Energy Transition and Reliability Challenges in Modern Power Grids

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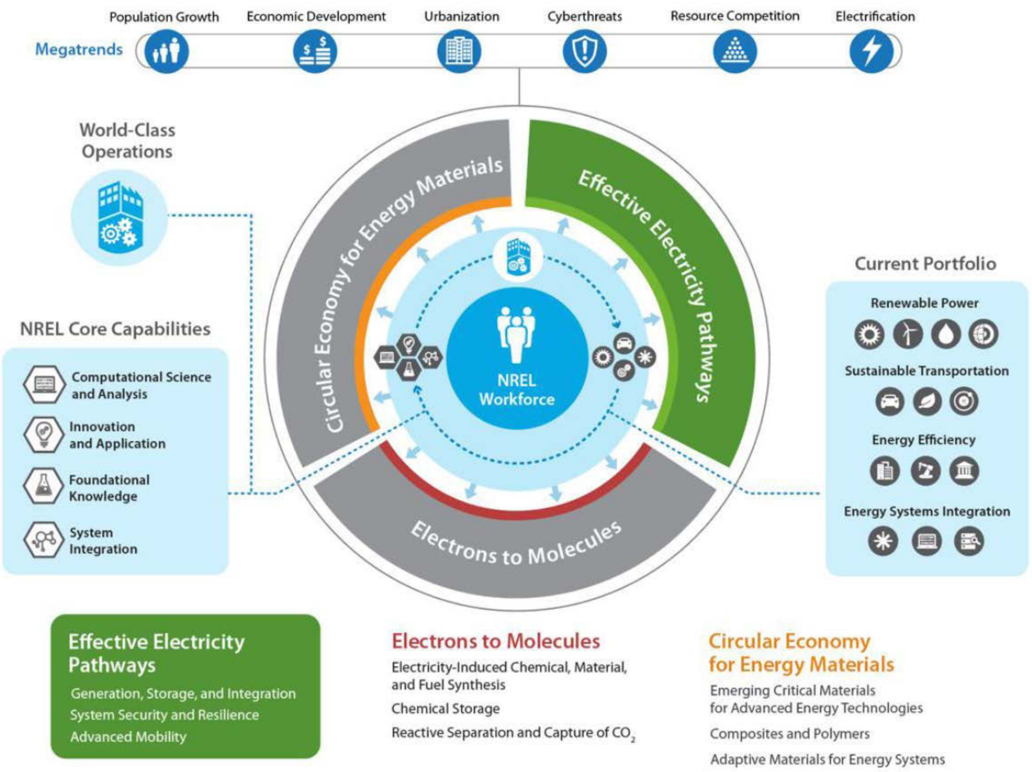
NREL Mission, Long-Term Strategy, and Vision



Megatrends

- Population Growth
- Economic Development
- Urbanization
- Cyberthreats
- Resource Competition
- Electrification

World-Class Operations

NREL Workforce

Circular Economy for Energy Materials

Effective Electricity Pathways

Electrons to Molecules

NREL Core Capabilities

- Computational Science and Analysis
- Innovation and Application
- Foundational Knowledge
- System Integration

Current Portfolio

- Renewable Power
- Sustainable Transportation
- Energy Efficiency
- Energy Systems Integration

Effective Electricity Pathways

Generation, Storage, and Integration

System Security and Resilience

Advanced Mobility

Electrons to Molecules

Electricity-Induced Chemical, Material, and Fuel Synthesis

Chemical Storage

Reactive Separation and Capture of CO_2

Circular Economy for Energy Materials

Emerging Critical Materials for Advanced Energy Technologies

Composites and Polymers

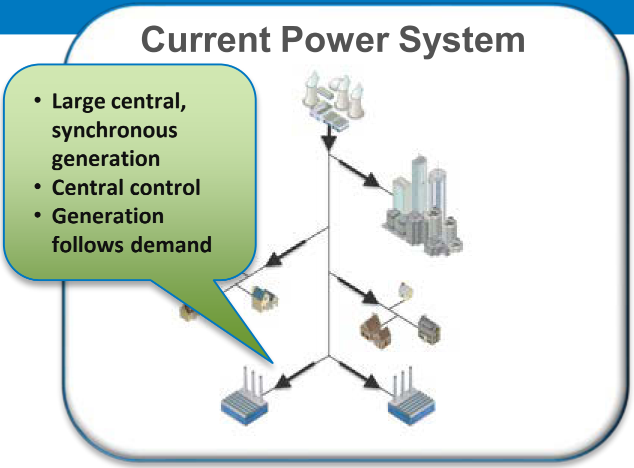
Adaptive Materials for Energy Systems

Source: NREL

NREL advances the science and engineering of energy-efficiency, sustainable transportation, and renewable power technologies and provides the knowledge to integrate and optimize energy systems.

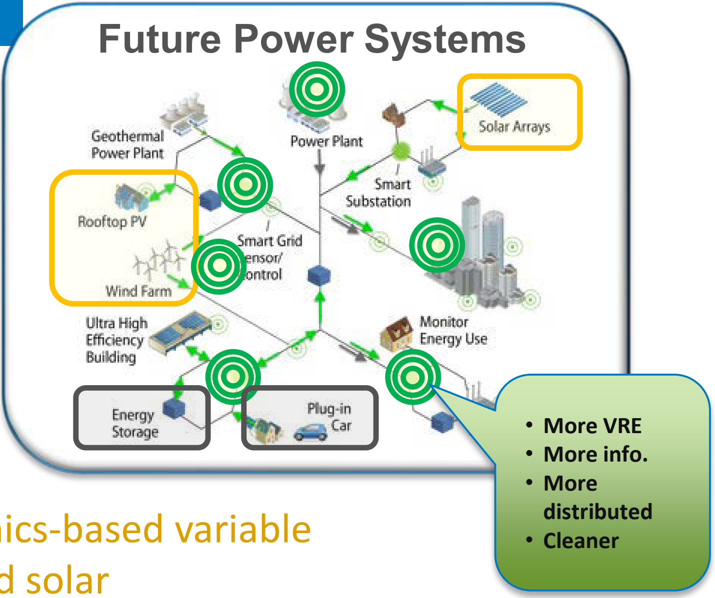
Source: NREL

Evolution of the Power System



Current Power System

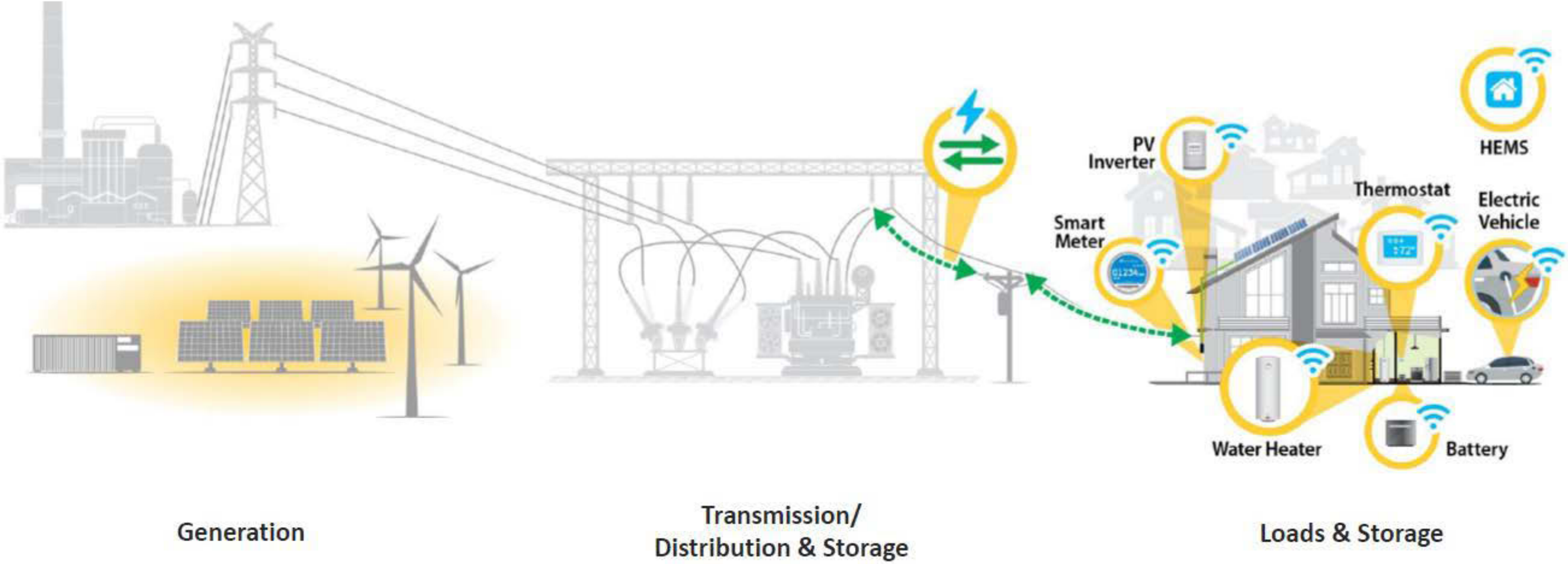
- **Large central, synchronous generation**
- **Central control**
- **Generation follows demand**



