U.S. DEPARTMENT OF ENERGY

Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

# Market and Reliability Opportunities for Wind on the Bulk Power System

# Project ID #M4

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Audun Botterud (Argonne National Laboratory)

# FY17-FY18 Wind Office Project Organization

"Enabling Wind Energy Options Nationwide"

| Technology Development | Market Acceleration & Deployment |
| --- | --- |
| Atmosphere to Electrons | Stakeholder Engagement, Workforce Development, and Human Use Considerations |
| Offshore Wind | Environmental Research |
| Distributed Wind | Grid Integration |
| Testing Infrastructure | Regulatory and Siting |
| Standards Support and International Engagement | |
| Advanced Components, Reliability, and Manufacturing | |

Analysis and Modeling (cross-cutting)

# Project Overview

## M4: Market and Reliability Opportunities for Wind on the Bulk Power System

### Project Summary

This project aims to understand the impact of wind and other zero-marginal cost resources on reliability and revenue sufficiency under a wide range of market design options and revenue sources. Understanding the broader impacts to wind and other technologies is key to supporting reliability.

### Project Objective & Impact

This project provides insights into key drivers of wholesale electricity energy and ancillary service prices, including resource adequacy level, operating reserve treatment, and price formation rules. Other aspects of the project include enabling a greater understanding of capacity market rules and investor behavior. One key outcome is the creation of a methodology for ensuring scenarios studied in market design analysis have similar reliability/resource adequacy metrics.

### Project Attributes

**Project Principal Investigator(s)**

Jessica Lau (NREL)
Audun Botterud (ANL)

**DOE Lead**

Charlton Clark

**Project Partners/Subs**

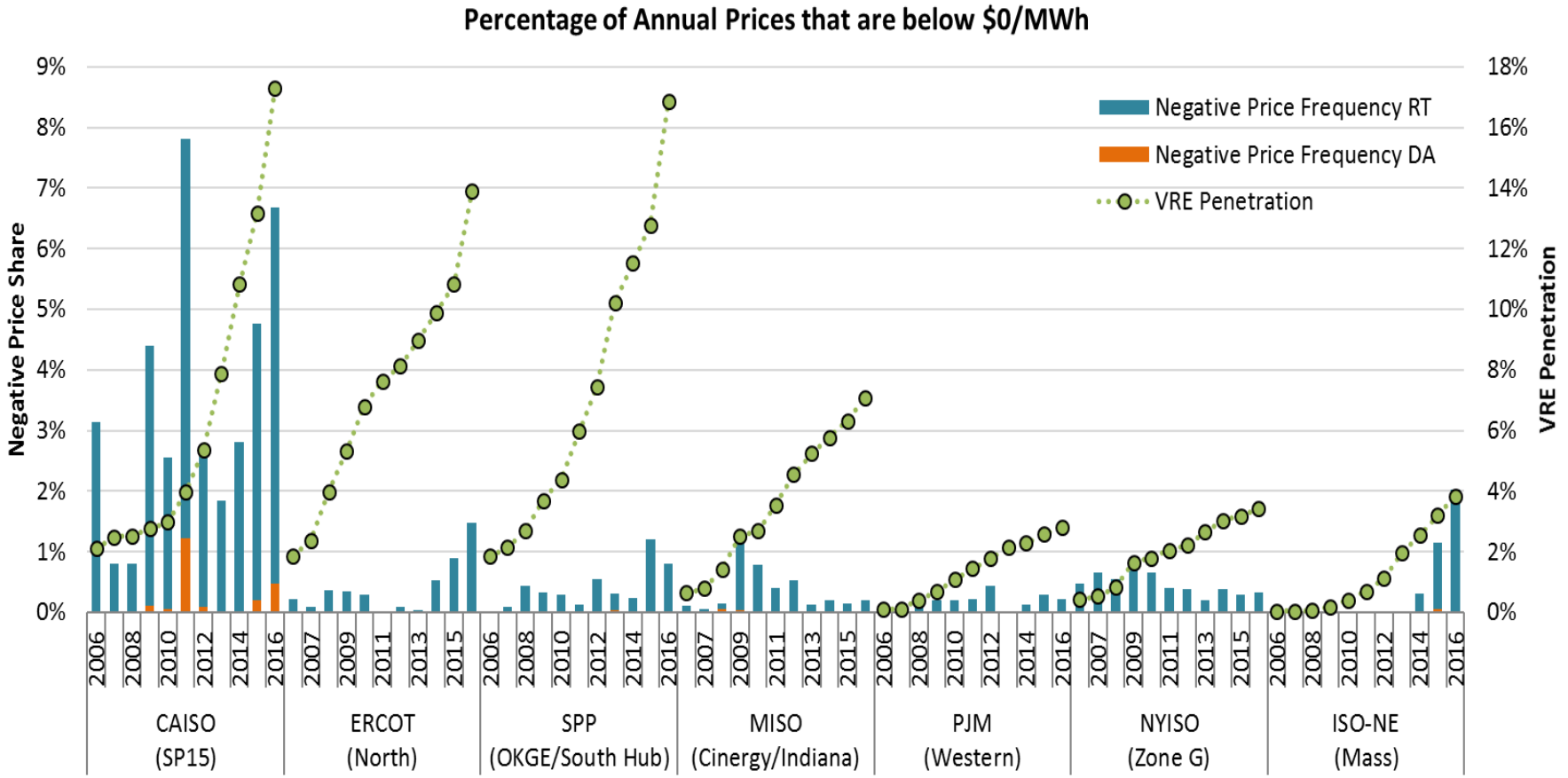
Erik Ela (EPRI)
Robin Hytowitz (EPRI)

**Project Duration**

April 2016–April 2019

# Technical Merit and Relevance (1)

Increasing wind and variable energy resources can drive wholesale electric prices to low and negative levels.




