Market Design Concepts for Evolving Power Systems

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Why are we talking about markets?

- **Competitive wholesale electricity markets** cover a large portion of the U.S. grid, as well as many other areas in the world

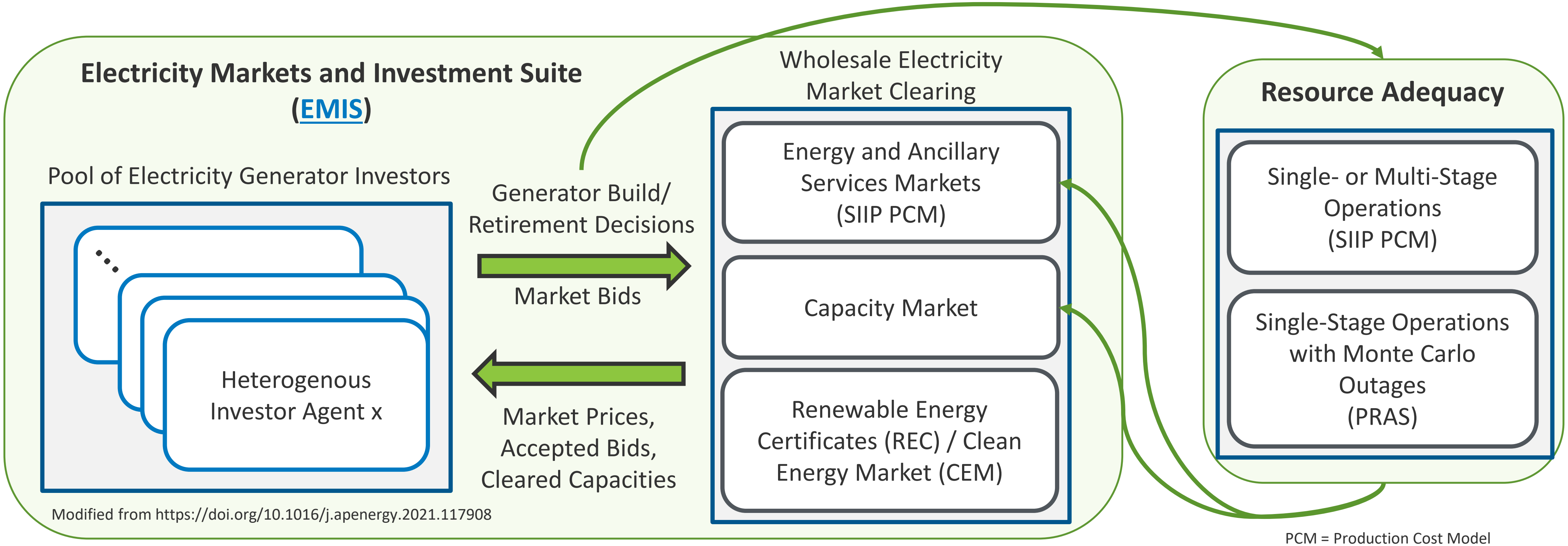
- System planners and operators in these market regions face a number of challenges in maintaining reliability, resiliency, and affordability amidst **evolving power systems**
    - Changing resource mix, including rapid investment in low- or zero-marginal-cost technologies and distributed energy resources
    - Advanced communication and control requirements
    - Energy infrastructure interdependencies
    - Increased electrification and consumer participation

- These challenges require both **technical and market design solutions**

- Market design impacts incentives for investment decisions, which in turn influences **resource adequacy**, and this interaction is especially challenging under future economic, policy, and system condition **uncertainty**

A fundamentally different modeling approach

- Capture interaction between market design, investment, and resource adequacy (RA)
- Represent multiple perspectives with nuances of investment landscape: imperfect information, risk attitudes, technology preferences, and financing parameters
- Integrate with NREL's Probabilistic Resource Adequacy Suite (PRAS) and Scalable Integrated Infrastructure Planning (SIIP) modeling framework



Electricity Markets and Investment Suite (EMIS)

Pool of Electricity Generator Investors

Heterogenous Investor Agent x

Generator Build/ Retirement Decisions

Market Bids

Market Prices, Accepted Bids, Cleared Capacities

Wholesale Electricity Market Clearing

Energy and Ancillary Services Markets (SIIP PCM)

Capacity Market

Renewable Energy Certificates (REC) / Clean Energy Market (CEM)

Resource Adequacy

Single- or Multi-Stage Operations (SIIP PCM)

Single-Stage Operations with Monte Carlo Outages (PRAS)

Modified from https://doi.org/10.1016/j.apenergy.2021.117908

PCM = Production Cost Model

Portfolio of projects exploring these interactions

1) **Technical Assistance to U.S. ISOs/RTOs**
   - Grid Modernization Laboratory Consortium (GMLC) project funded by DOE WETO, WPTO, OE, and NE, as well as upcoming project funded by DOE's joint-office (EERE-OE-GDO) "Grid Solutions" program
   - Leverage advanced tools, datasets and resources of the project partners to provide robust analytical support to address ISO/RTO-identified market design challenges
     - Argonne National Laboratory, NREL, Electric Power Research Institute, Lawrence Berkeley National Laboratory, Johns Hopkins University
   - Ongoing **stakeholder engagement** and coordination: Tailor analysis based on continual feedback from ISOs/RTOs, FERC, and other market experts

2) **Electricity Markets Analysis using EMIS modeling suite**
   - Analysis exploring the impact of different market designs/structures on investments (funding from DOE Office of Strategic Analysis)

Technical Assistance to U.S. ISOs/RTOs: GMLC project

NREL team:
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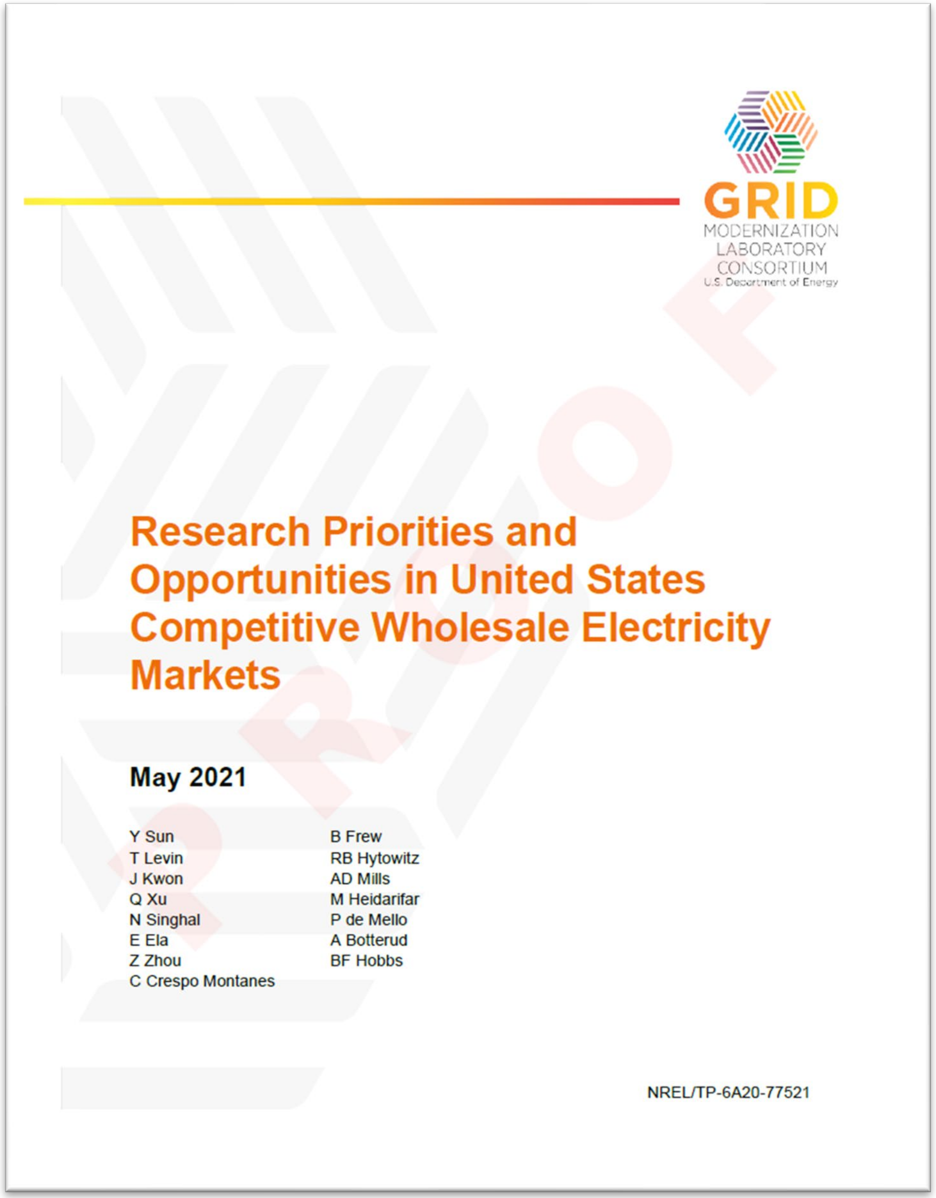
- Sourabh Dalvi
- Surya Chandan Dhulipala
- Gord Stephen