Future Power Systems

- **More VRE**
- **More info.**
- **More distributed**
- **Cleaner**

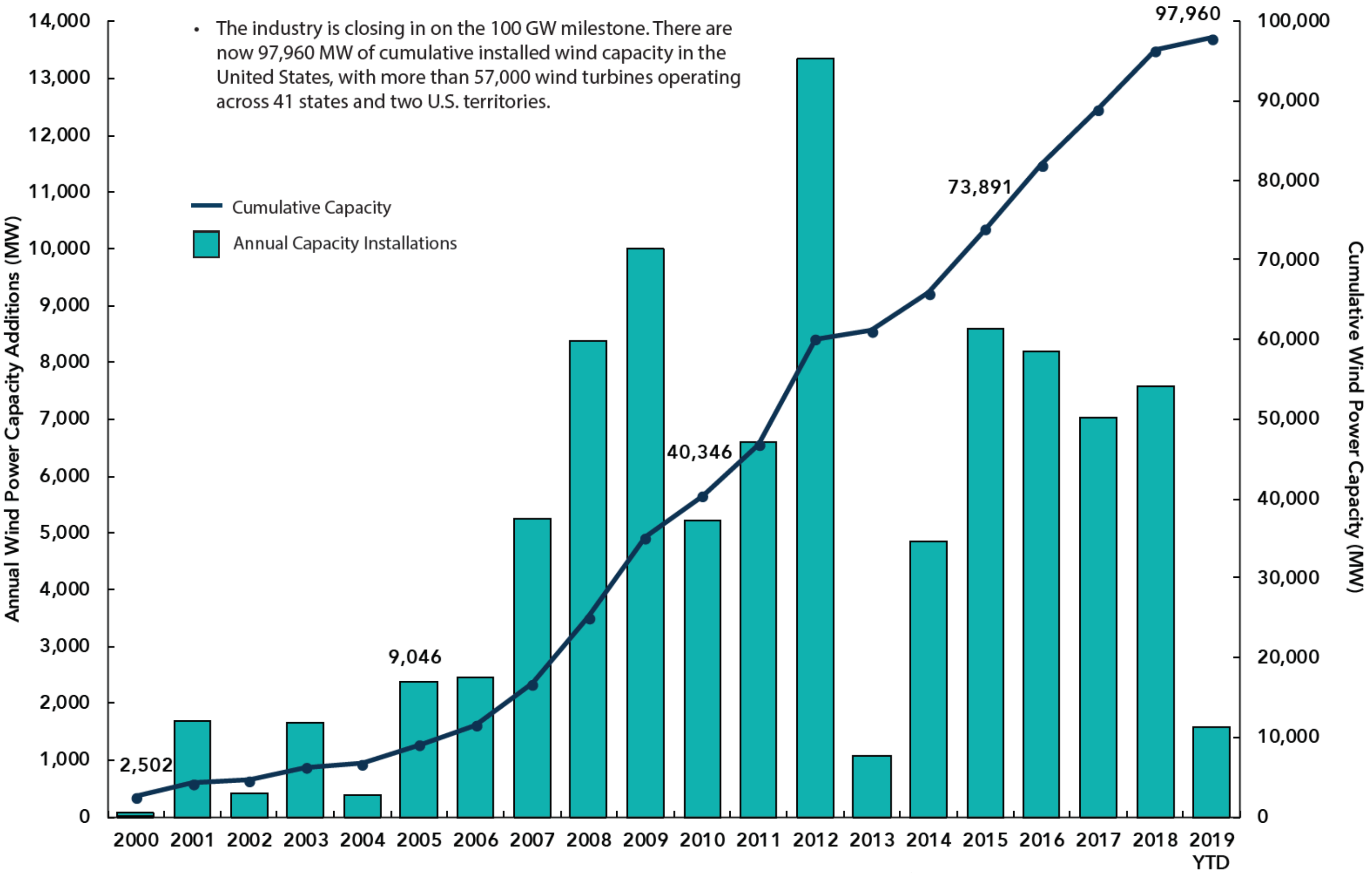
- Increasing levels of power electronics-based variable renewable energy (VRE)—wind and solar
- More use of communications, controls, data, and information (e.g., smart grids)—interoperability and cybersecurity issues
- Other new technologies: electric vehicles, distributed storage, flexible loads
- Becoming highly distributed—more complex to operate.



The grid is changing, largely at the edge

The cost of electricity generation is declining and new sectors are electrifying at an unprecedented pace, most notably transportation.

U.S. Wind Power Capacity

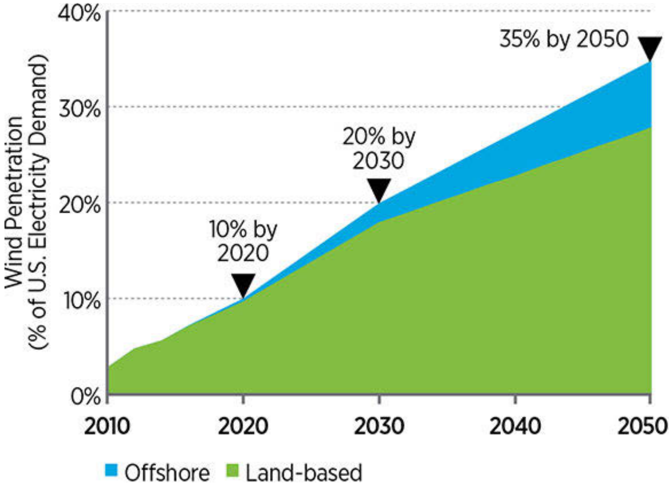

- The industry is closing in on the 100 GW milestone. There are now 97,960 MW of cumulative installed wind capacity in the United States, with more than 57,000 wind turbines operating across 41 states and two U.S. territories.