*Wiser et al., LBNL/ANL Report, Nov. 2017.*

# Technical Merit and Relevance (2)


United States Government Accountability Office

GAO

Report to Congressional Committees

December 2017

ELECTRICITY MARKETS

Four Regions Use Capacity Markets to Help Ensure Adequate Resources, but FERC Has Not Fully Assessed Their Performance

**Limited assessment of capacity markets drives research needs**

- $51 billion paid in four U.S. capacity markets, 2013–2016
- Lack of performance goals for capacity markets
- More and better assessment needed

# Technical Merit and Relevance (3)

## Motivation:

Proper market mechanisms are key to achieving long-term resource adequacy with high wind and variable renewable energy penetration

## Research Question:

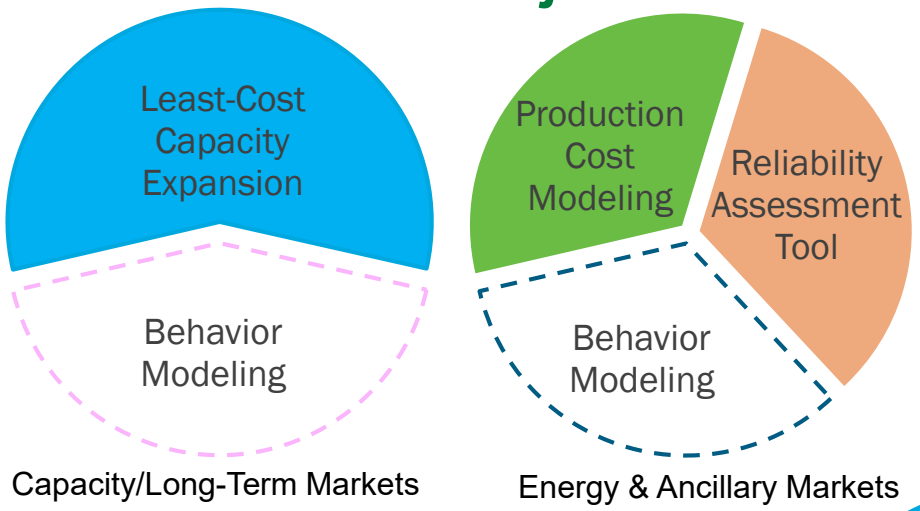
With the impact of wind and (near-) zero marginal cost, how can different market designs impact resource adequacy and revenue sufficiency?

| | |
|---|---|
| Resource Adequacy: A reliability metric showing to what extent adequate capacity is available to serve load; often assessed with metrics such as loss of load expectation. | Revenue Sufficiency: When payments to maintain a reliable grid (including energy, capacity, and flexibility) cover the fixed and variable costs for the resources providing those services. |

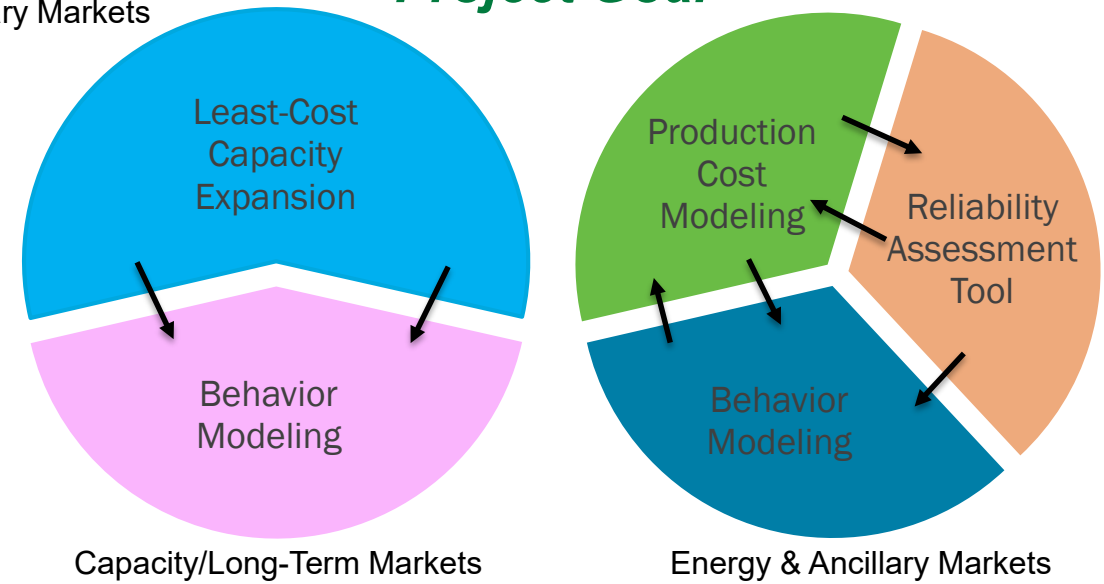
# Approach and Methodology (1)

**ANL & NREL examined generator revenue in capacity, energy, & ancillary services markets**

***Before Project***




***Project Goal***



# Approach and Methodology (2)

What happens to prices when wind generation increases?