GRID MODERNIZATION LABORATORY CONSORTIUM
U.S. Department of Energy

Research Priorities and Opportunities in United States Competitive Wholesale Electricity Markets

May 2021

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J Kwon
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NREL/TP-6A20-77521

Report: https://www.nrel.gov/docs/fy21osti/77521.pdf
Webinar: https://www.esig.energy/event/webinar-research-opportunities-around-the-evolution-of-iso-rto-wholesale-electricity-markets/

	Objective
Incentivizing reliability services and operational flexibility	- The system has enough operational flexibility to maintain reliability throughout short-term operations.
Integrating new and emerging technologies	- Emerging technologies (e.g., VRE, storage and DERs) can participate in wholesale markets and be efficiently integrated into the power system.
Resource adequacy and system resilience	- The system has enough capacity in the future to serve demand and maintain long term reliability.
Energy price formation	- Prices for energy and other services reflect the value that they provide to the power system.
Transmission-distribution coordination	- Distributed resources can efficiently interact with transmission level wholesale markets.
Transmission planning	- Transmission infrastructure is coordinated with generation expansion planning and costs are efficiently allocated.

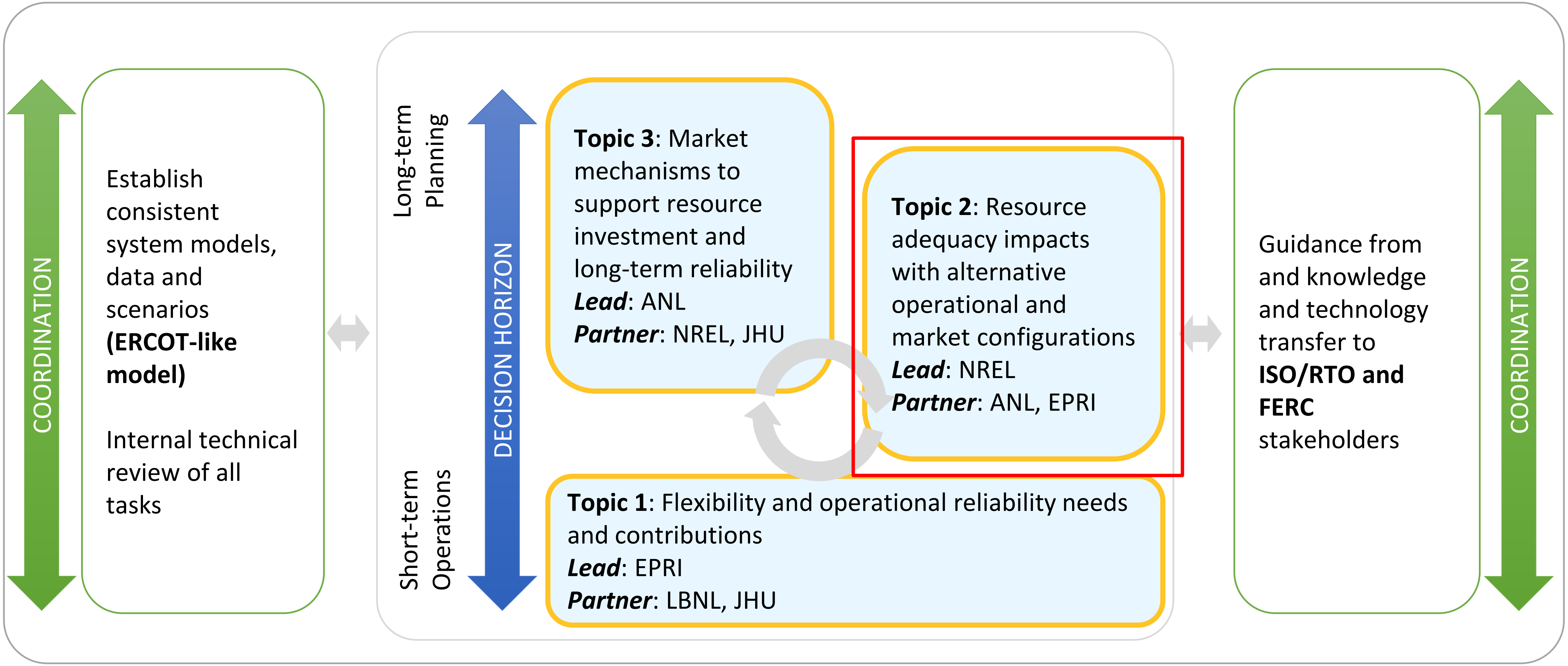
ISO/RTO-informed prioritization

PRIORITY

PRIORITY

	Challenge 1	Challenge 2	Challenge 3	Challenge 4	Challenge 5	Challenge 6	Challenge 7
Reliability and Flexibility	New reserve/flexibility products	Deliverability of reserve products	Ancillary service market redesign	Temporal considerations	Frequency response and other services	Cost recovery during emergencies	
Emerging Technologies	Reliability services with growing VRE	Emerging resource market participation	Resource adequacy contribution of emerging resources	Risk hedging through forward contracts			
Resource Adequacy	Reliability assessment and implementation	Capacity credit calculation	Accommodating state-level policies into capacity markets	Defining capacity demand curves	Capacity contribution of imports	Firm capacity for extreme weather	Risk mitigation in capacity markets and bilateral contracts
Price Formation	Zero-marginal cost world	Scarcity and shortage pricing	Multi-period market pricing and settlement	Active demand-side participation	Carbon pricing or GHG emissions		
T&D Coordination and Wholesale-Retail Interactions	Grid services provision from DERs	Improved situational awareness of DERs	Modeling of TSO-DSO coordination	TSO-DSO coordination mechanisms	Data management and communication	Regulatory and policy concerns	Distribution level management
Transmission Planning	Long run grid planning uncertainties	Transmission investment co-optimization	Grid planning needs identification	Benefit measurement and cost allocation	FTR auction efficiency	FTR revenue adequacy	