Source: AWEA Second Quarter 2019 U.S. Wind Industry Market Report

Vision

Wind energy could supply **20%** of the U.S. electrical demand by **2030.**

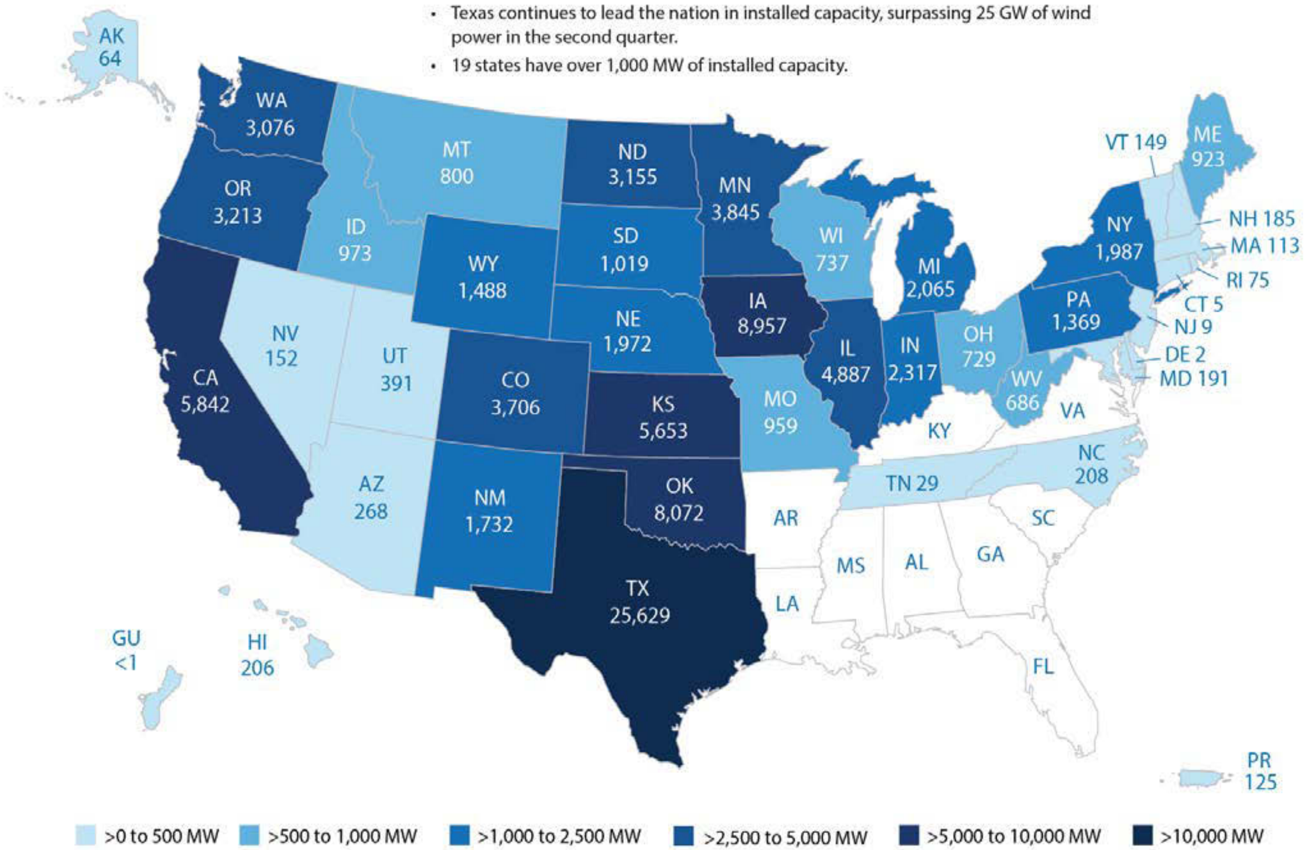
U.S. DOE Wind Vision Study scenarios



Source: Dennis Schroeder, NREL

Source: Dennis Schroeder, NREL

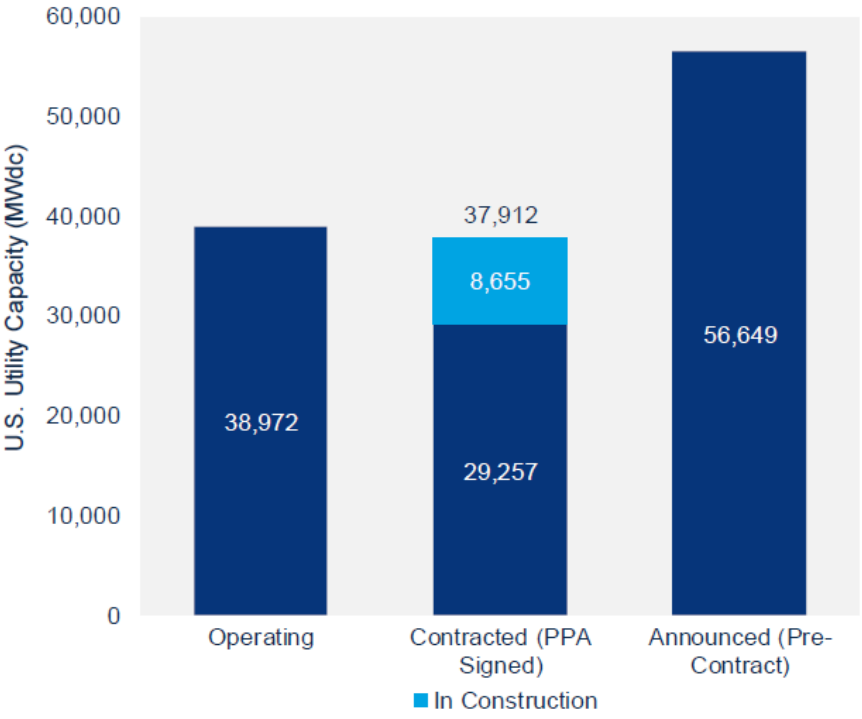
U.S. Wind Power Installed Capacity by State

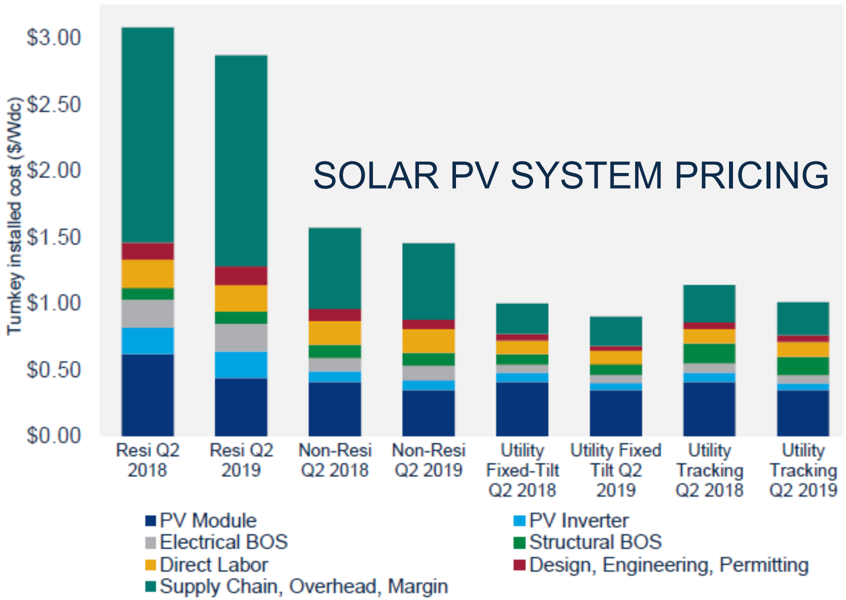


- Texas continues to lead the nation in installed capacity, surpassing 25 GW of wind power in the second quarter.
- 19 states have over 1,000 MW of installed capacity.