## FY 2017

### NREL

- Built modeling database and software
- Created ERCOT and GMLC test system
- Conducted price sensitivity analysis

### ANL

- Reviewed existing U.S. capacity markets
- Developed a game theoretical model for capacity expansion

## FY 2018

### NREL

- Designed and implemented iterative modeling approach and software to assess reliability and production cost
- Identified the relationship between resource adequacy level and prices
- Modeled and investigated different pricing approaches and their impact on pricing

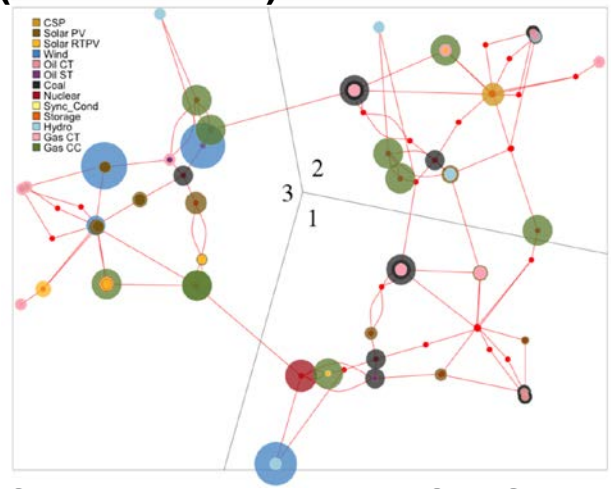
### ANL

- Complete review of existing U.S. capacity markets
- Completed development of a game theoretical model for capacity expansion
- Conducted case study of modeling framework on realistic system

# Approach and Methodology (3)

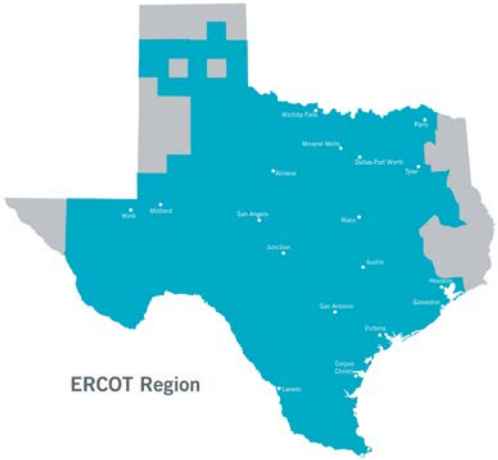
Developing system representations are vital to rigorous benchmarking and ensures relevance to fleet modernization

**Reliability Test System – Grid Modernization Lab Consortium (RTS-GMLC)**




- **Created through DOE GMLC**
  - IEEE asked NREL to help update RTS-96, including adding natural gas CC, time synchronized load, and renewable resources
- **Made public on Github and gaining users**

**Electric Reliability Council of Texas**

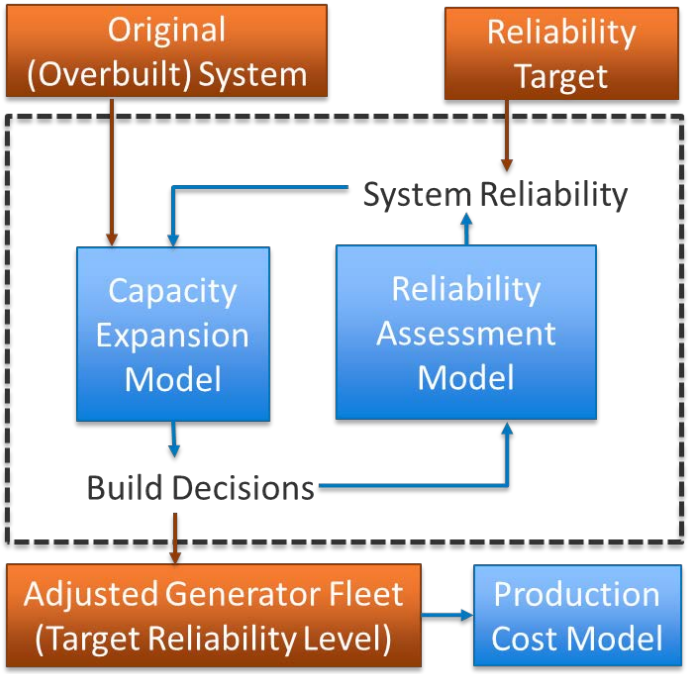



- **Worked with ERCOT to develop system representation**
  - Production cost model
  - Capacity expansion models
- **Enables direct benchmarking**