3 topics for technical analysis



Establish consistent system models, data and scenarios **(ERCOT-like model)**

Internal technical review of all tasks

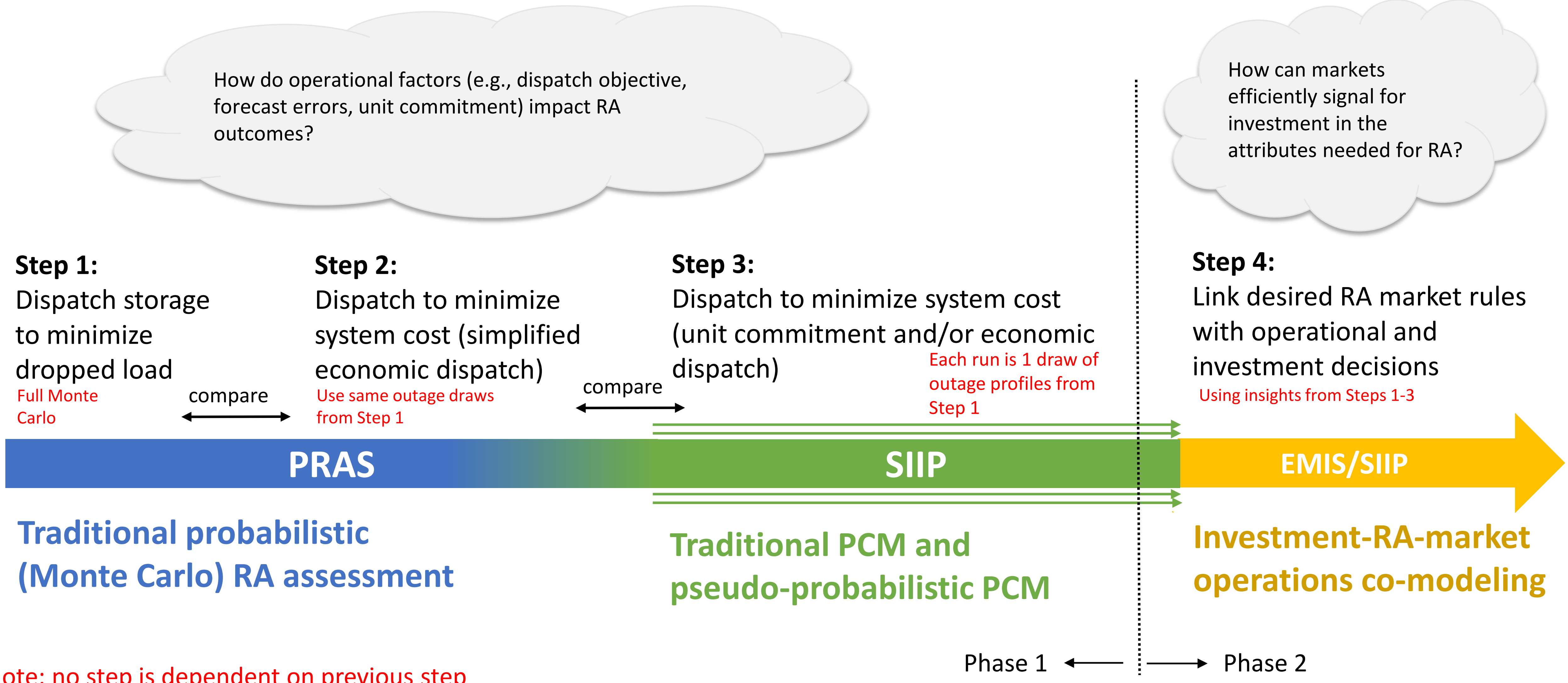
Topic 3: Market mechanisms to support resource investment and long-term reliability
Lead: ANL
Partner: NREL, JHU

Topic 2: Resource adequacy impacts with alternative operational and market configurations
Lead: NREL
Partner: ANL, EPRI

Topic 1: Flexibility and operational reliability needs and contributions
Lead: EPRI
Partner: LBNL, JHU

Guidance from and knowledge and technology transfer to **ISO/RTO and FERC** stakeholders

NREL’s modeling approach



How do operational factors (e.g., dispatch objective, forecast errors, unit commitment) impact RA outcomes?

How can markets efficiently signal for investment in the attributes needed for RA?

Step 1:
Dispatch storage to minimize dropped load
Full Monte Carlo

compare

Step 2:
Dispatch to minimize system cost (simplified economic dispatch)
Use same outage draws from Step 1

compare

Step 3:
Dispatch to minimize system cost (unit commitment and/or economic dispatch)
Each run is 1 draw of outage profiles from Step 1

Step 4:
Link desired RA market rules with operational and investment decisions
Using insights from Steps 1-3

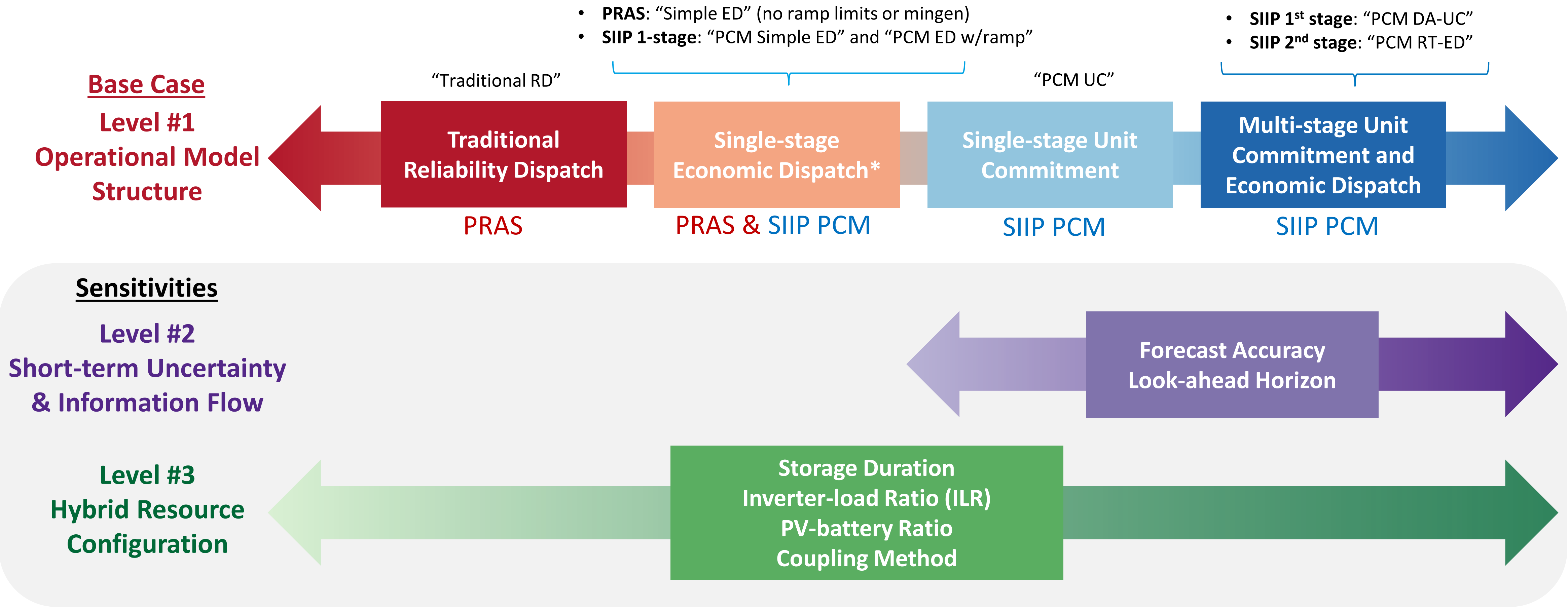
Traditional probabilistic (Monte Carlo) RA assessment

Traditional PCM and pseudo-probabilistic PCM

Investment-RA-market operations co-modeling

Note: no step is dependent on previous step

Phase 1 analysis focused on RA: 3 levels



Base Case

Level #1
Operational Model Structure

"Traditional RD"

Traditional Reliability Dispatch

PRAS

- **PRAS**: "Simple ED" (no ramp limits or mingen)
- **SIIP 1-stage**: "PCM Simple ED" and "PCM ED w/ramp"

Single-stage Economic Dispatch*

PRAS & SIIP PCM

"PCM UC"

Single-stage Unit Commitment

SIIP PCM

- **SIIP 1st stage**: "PCM DA-UC"
- **SIIP 2nd stage**: "PCM RT-ED"

