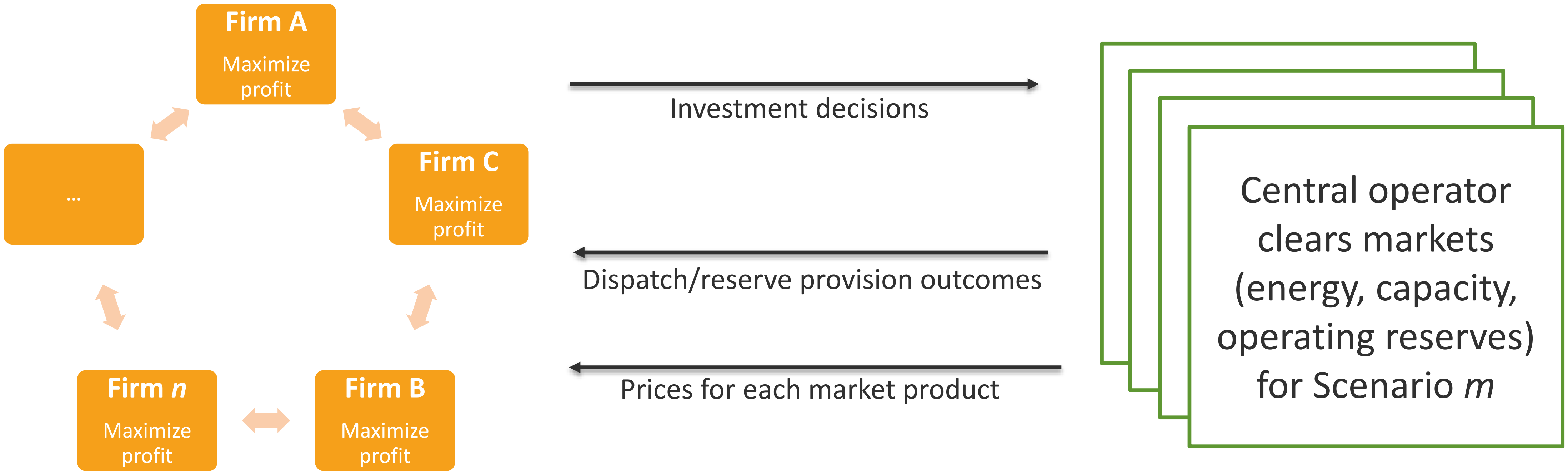
Capturing Market Structures and *Imperfect* Economic Actors:

Current leading power system investment and operations models all use linear- or mixed integer programming approaches and assume perfect markets/competition/information

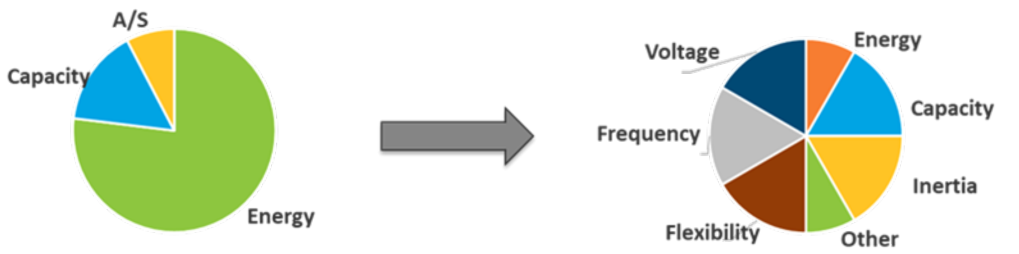
This limits our ability to resolve the implications of alternative market structures (e.g. *energy only* vs. *energy and capacity*) on investment and operations

Electricity Markets and Investment Suite (EMIS):

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



How can markets efficiently support an ever-evolving power grid?



Quantifying the need for and provision of system resiliency

Energy assurance for critical infrastructure: Incorporating resilience in optimization and simulation models

Figure 1. The Resilience Analysis Process.

Table 5. Model Constructs Used to Analyze Resilience Planning in v2018 ReEDS

Modification (Scenario Abbreviation)	Intent	Model Constraints and Parameter Range
Increased operating reserve requirement	Greater flexibility responding to short-term outages	3%–15% of load required as spinning reserves
Increased planning reserve requirement	Improve resource adequacy under outages at peak	Regional planning reserve requirement increased by 40%[a]
Higher generator outage rates	Plan for more frequent generator outages	Generator forced outage rate increased by 50%[a]
Higher transmission outage rate	Plan for more frequent transmission outages	Transmission forced outage rate increased up to 50%[a]
Higher transmission outage rate plus option to purchase "resilience capacity"	Allow construction of resilient transmission capacity, e.g., undergrounding	Transmission forced outage rate increased up to 50%[a]

[a] Parameter increases or reductions reflect percent changes relative to default assumptions in the 2018 version of the ReEDS model.

Sources: Watson et al. (2015); Murphy et al. (2020)

Summary

- **Current state of the art**: integrated model workflow to capture a range of economic and physical phenomena at multiple spatial and temporal scales
- **What's next/where we are going**:
  - Continued improvement of existing capacity expansion, production cost (UC&ED), probabilistic resource adequacy, and AC power flow tools to capture phenomena associated with increasing penetration of inverter-based techs
  - Integrated framework for energy system models enabling robust interactions and computational methods
  - Power system models that can examine investment and operational behavior under perfect *and imperfect* market conditions

Thank you

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