# Approach and Methodology (4)

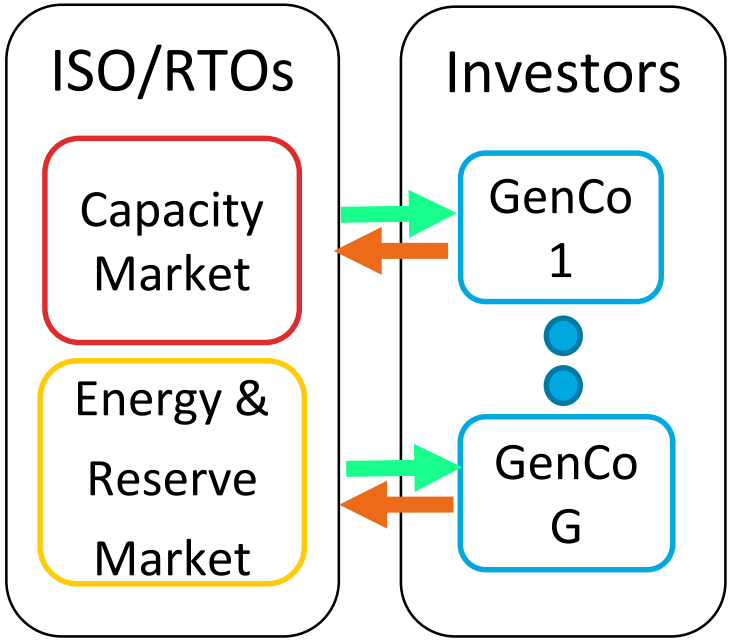
Designing and developing next-generation software for electricity markets and reliability

## Assessing Energy Markets




- Electrical Operations & Production Cost Model (PLEXOS & PSO)
- Probabilistic Resource Adequacy Suite (NREL)
- Capacity Expansion Model (NREL)

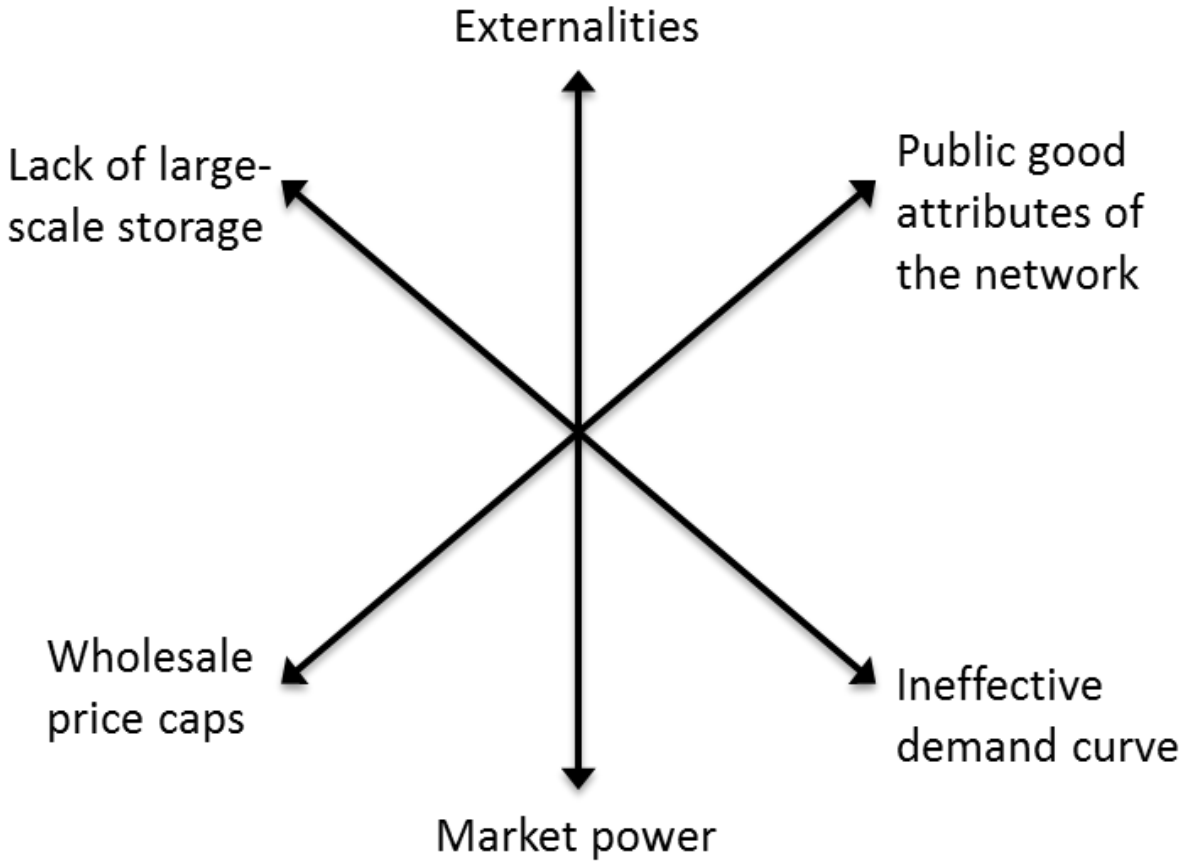
## Assessing Capacity Markets




- Multi-Agent Market-based Resource Adequacy Assessment Framework (ANL)
- Least-Cost Generation Expansion Benchmark Model (ANL)