Multi-stage Unit Commitment and Economic Dispatch

SIIP PCM

Sensitivities

Level #2
Short-term Uncertainty & Information Flow

Forecast Accuracy
Look-ahead Horizon

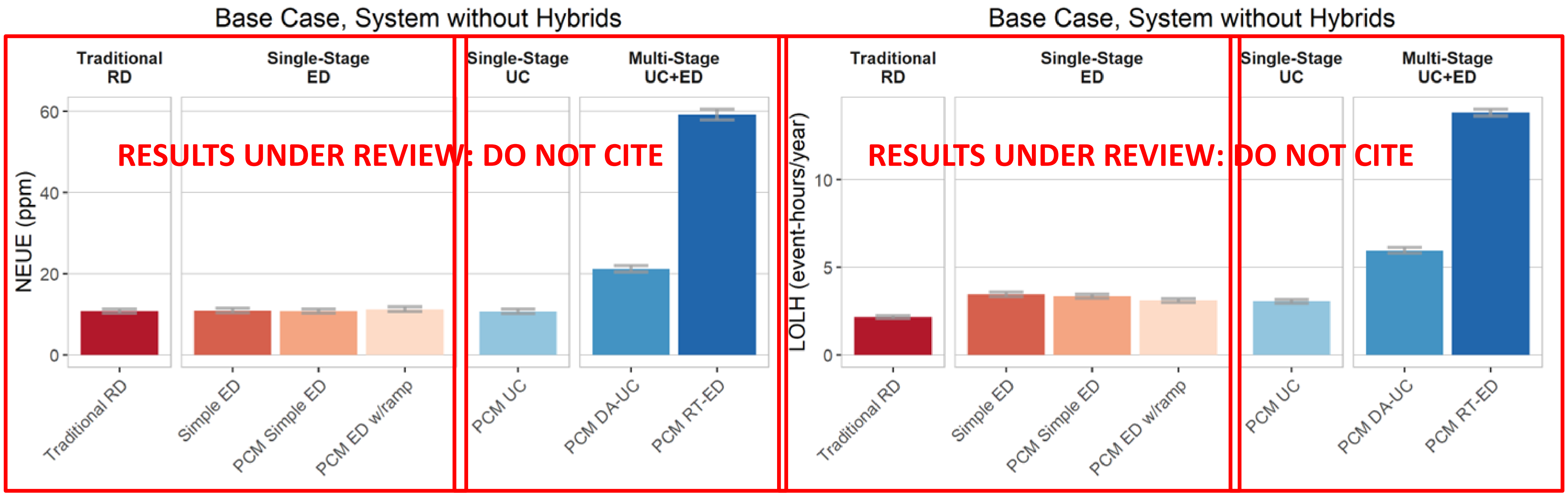
Level #3
Hybrid Resource Configuration

Storage Duration
Inverter-load Ratio (ILR)
PV-battery Ratio
Coupling Method

RESULTS UNDER REVIEW: DO NOT CITE

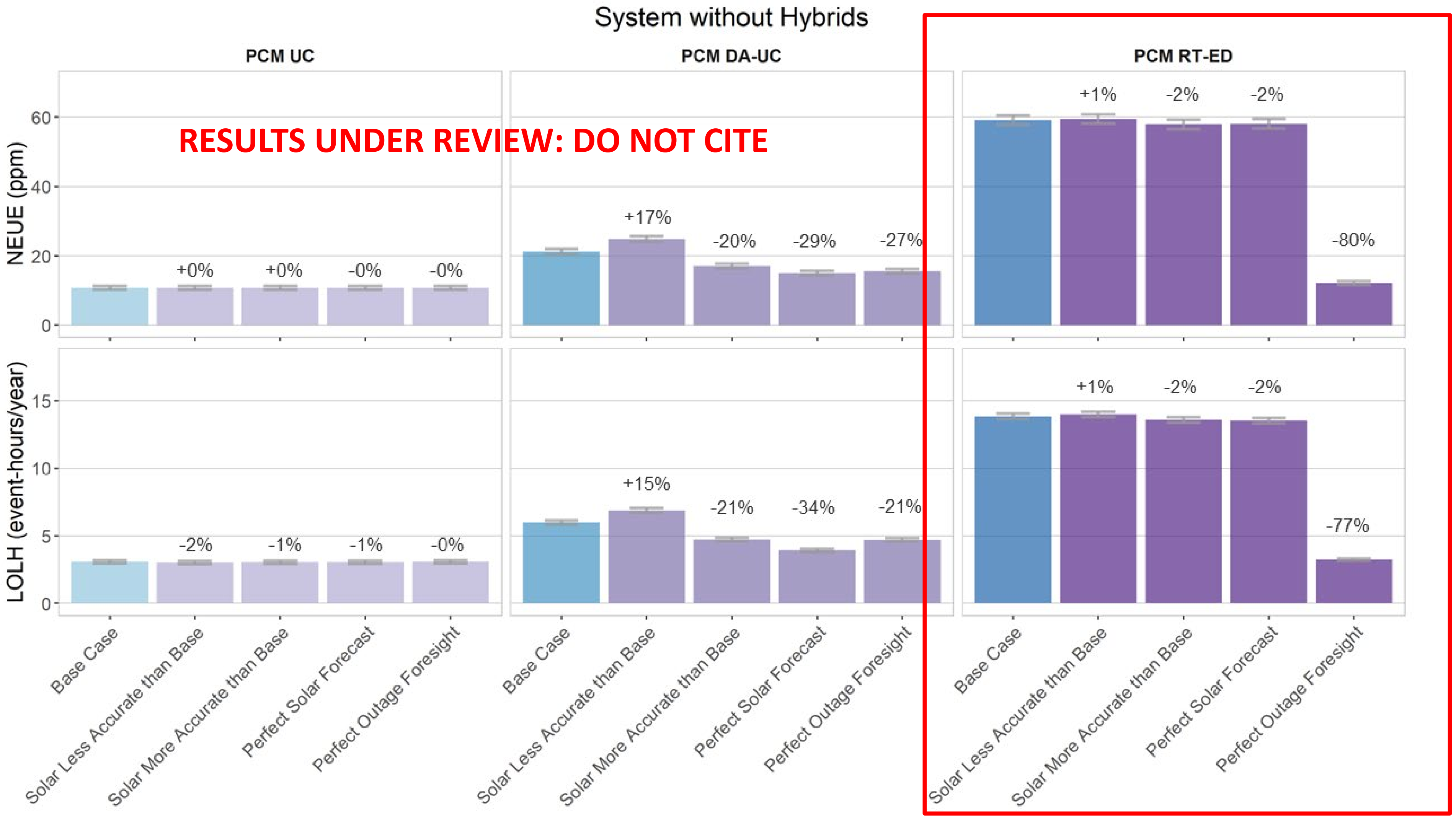
Apply to two different PV+battery hybrid contribution levels (bookends of 0% and 100%)

Multi-stage probabilistic assessments may provide a more robust evaluation of RA by capturing a wider range of operational and system interactions



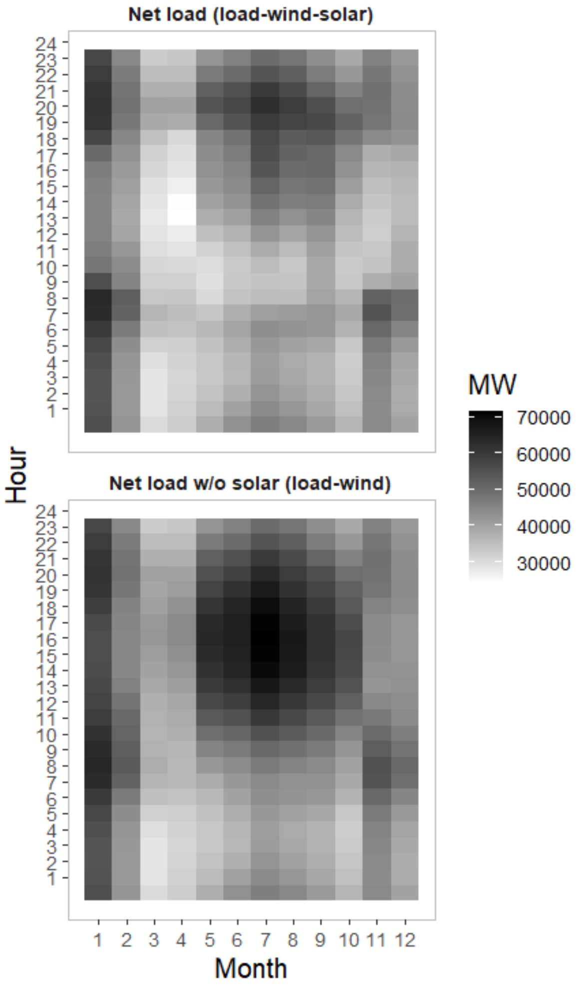
- Incorporating simplified economic dispatch in probabilistic RA models yields more dropped load due to lack of outage forecast in daily solve look-ahead
- Enforcing unit commitment can have a significant impact on dropped load results, but this is driven primarily by the interaction with forecast error
- More detailed operational representation has 1-2 orders of magnitude longer run time