Source: AWEA Second Quarter 2019 U.S. Wind Industry Market Report

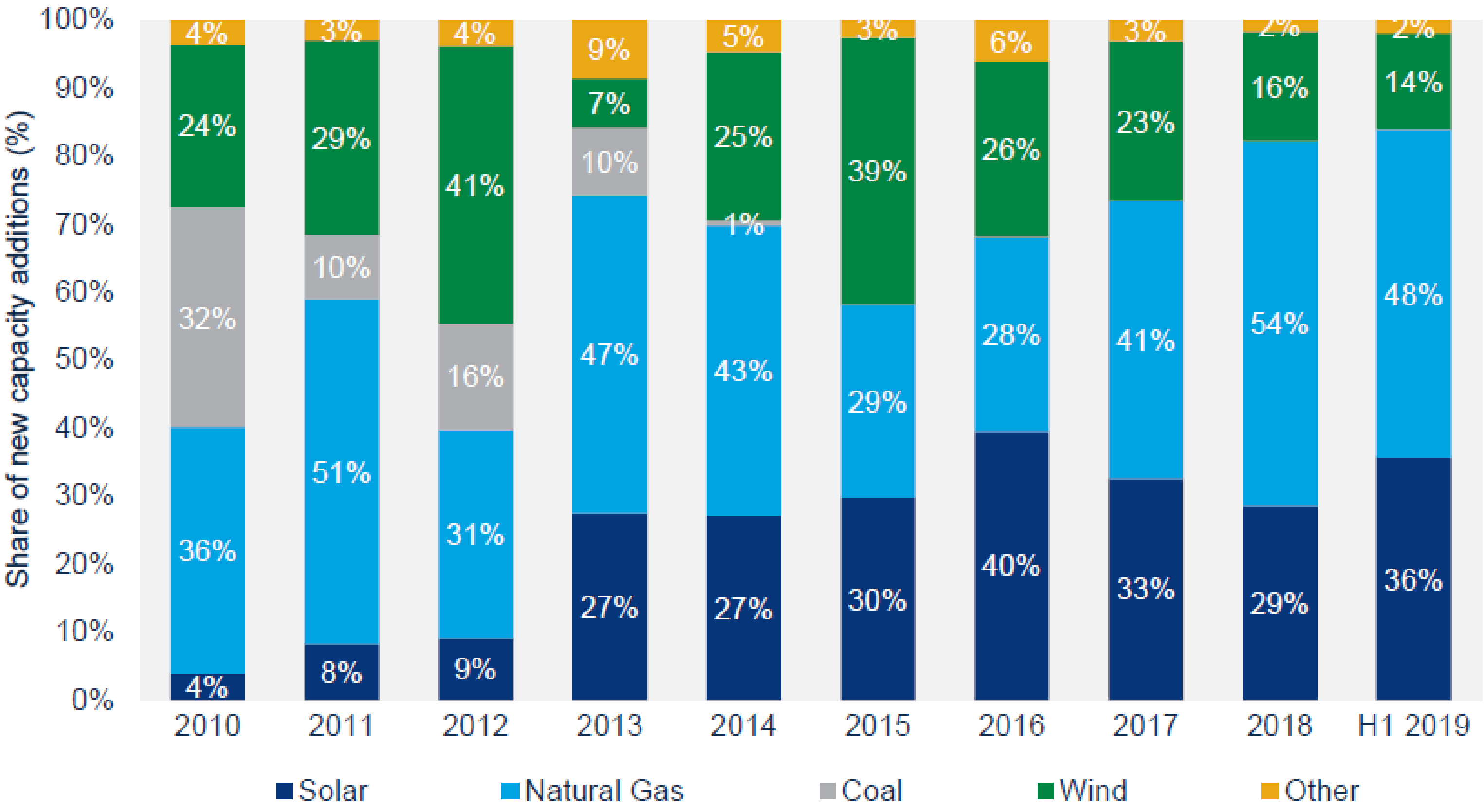
U.S. Utility-Scale PV Pipeline




SOLAR PV SYSTEM PRICING

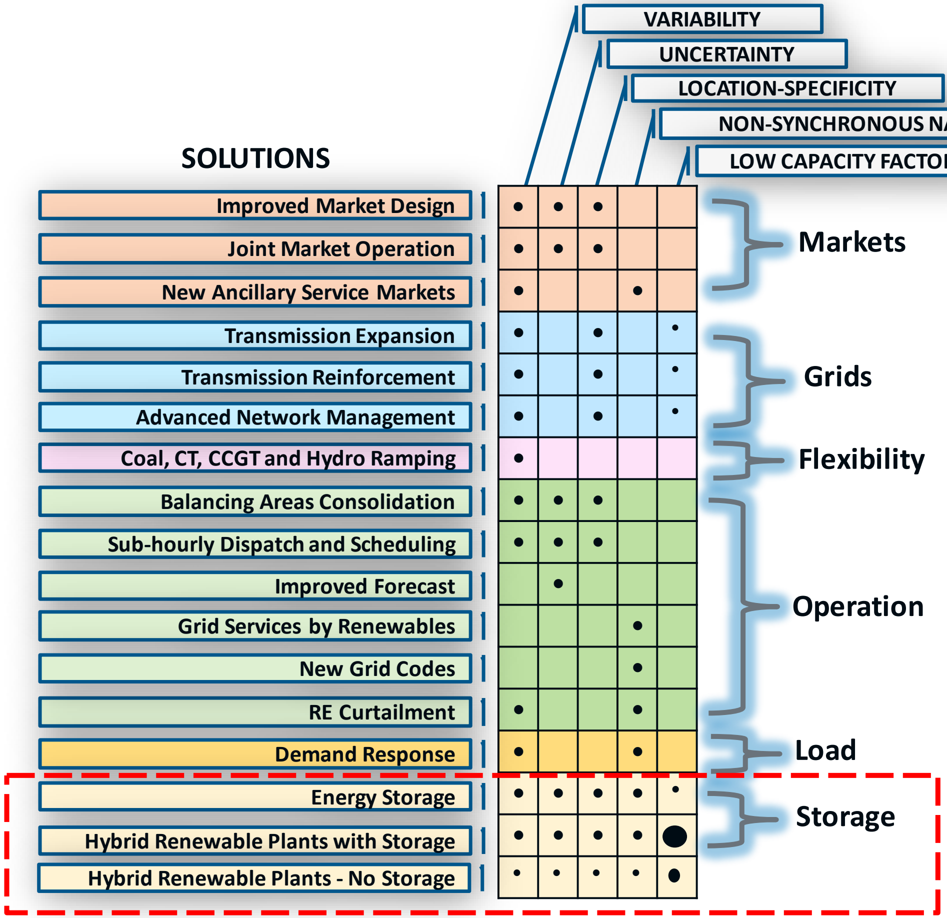
Source: Wood Mackenzie, “Power & Renewables”