# Accomplishments and Progress (1)

## It's complicated: electricity market "failures"



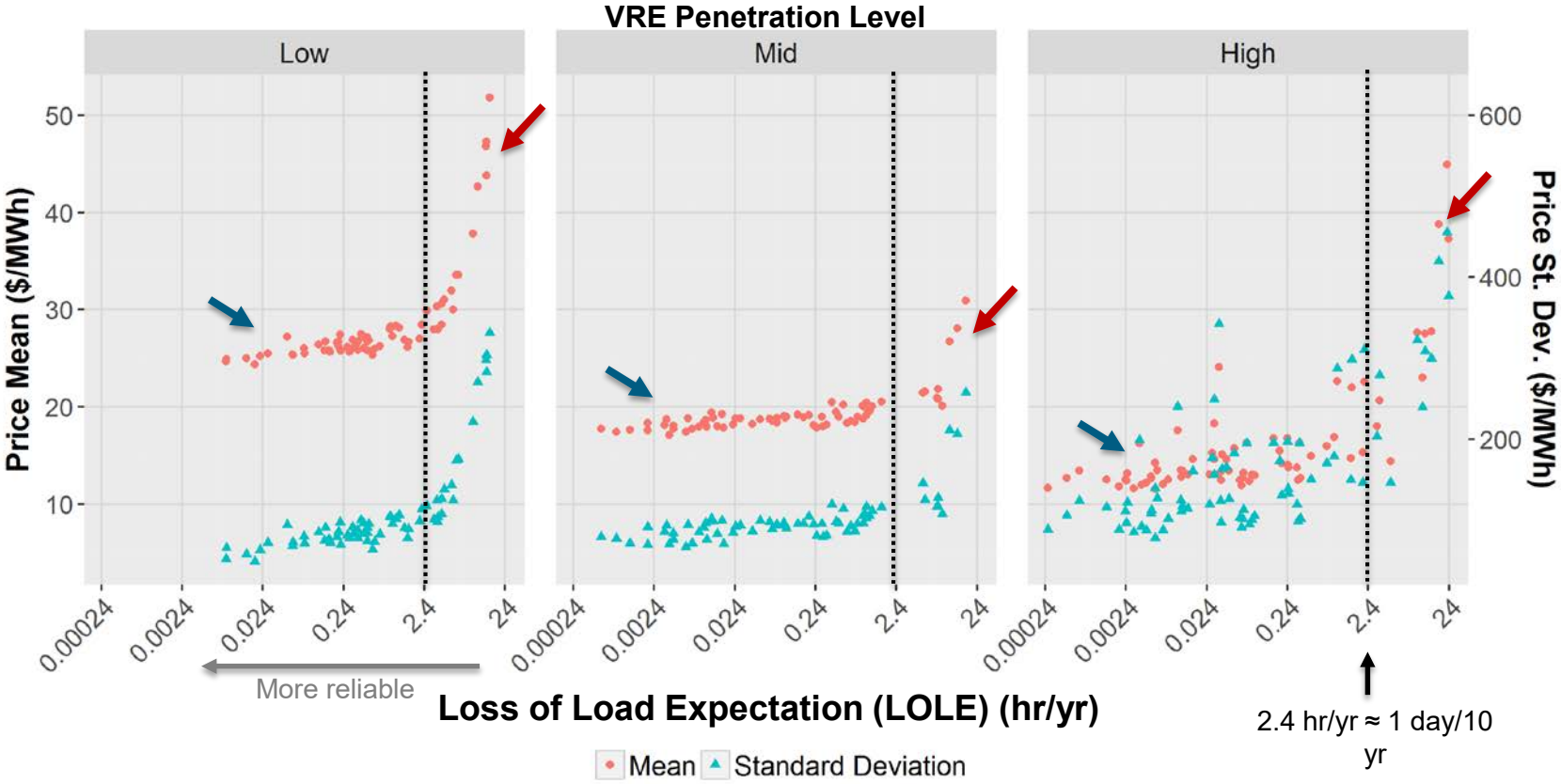

B. Frew, K. Clark, A. Bloom, and M. Milligan. "Marginal Cost Pricing in a World without Perfect Competition: Implications for Electricity Markets with High Shares of Low Marginal Cost Resources," NREL Technical Report, December 2017.

# Accomplishments and Progress (2)

Prices can be highly sensitive to resource adequacy levels. Grid integration studies can further exacerbate potential price biases.

**Higher Reliability (Lower LOLE)**
Average prices are lower and less volatile

**Lower Reliability (Higher LOLE)**
Average prices are higher due to price spikes




B. Frew, G. Stephen, D. Sigler, J. Lau, W. Jones, and A. Bloom. "Evaluating Resource Adequacy Impacts on Energy Market Prices Across Wind and Solar Penetration Levels," *The Electricity Journal*, March 2019 (submitted)

# Accomplishments and Progress (3)

Price formation changes can increase transparency, but may have minimal profit impact on all generators. More work on various pricing needed.