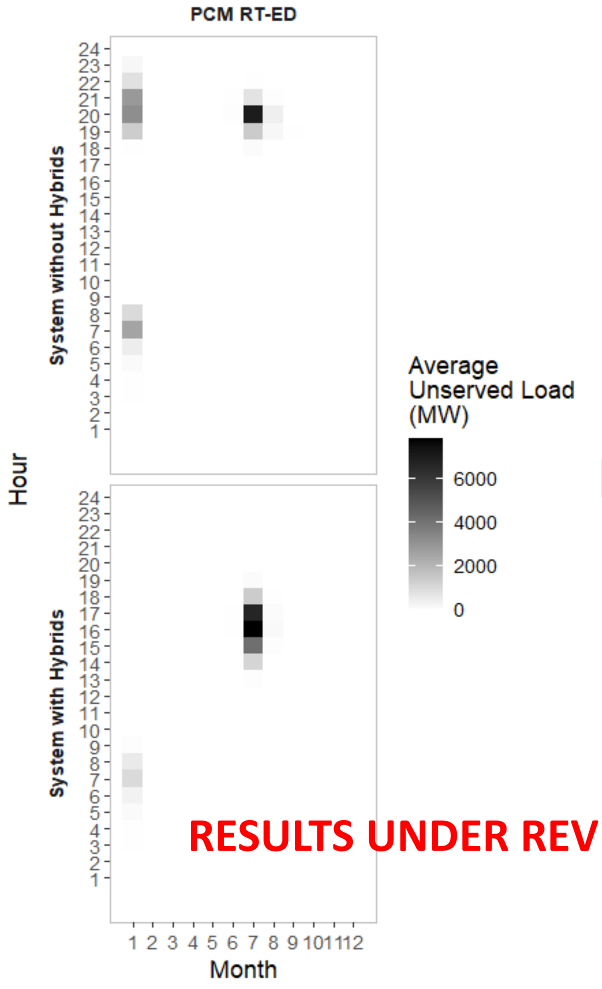
Information on thermal availability impacts RA performance by an order of magnitude more than solar resource forecasts

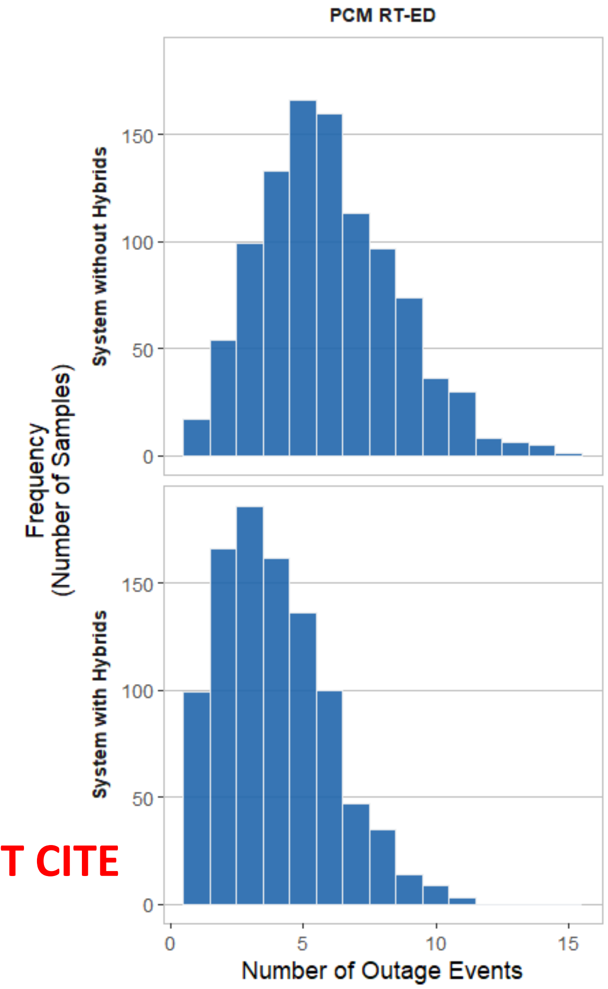


Thermal generator availability forecast accuracy matters more than solar forecast accuracy, which is driven by the comparatively larger magnitude of thermal outages than solar forecast errors within our test system

Flexibility provided by PV+battery hybrid can shift the timing and reduce frequencies of system load shedding events





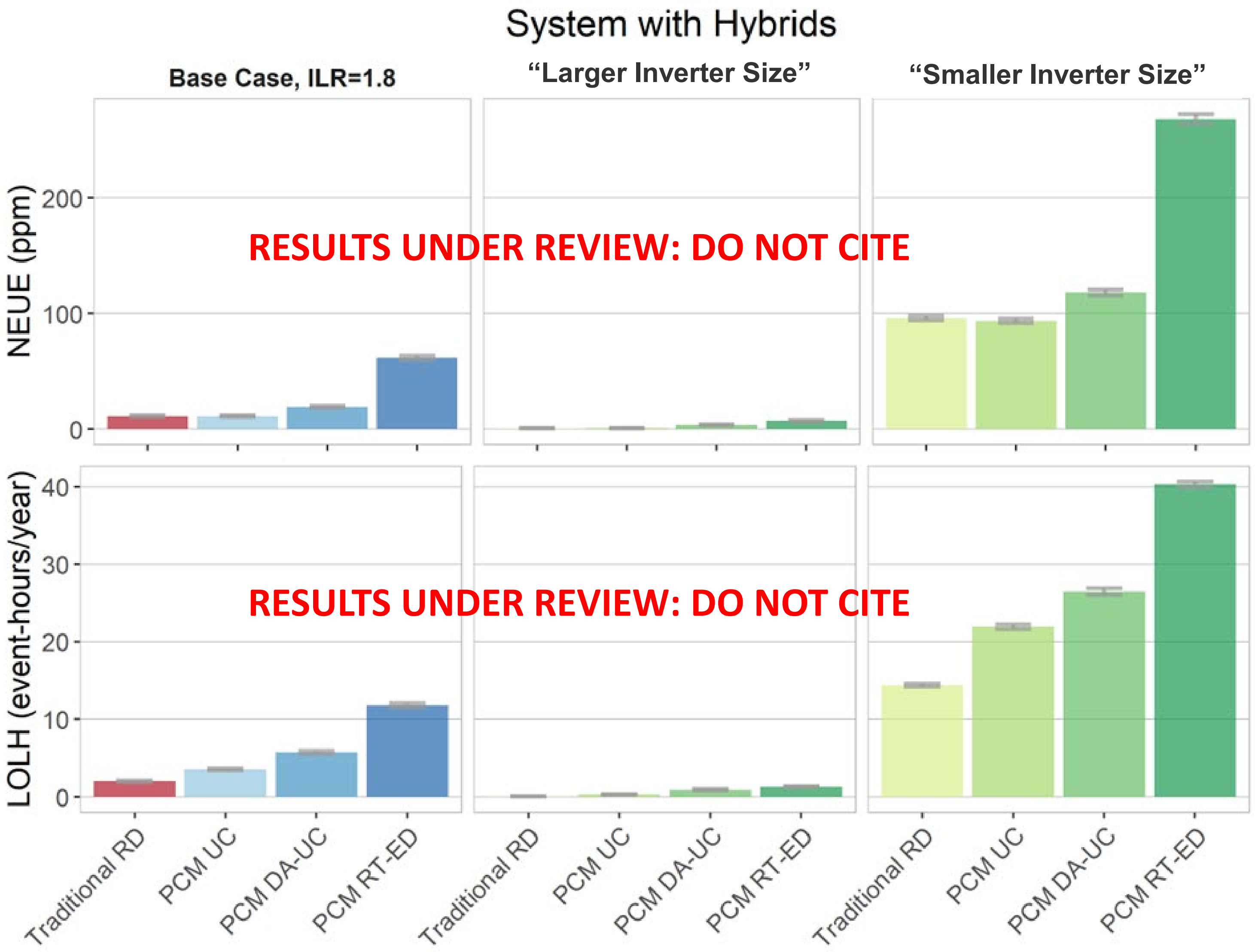


RESULTS UNDER REVIEW: DO NOT CITE

Shift in unserved load timing is driven by hybrid's flexibility, resulting in:

- Decrease in unserved load in winter
- Need for multiple RA metrics to fully capture the benefits of hybrids

Hybrid inverter size can impact RA levels by 1-2 orders of magnitude



Hybrid inverter size has a significant impact on RA results due to clipping, but other hybrid configuration settings have minimal impact

Next step is Phase 2: focus on market design

- Build on insights from Phase 1 results to explore how markets can efficiently signal for the attributes needed for RA in evolving power systems
  - Use an expanded *PRAS-SIIP-EMIS* model linkage to compare **different market designs**
  - Explicitly connect **multiple timescales**: resource adequacy, capacity expansion, and production cost modeling

- Key research questions
  - How do **scarcity pricing mechanisms** (e.g., ORDC) and **capacity markets** impact RA?
  - How do RA outcomes within each market design differ under normal weather conditions vs. **extreme weather conditions**?

- Key model and data elements
  - **Correlated thermal outages**
  - Wind, solar, and load profiles reflecting **extreme weather** conditions

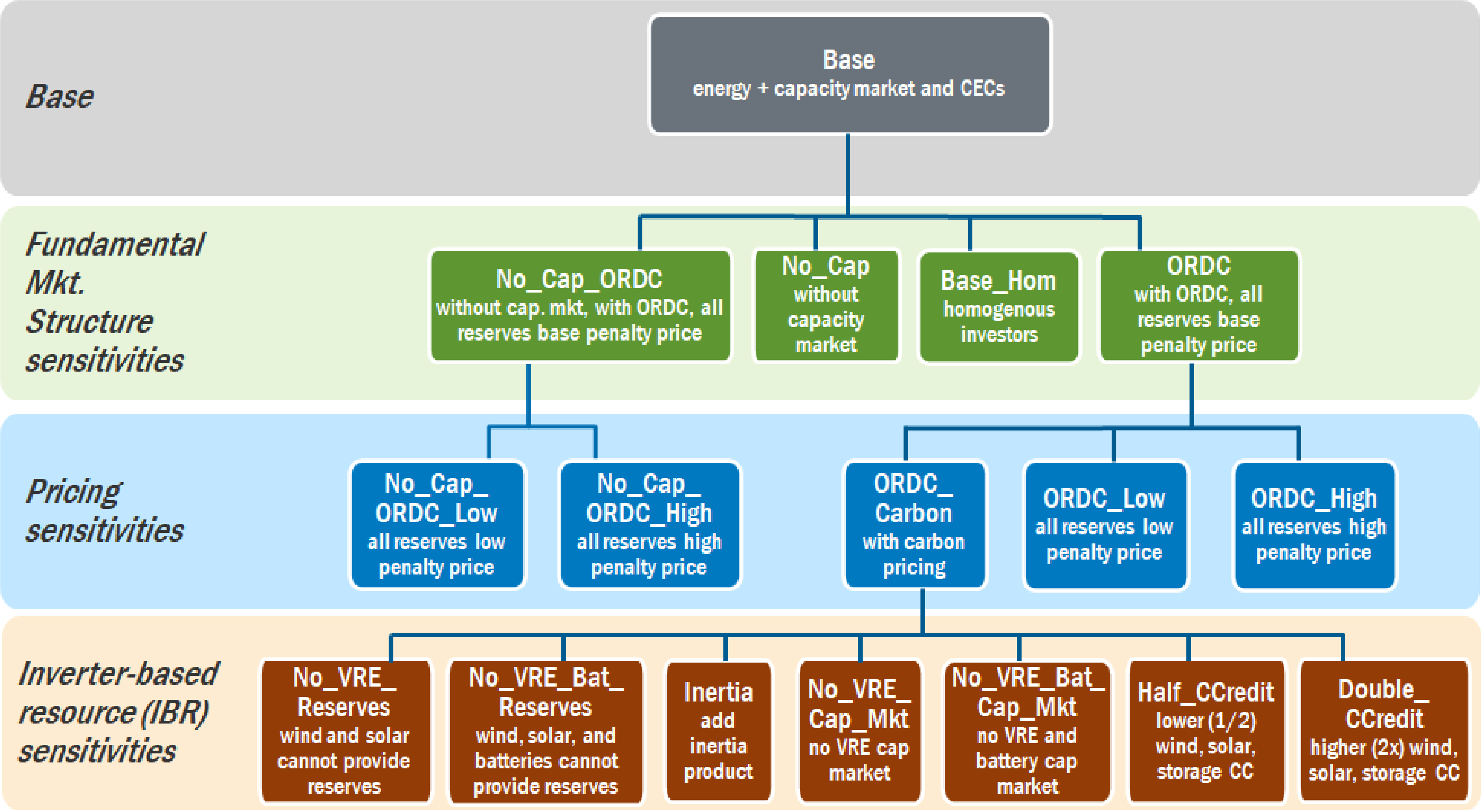
Electricity market design analysis using EMIS

NREL team:
- Bethany Frew
- Bashar Anwar
- Sourabh Dalvi

+ Adria Brooks (DOE)

Explore impact of various market designs on generation deployment and operations

RESULTS UNDER REVIEW: DO NOT CITE



Base

Base
energy + capacity market and CECs

Fundamental Mkt. Structure sensitivities

No_Cap_ORDC
without cap. mkt, with ORDC, all reserves base penalty price

No_Cap
without capacity market

Base_Hom
homogenous investors

ORDC
with ORDC, all reserves base penalty price

Pricing sensitivities

No_Cap_ORDC_Low
all reserves low penalty price

No_Cap_ORDC_High
all reserves high penalty price

ORDC_Carbon
with carbon pricing

ORDC_Low
all reserves low penalty price

ORDC_High
all reserves high penalty price

Inverter-based resource (IBR) sensitivities

No_VRE_Reserves
wind and solar cannot provide reserves

No_VRE_Bat_Reserves
wind, solar, and batteries cannot provide reserves

Inertia
add inertia product

No_VRE_Cap_Mkt
no VRE cap market

No_VRE_Bat_Cap_Mkt
no VRE and battery cap market

Half_CCredit
lower (1/2) wind, solar, storage CC

Double_CCredit
higher (2x) wind, solar, storage CC

- Apply to three 2035 clean energy targets (CETs): 45%, 75%, and 100%
- Use EMIS agent-based simulation with modified RTS test system https://doi.org/10.1016/j.apenergy.2021.117908
- Consider energy, ancillary services, capacity, and clean energy credit (CEC) products

ORDC = Operating Reserve Demand Curve; CC = capacity credit

High-level key outcomes

RESULTS UNDER REVIEW: DO NOT CITE

- Layering numerous market products and/or rules can sometimes significantly increase **complexity** without providing additional benefit to the grid physics, economics, or policy goals