New U.S. Electricity Capacity Additions

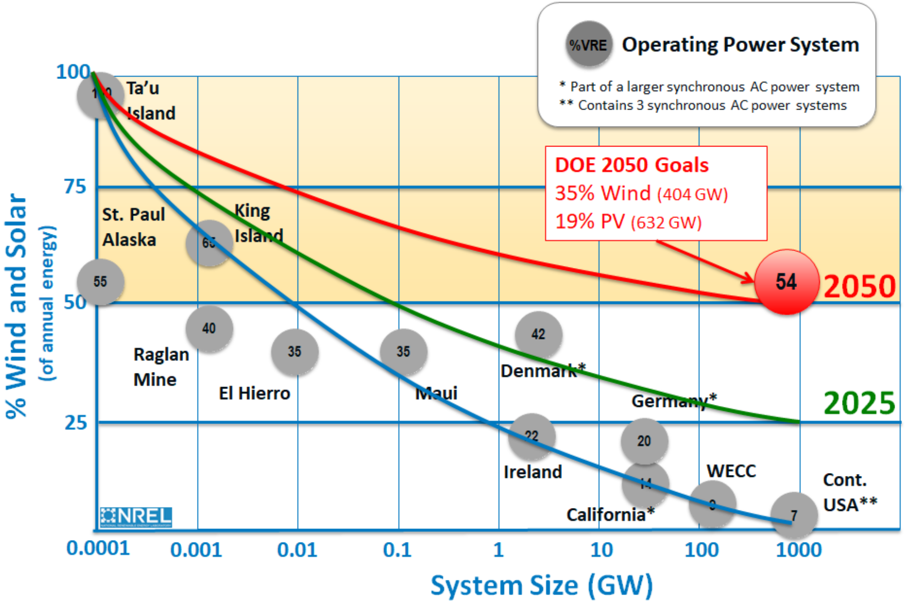


Source: AWEA Second Quarter 2019 U.S. Wind Industry Market Report

Grid Integration Challenges

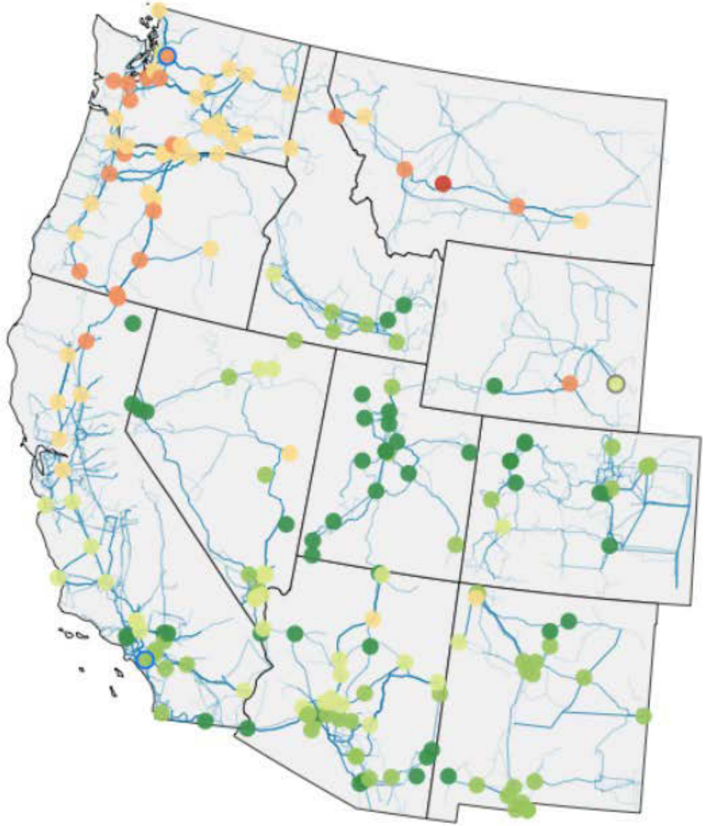


SOLUTIONS	VARIABILITY	UNCERTAINTY	LOCATION-SPECIFICITY	NON-SYNCHRONOUS NATURE	LOW CAPACITY FACTOR	
Improved Market Design	●	●	●			Markets
Joint Market Operation	●	●	●			
New Ancillary Service Markets	●			●		
Transmission Expansion	●		●		•	Grids
Transmission Reinforcement	●		●		•	
Advanced Network Management	●		●		•	
Coal, CT, CCGT and Hydro Ramping	●					Flexibility
Balancing Areas Consolidation	●	●	●			Operation
Sub-hourly Dispatch and Scheduling	●	●	●			
Improved Forecast		●				
Grid Services by Renewables				●		
New Grid Codes				●		
RE Curtailment	●			●		
Demand Response	●			●		Load
Energy Storage	●	●	●	●	•	Storage
Hybrid Renewable Plants with Storage	●	●	●	●	⬤	
Hybrid Renewable Plants - No Storage	•	•	•	•	●	

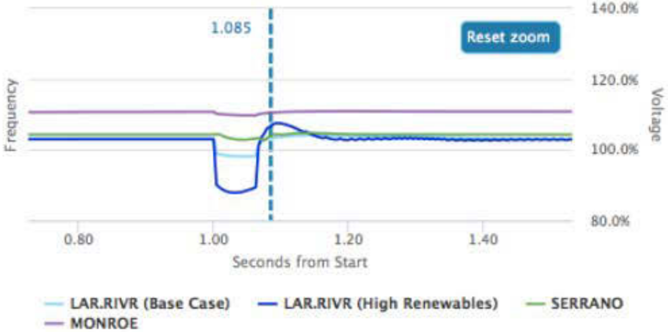


Source: B. Kroposki, NREL

Western Wind and Solar Integration Study



*The primary objectives of Phase 3 of the Western Wind and Solar Integration Study (WWSIS-3) were to examine the large-scale transient stability and frequency response of the Western Interconnection with high wind and solar penetration. WWSIS-3 evaluated a variety of system conditions, disturbances, locations, and renewable penetration levels to help draw broader conclusions. Key finding was that **with good system planning, sound engineering practices, and commercially available technologies, the Western Interconnection can withstand the crucial first minute after grid disturbances with high penetrations of wind and solar.***

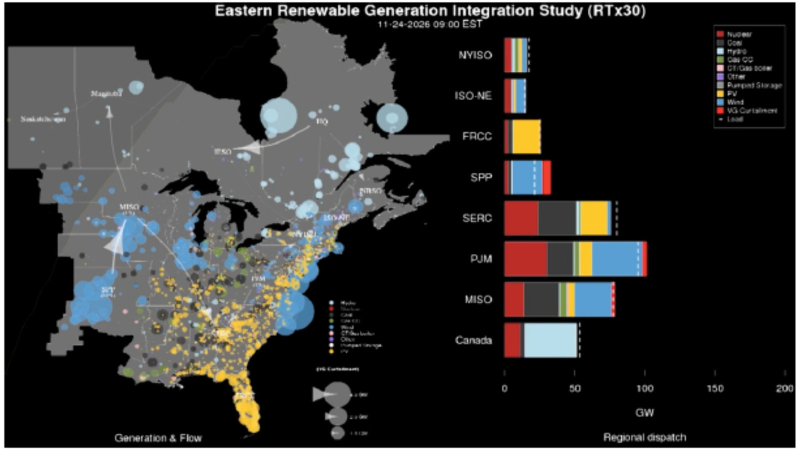


Impact
Western Interconnect can survive a major contingency outage with 30% variable generation (inverter-based)

http://www.nrel.gov/docs/fy16osti/64822.pdf

Eastern Renewable Grid Integration Study (ERGIS)

- **Goals**
  - Operational impact of 30% wind and solar penetration on the Eastern Interconnection at a 5-minute resolution.
  - Efficacy of mitigation options in managing variability and uncertainty in the system.



Operational Areas of Interest
- Reserves
  - Types
  - Quantities
  - Sharing
- Commitment and Dispatch
  - Day-ahead
  - 4-hour-ahead
  - Real-time
- Inter-regional Transactions
  - 1-hour
  - 15-minute
  - 5-minute

Impact
Demonstrated that very large power systems can operate at a 5-min dispatch with 30% VRE

Eastern Renewable Energy Integration Study (ERGIS) (2016)
http://www.nrel.gov/grid/ergis.html