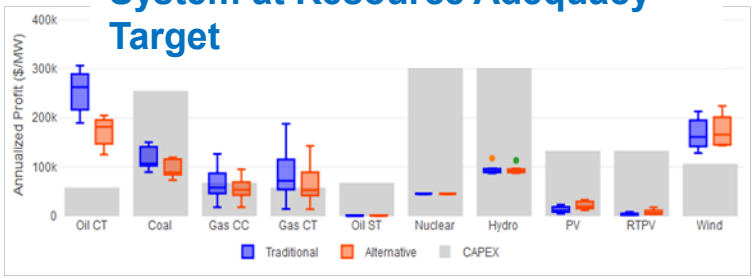
**LMP:** Locational Marginal Price

**ELMP:** Extended LMP
Accounts for additional operating costs and allows resources to set price that otherwise would be ineligible

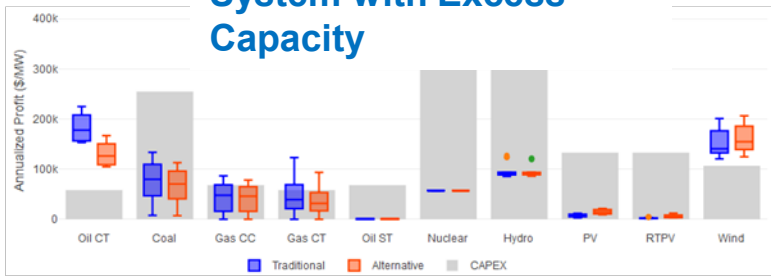
## Annual Profits/MW installed

High Renewable

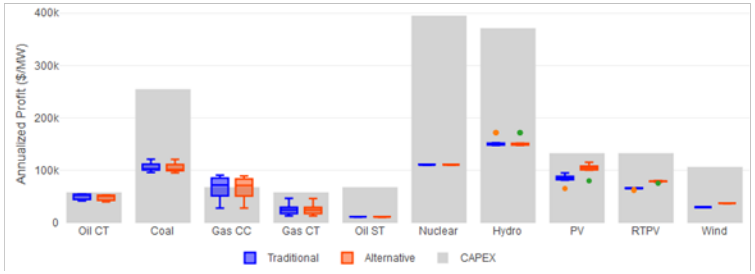
System at Resource Adequacy Target

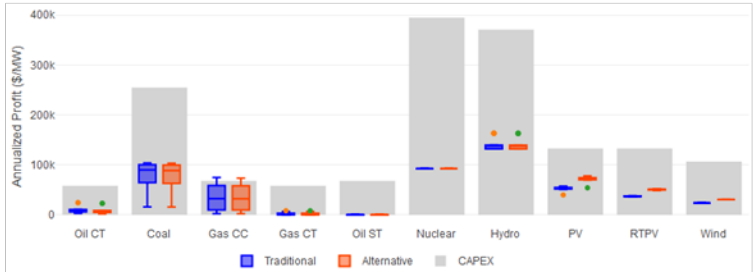



System with Excess Capacity




Low Renewable



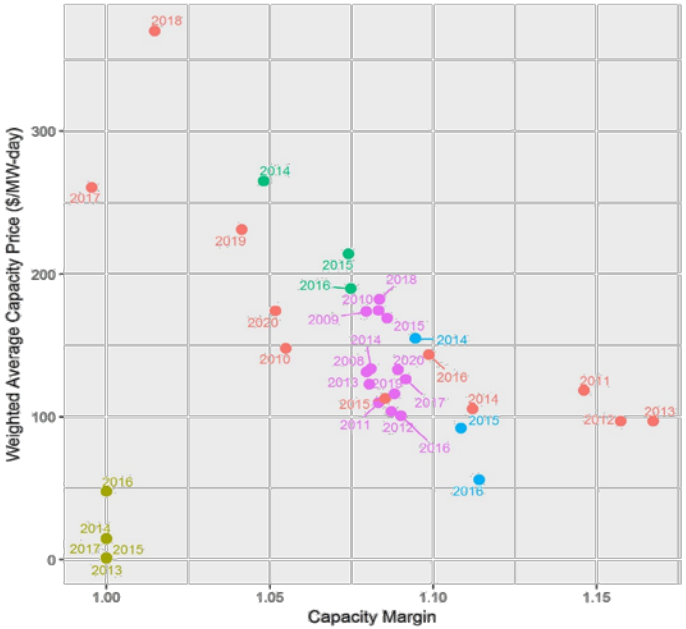

**Box plots of profits per resource compared to capital expenditure values**

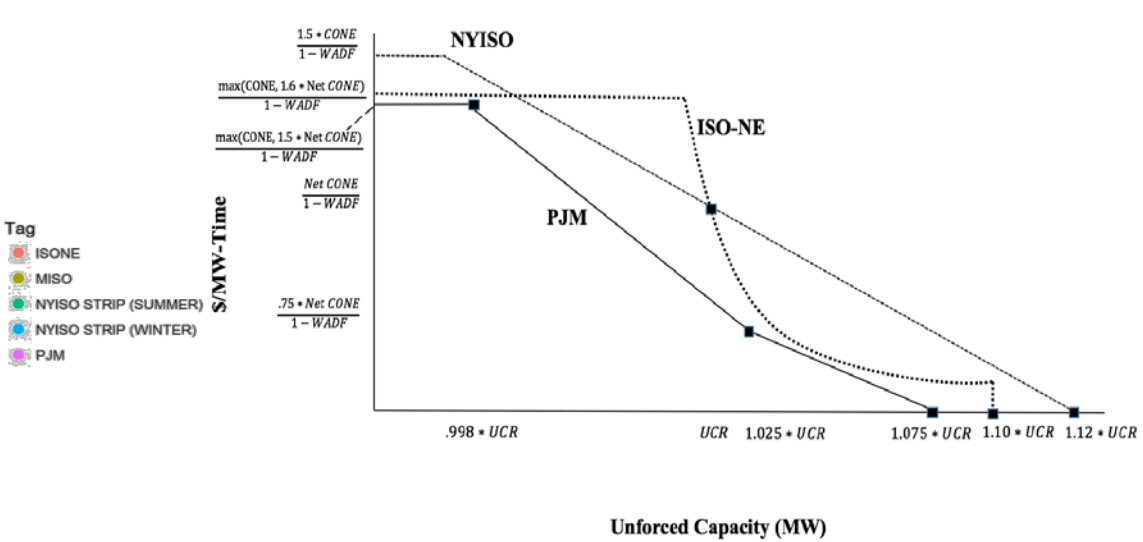
CAPEX represents any new builds; not a direct reflection of existing installed capacity cost

R. B. Hytowitz, B. Frew, G. Stephen, E. Ela, J. Lau, N. Singhal, and A. Bloom, "Impacts of Price Formation Efforts Considering High Renewable Penetration Levels and System Resource Adequacy Targets," NREL Technical Report, March 2019 (draft)

# Accomplishments and Progress (4)

- **Reviewed U.S. Capacity Markets**
  - Four ISO/RTO systems have capacity markets
  - Focus on performance incentives, qualifying capacity for renewables, demand curves for capacity
  - Many administrative parameters
  - Frequent re-design of capacity markets (e.g. two-tier markets)
  - No convergence on capacity market design