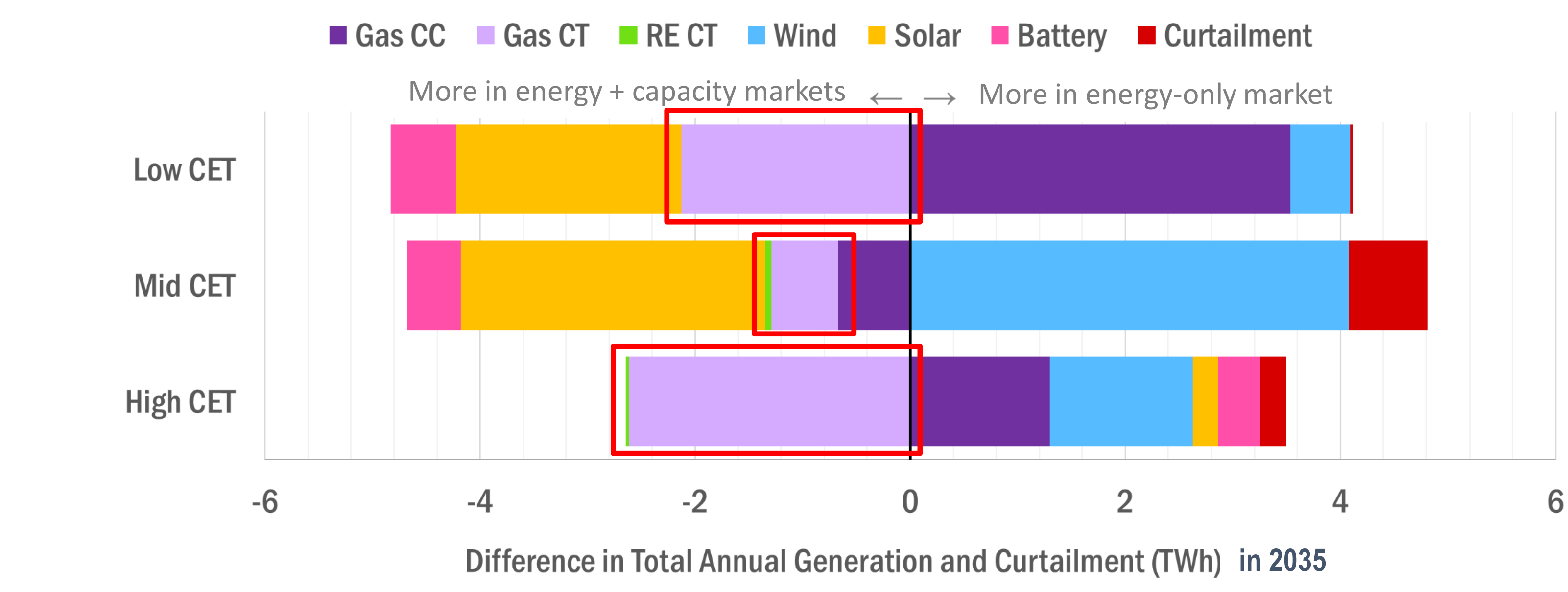
- Possible **substitutionary roles** between certain market products/policies, suggesting that only one well-designed option is needed

- Certain combinations of products can yield non-intuitive outcomes, indicating the need to thoroughly evaluate any potential new market design in the desired system for **unintended consequences**

- We highlight 3 key findings here, but more are discussed in forthcoming publication

Key Finding 1

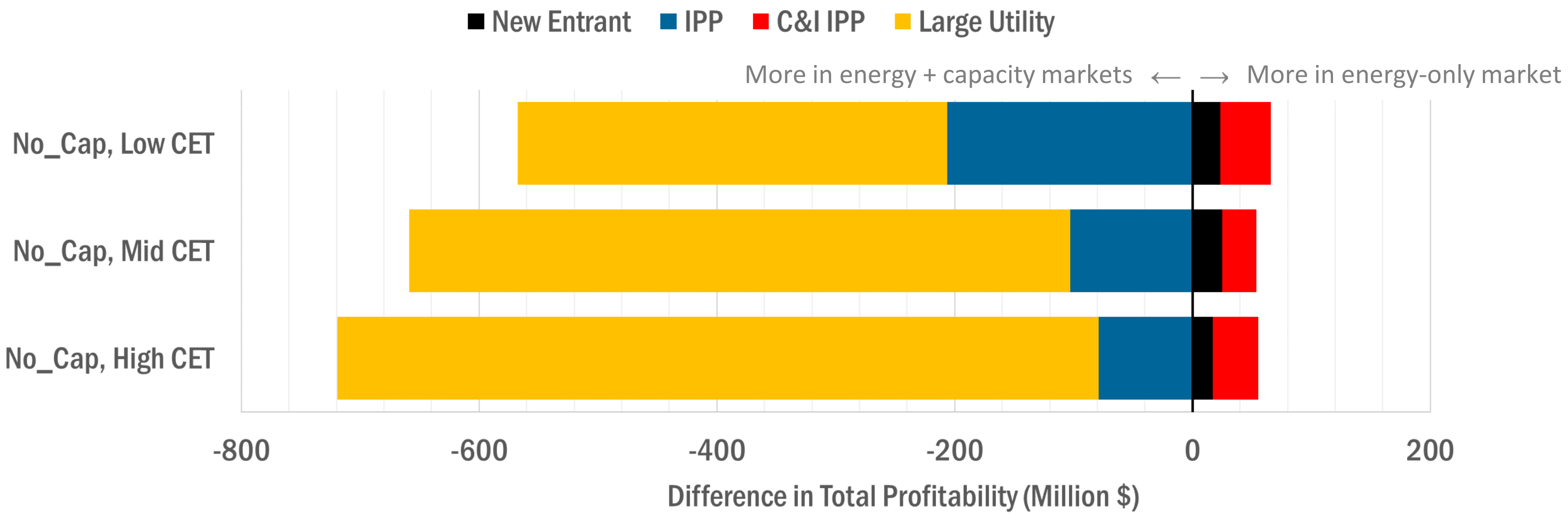
- A carefully designed energy-only market structure can achieve the same system-wide clean energy goals (on a capacity procurement basis) as a capacity market but with noticeably reduced peaking generation capacity and generation



RESULTS UNDER REVIEW: DO NOT CITE

Investor-level profitability also differs

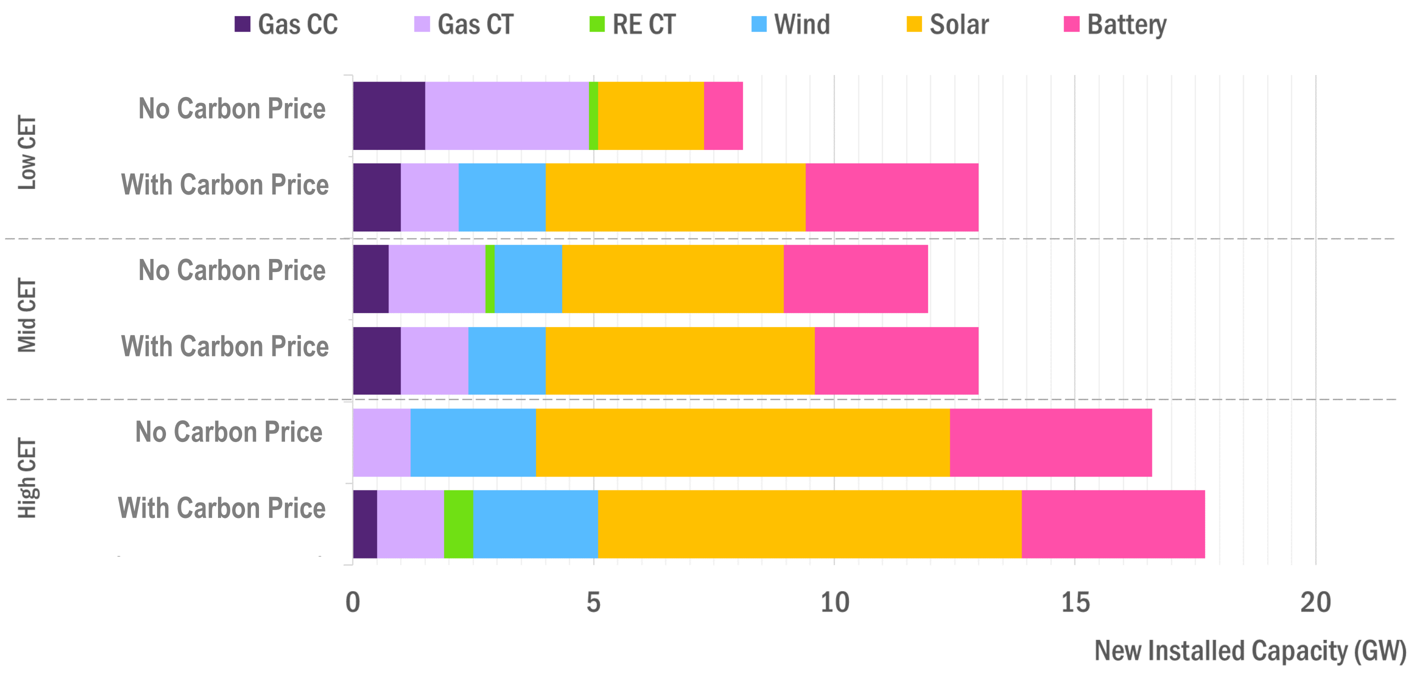
- Firms that invest in thermal units (IPP and Large Utility) have larger profitability in energy + capacity market
- Firms that only build clean energy (New Entrant and C&I IPP) have slightly larger profitability in energy-only market → higher revenues from CEC (higher going forward cost) and energy (more frequent operating reserve scarcity pricing) overcome lack of capacity revenue