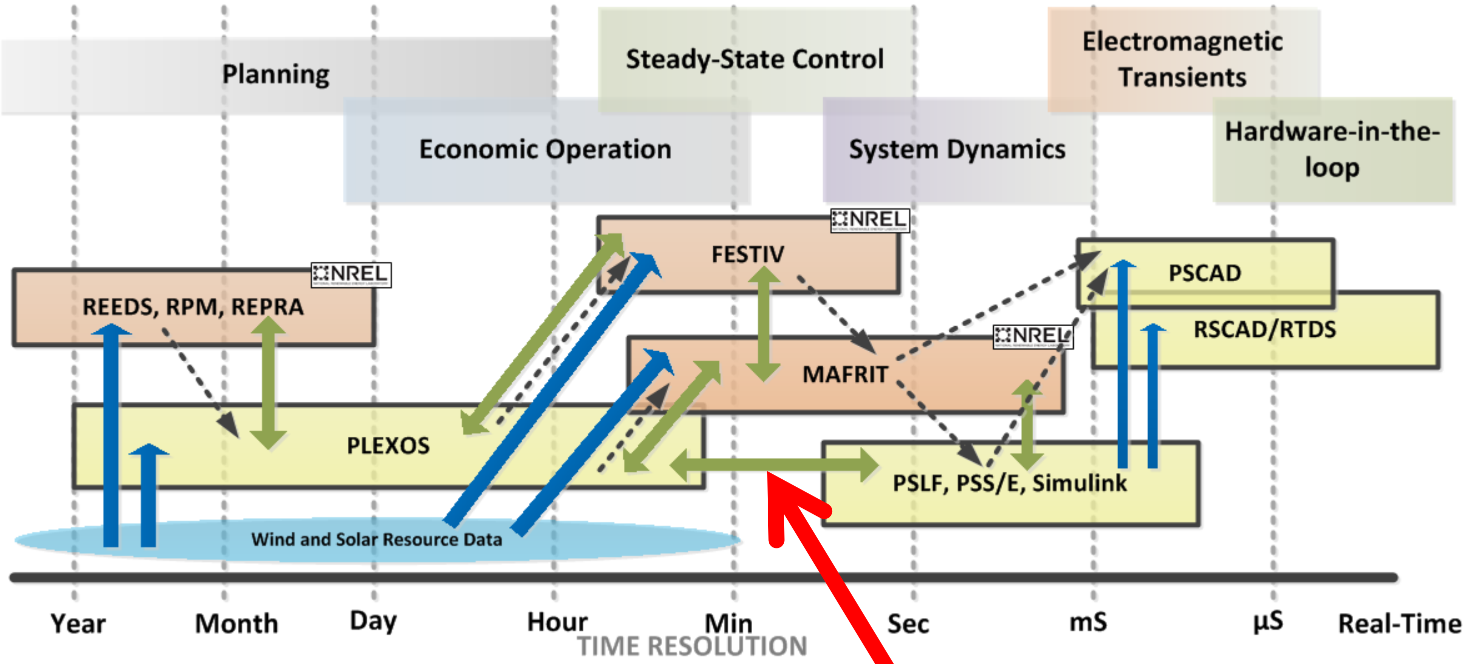
U.S. DOE Grid Modernization Intiative

- In 2016, DOE announced the first Grid Modernization Initiative—a comprehensive, $220 million, 3-year plan to mobilize 87 projects across the country, bringing together DOE and the national laboratories with more than 100 companies, utilities, research organizations, state regulators, and regional grid operators to pursue critical research and development in advanced storage systems, clean energy integration, standards and test procedures, and a number of other key grid modernization areas.

- In 2019, the second Grid Modernization Laboratory Consortium initiative was issued, focused on 5 major research areas:
  - Resilience
  - Energy Storage and System Flexibility
  - Advanced Sensors and Data Analytics
  - Institutional Support and Analysis
  - Cyber-Physical Security
  - Generation.

GRID
MODERNIZATION INITIATIVE
U.S. Department of Energy

NREL Software Tools for Grid Integration Studies

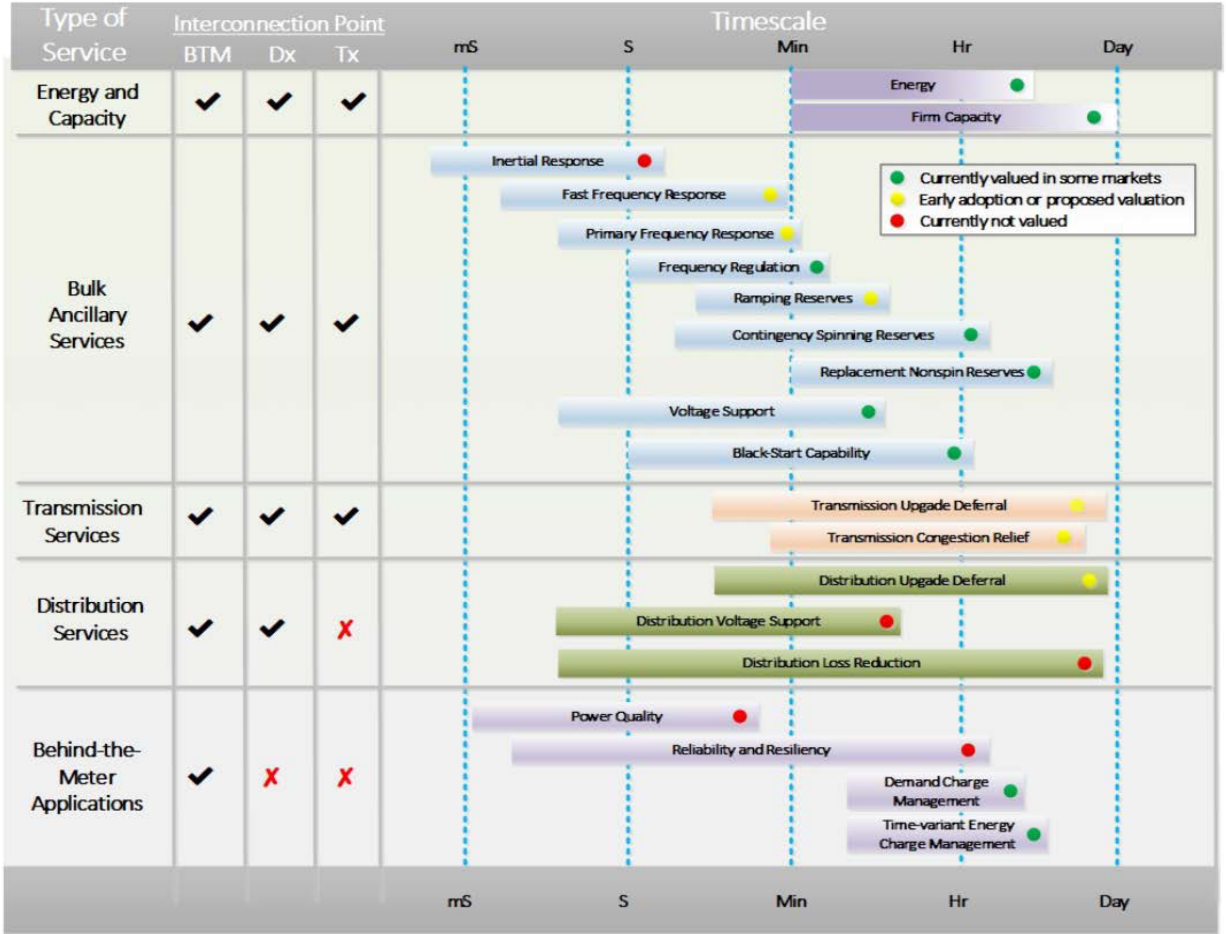


Gap with the existing commercial software tools

NREL in-house modeling tools:

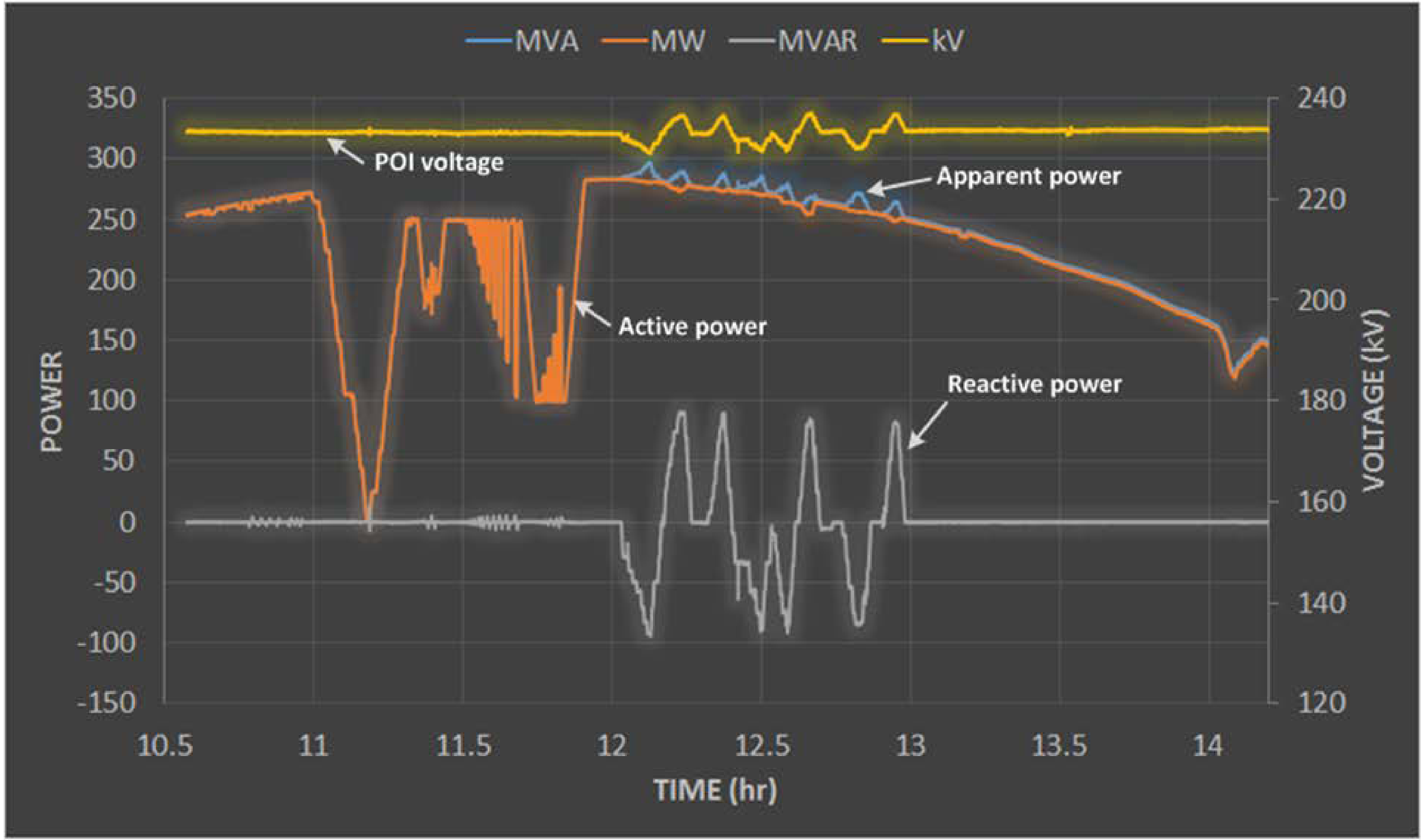
- REEDS: Regional Energy Deployment System model
- RPM: Resource Planning Model tool
- REPRA: Renewable Energy Probabilistic Resource Assessment tool
- FESTIV: Flexible Energy Scheduling Tool for Integrating Variable Generation
- MAFRIT: Multi-Area Frequency Response Integration Tool

Services by Battery Energy Storage Systems



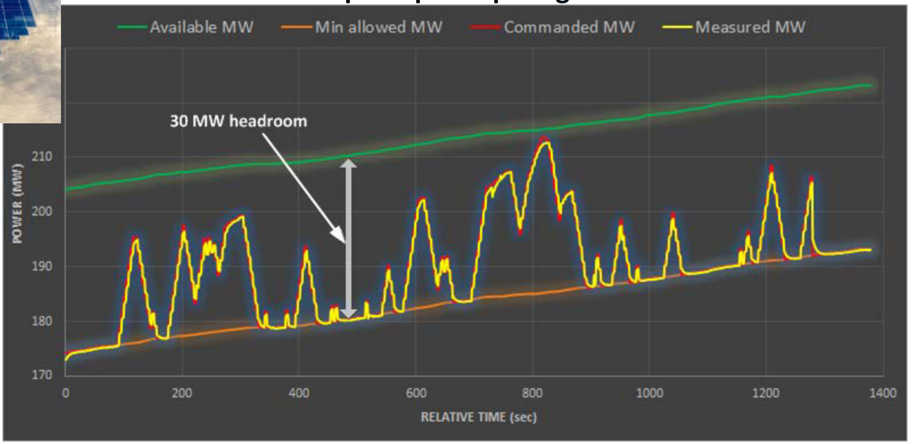
Type of Service	Interconnection Point		
	BTM	Dx	Tx
Energy and Capacity	✓	✓	✓
Bulk Ancillary Services	✓	✓	✓
Transmission Services	✓	✓	✓
Distribution Services	✓	✓	✗
Behind-the-Meter Applications	✓	✗	✗

Testing 300-MW PV Plant in CAISO Service Territory

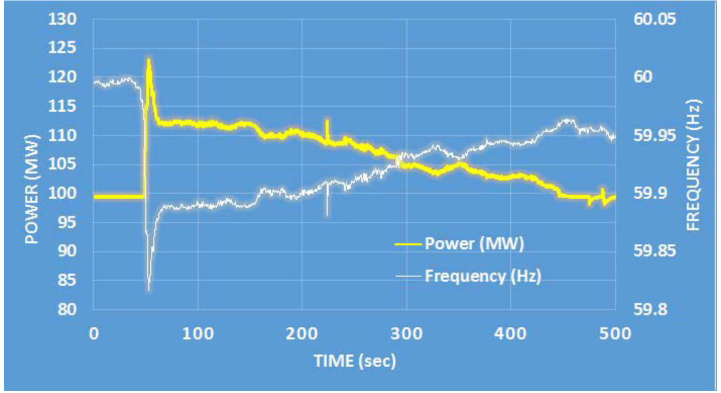


Testing 300-MW PV Plant in California

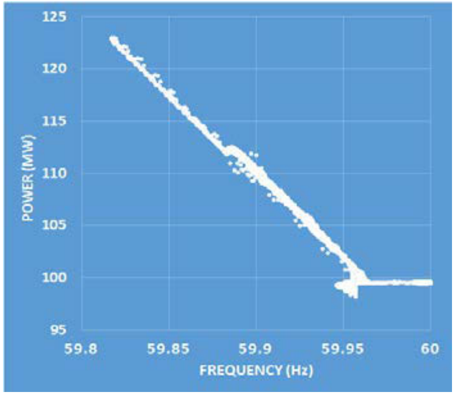
300-MW PV plant participating in AGC



Example of 3% droop test (underfrequency)



Measured droop response



Measured Regulation Accuracy by 300-MW PV Plant

Time Frame	Solar PV Plant Test Results
Sunrise	93.7%
Middle of the day	87.1%
Sunset	87.4%

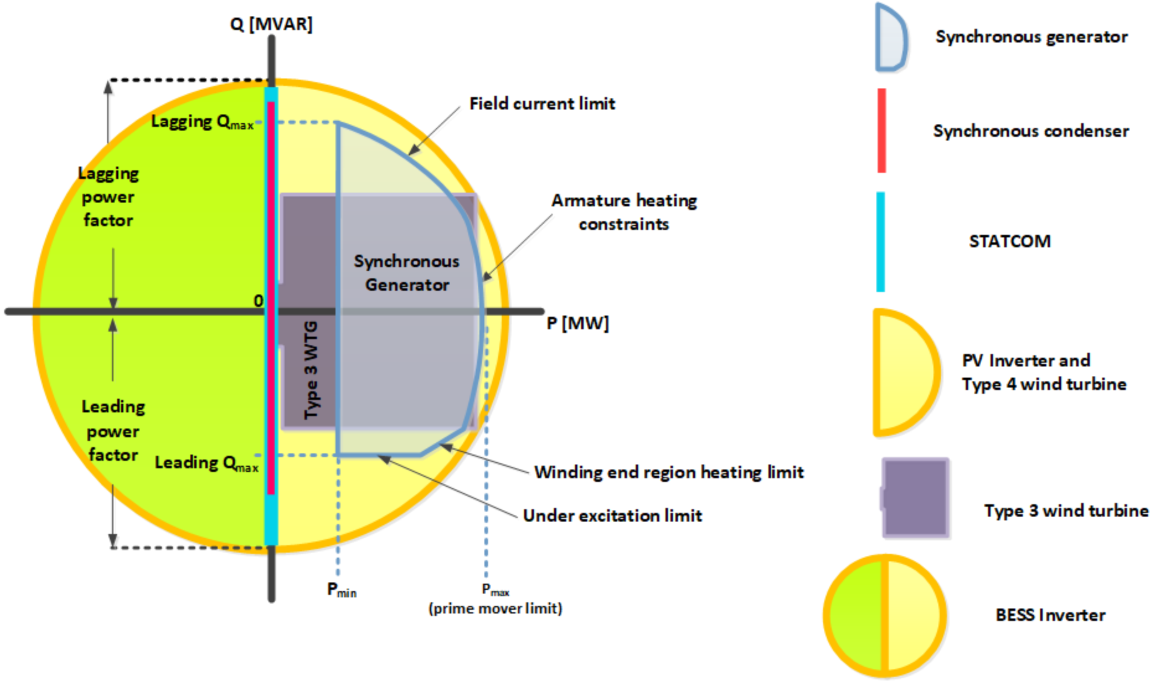
Typical Regulation-Up Accuracy of CAISO Conventional Generation