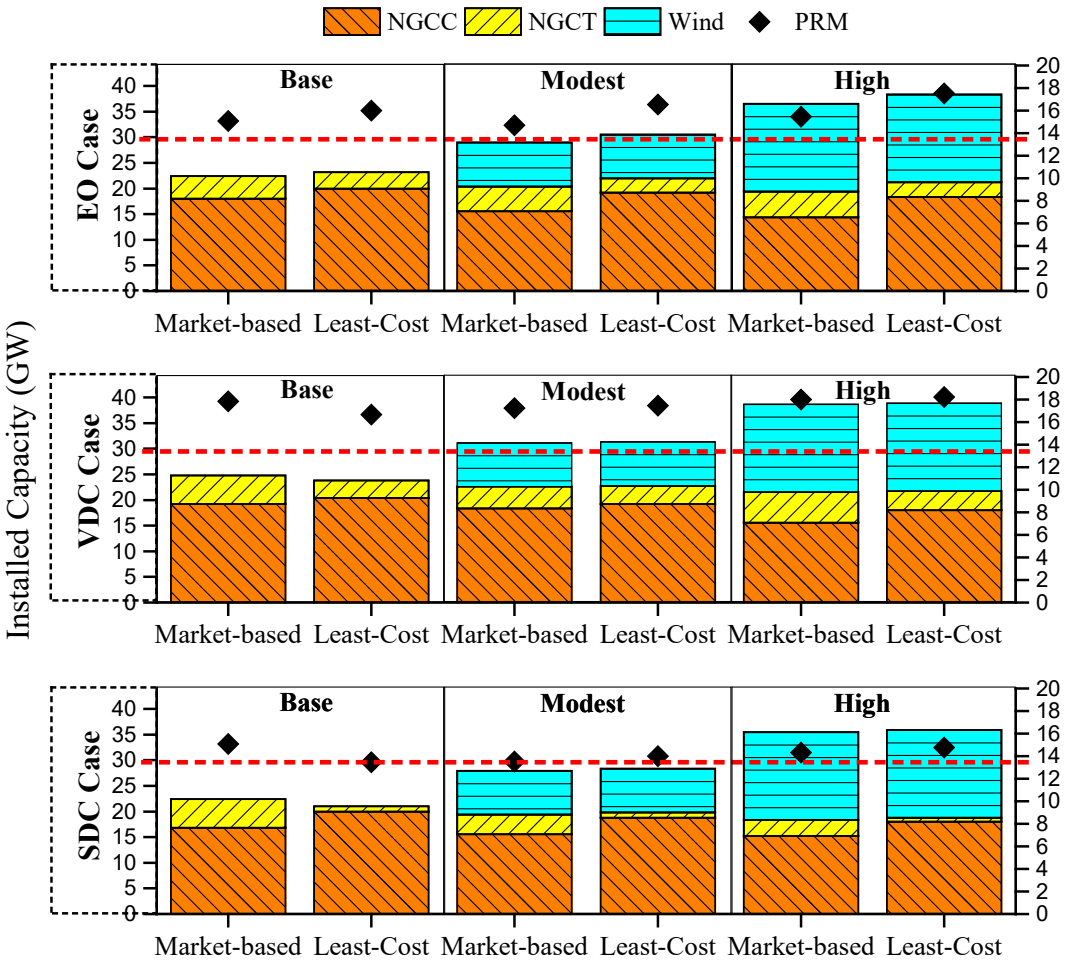



C. Byers, T. Levin, A. Botterud, "Capacity market design and renewable energy: Performance incentives, qualifying capacity, and demand curves," *Electricity Journal*. 31(1), pp. 65–74, 2018.

# Accomplishments and Progress (5)

*Least-cost vs Market-based Model*




J. Kwon, Z. Zhou, T. Levin, A. Botterud, "Market-based Resource Adequacy Assessment Framework under High Wind Penetrations," *submitted to IEEE Trans. Power Systems*, March 2019.

**Case study of "ERCOT" system**

- Energy only (EO) market, capacity market with vertical (VDC) or sloping (SDC) demand curve

**Market-based results show**:

- Investments depend on scarcity pricing and capacity market rules
- Reserve margin met under all wind levels and market designs
- Capacity markets tend to give more capacity than energy-only markets

**Compared to least-cost benchmark**:

- Market-based results show higher investments in NGCT
- Least-cost benchmark may give less capacity than market-based

# Accomplishments and Progress (6)

Energy-only market gives higher energy and reserve prices, but no additional capacity payments.

## Resulting Energy, Reserve, Capacity Prices

| Scenario | Market Design | Energy | Reserve | Capacity |
|---|---|---|---|---|
| | | $/MWh | $/MW | $/MW-day |
| Base | EO | 9,001/59 | 8,954/28 | - |
| | VDC | 2,297/39 | 2,250/8 | 123 |
| | SDC | 897/38 | 850/6 | 148 |
| Modest | EO | 9,001/70 | 8,954/39 | - |
| | VDC | 2,297/41 | 2,250/11 | 123 |
| | SDC | 2100/42 | 2,053/12 | 198 |
| High | EO | 9,001/69 | 8,954/39 | - |
| | VDC | 2,297/40 | 2,250/11 | 123 |
| | SDC | 2100/41 | 850/10 | 173 |