RESULTS UNDER REVIEW: DO NOT CITE

Key Finding 2

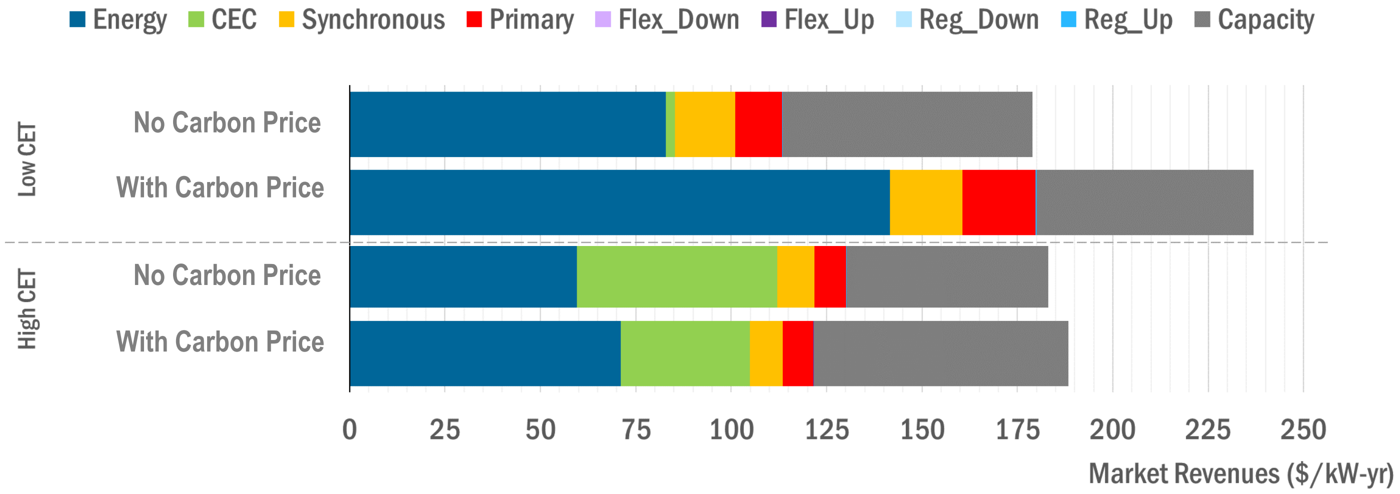
- Carbon pricing and CEC (linked to CET policy) can both achieve clean energy goals
  - At low CET levels, carbon pricing is more effective
  - At high CET levels, carbon pricing and CEC market may be substitutionary



RESULTS UNDER REVIEW: DO NOT CITE

This dynamic is reflected by revenue tradeoffs

- At Low CET levels
  - Introducing carbon pricing increases energy and operating reserve revenues, which reduces CEC revenues (reduces going forward cost and, thus, bids)
  - Net effect is larger overall revenues with carbon pricing
- At High CET levels
  - Much less difference, suggesting possible market redundancies by stacking both policies

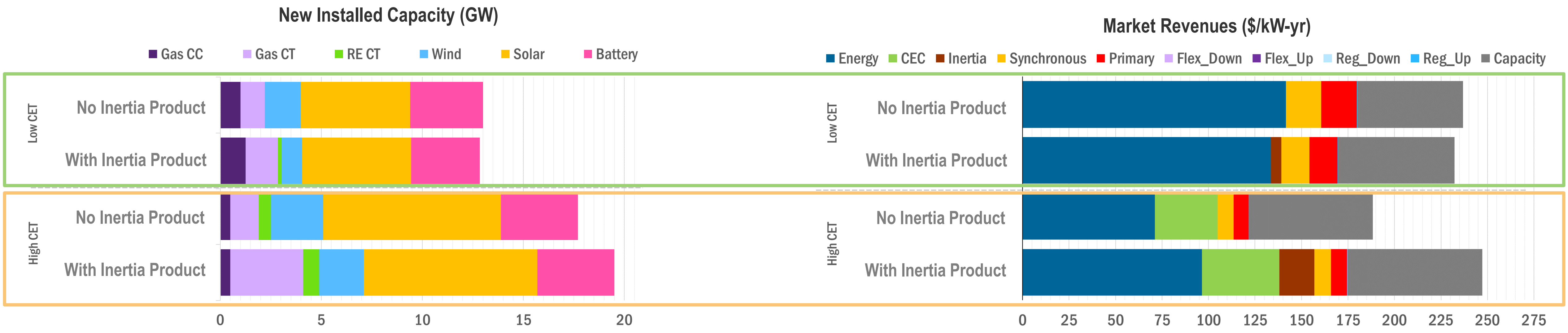


RESULTS UNDER REVIEW: DO NOT CITE

Key Finding 3

RESULTS UNDER REVIEW: DO NOT CITE

- At high CETs, adding an inertia product can favor technologies that support both the technical capability and overarching policy goal but also result in potentially redundant resource utilization



At low CET:

- Little impact to capacity and generation
- Smaller total operating reserve and energy revenues due to inertia-driven thermal commitment

At high CET:

- Larger installed capacities and generation of gas CTs and RE-CTs (also needed for CET)
- Larger curtailment (and cost) due to inertia-driven commitment of CTs while still needing VRE for CET
- Significantly larger inertia and energy prices due to inertia scarcity events

Next step: explore RA-market design interface

- Key research question
  - How do **scarcity pricing mechanisms** (e.g., ORDC) and **capacity market designs** impact RA, particularly in combination with other market and policy elements?

- Use an expanded *PRAS-SIIP-EMIS* model linkage to compare **different market designs**
  - Different capacity market demand curves (static, scaled by load growth, informed by RA outlook each year)
  - Different ORDC informed by RA outlook (convolution-based, sequential Monte Carlo)
  - Various combinations of carbon price and/or clean energy credit market
  - Various operating reserve scarcity pricing assumptions

Some closing thoughts

High level insights

(based on analysis with stylized case studies)

- **Everything is connected**
  - Lines are blurring between traditional RA assessment and operations, and markets may need modifications to more efficiently signal for desired RA outcomes
    - e.g., longer horizon considerations, such as for long-duration energy storage

- **The details can matter**
  - Small market design changes can have non-trivial impacts on grid evolution and operations, and sometimes unintentional/non-intuitive results are observed
  - There may be more than one way to achieve a desired endpoint
  - There is no free lunch (e.g., need to pay for capacity or have scarcity pricing)

- **More research and data** are needed to explore different systems, conditions, and market designs

Moving forward: our vision for markets research

- Analysis driven by and explicitly considering perspectives from **multiple stakeholders**
  - Key vehicle is suite of technical assistance projects
  - Build and apply new capabilities, ultimately allowing us to respond to quick turn-around needs
  - One priority is interface of RA and market design

- Eventual goal is completely **integrated modeling**
  - Across perspectives, time domains, and devices/areas
  - Another NREL capability: Holistic Electricity Model (HEM)

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Thank you!

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