**EO**: Energy only market
**VDC**: Capacity Market with vertical demand curve
**SDC**: Sloping demand curve

# Accomplishments and Progress (7)

## Summary of Findings

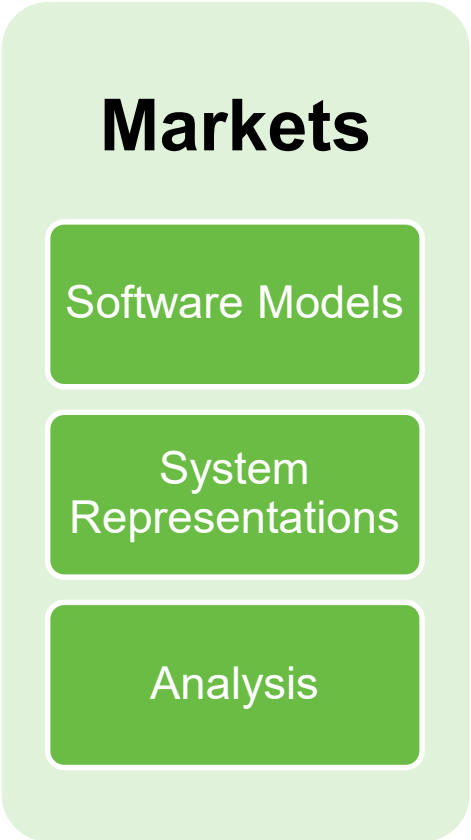
The novel modeling approaches and algorithms developed in this project enable us to study these complex interactions in electricity markets with more variable renewable energy

- The uncertainty of variable renewable energy can lead to greater occurrence of scarcity pricing and zero/negative price events.
- Prices can be highly dependent on the choice of administratively set scarcity pricing schemes.
- Variable renewable energy ability and eligibility to provide reserves can change generation dynamics and revenue.
- Electricity market design influences technology choice and investment levels.
- There are substantial variations in rules governing existing capacity markets.
- System reliability can be maintained under different market designs.

# Accomplishments and Progress (7)

## Summary of Accomplishments

- All milestones were completed on time; two required time extensions to complete
- There were no go/no-go decision points




- Designed and implemented novel modeling software and applications for researching wholesale electricity markets in increasing wind generation futures
- Created system representations for regional research of ERCOT-like and RTS-GMLC Published more than 10 technical and peer-reviewed papers
- Presented and led panels in more than 16 industry events, including conferences to share this project's findings and engage with stakeholders

# Communication, Coordination, and Commercialization

The project team had one-on-one discussions, presentations, and workshop participations with more than 11 organizations to share this project's findings and expertise.