	Combined Cycle	Gas Turbine	Hydro	Limited Energy Battery Resource	Pump Storage Turbine	Steam Turbine
Regulation-Up Accuracy	46.88%	63.08%	46.67%	61.35%	45.31%	40%

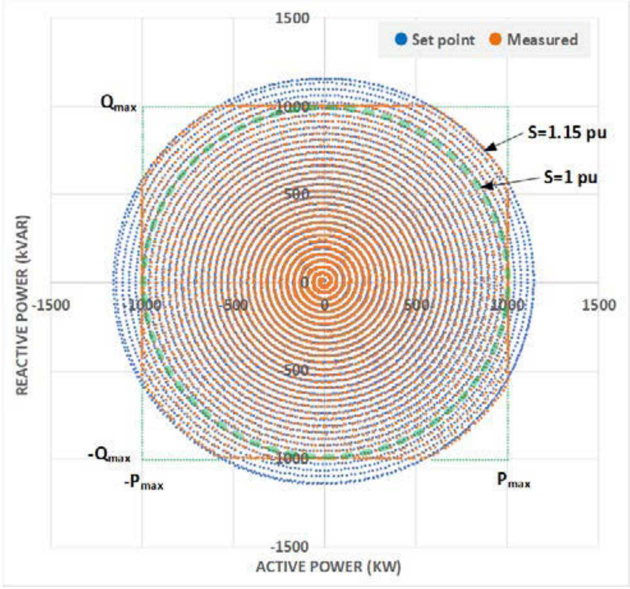
Regulation accuracy by this PV plant is 24%–30% better than fast gas turbine technologies.

Reactive Power Capabilities of Inverter-Coupled Resources

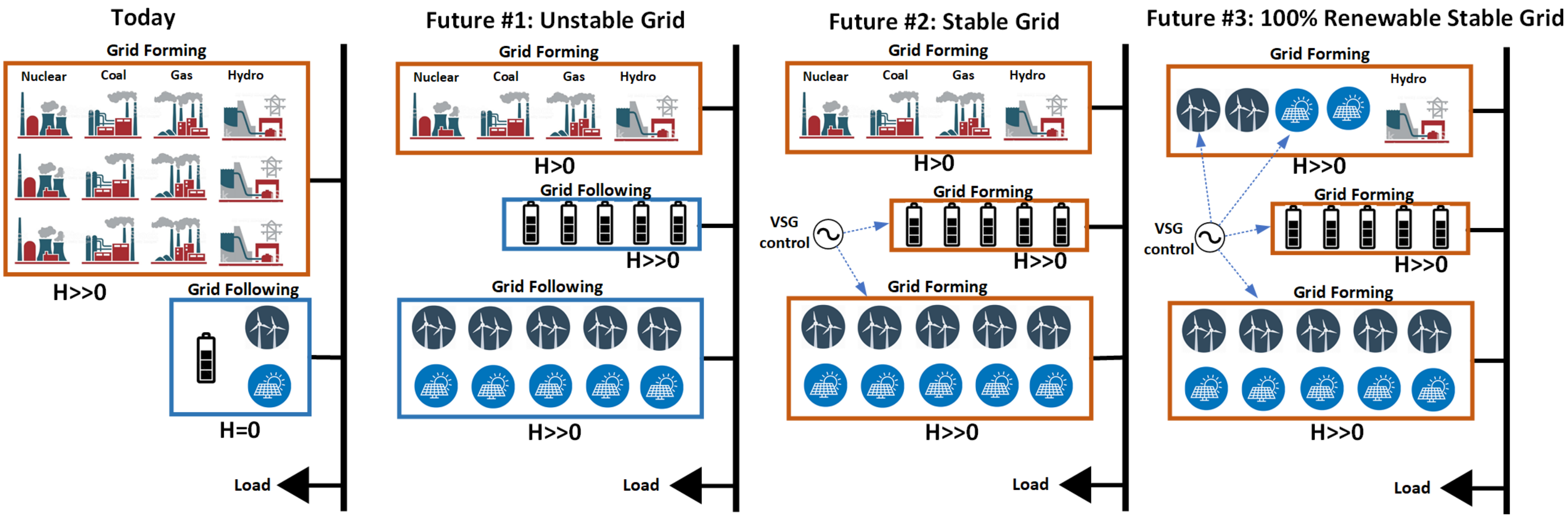
Comparison of reactive power capabilities



Measured P-Q capability of 1-MW/1-MWh Li-ion BESS



Grid-Forming: Essential for Stable Operation



Black-Start Stages

The black-start process can be divided into three stages:

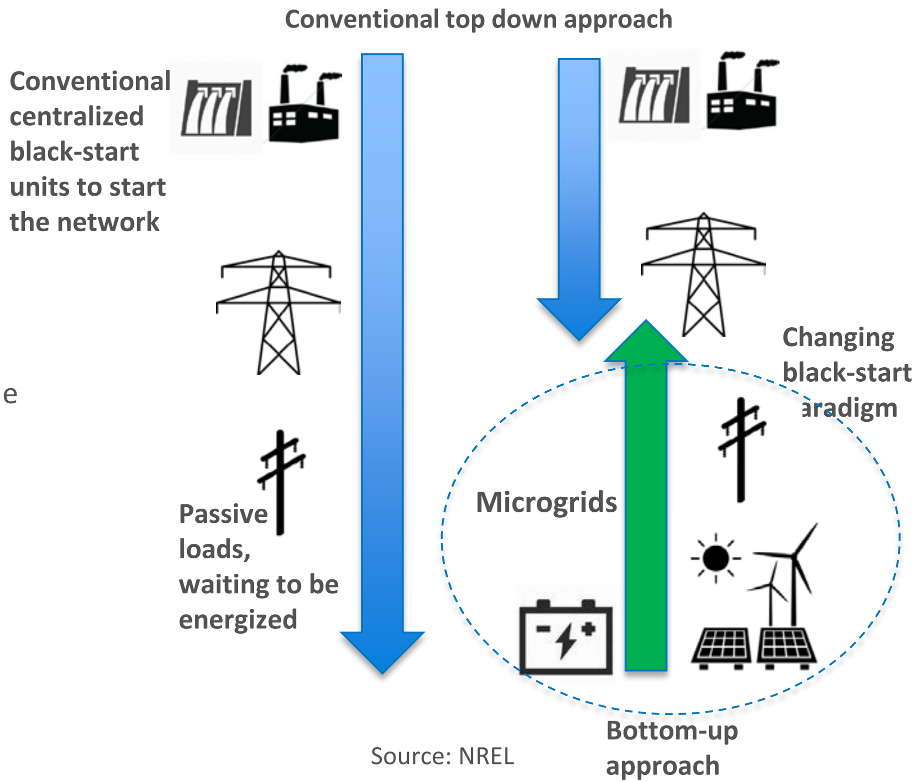
- **Preparation stage**
- **Network reconfiguring**
- **Load restoration.**

A typical restoration plan for the bulk power system includes the following essential steps:

- System status identification: blackout boundaries and location in respect to critical loads, status of circuit breakers, capacity of available black-start units, etc.
- Starting at least one black-start unit to supply critical loads, such as nuclear or large thermal power plants
- Progressive restoration: step-by-step supply of other loads, avoiding over- and undervoltage conditions.

The restoration strategies:

- Serial: simpler strategy, slower but more stable
- Parallel: quicker but more complex.



Conventional top down approach

Conventional centralized black-start units to start the network

Passive loads, waiting to be energized

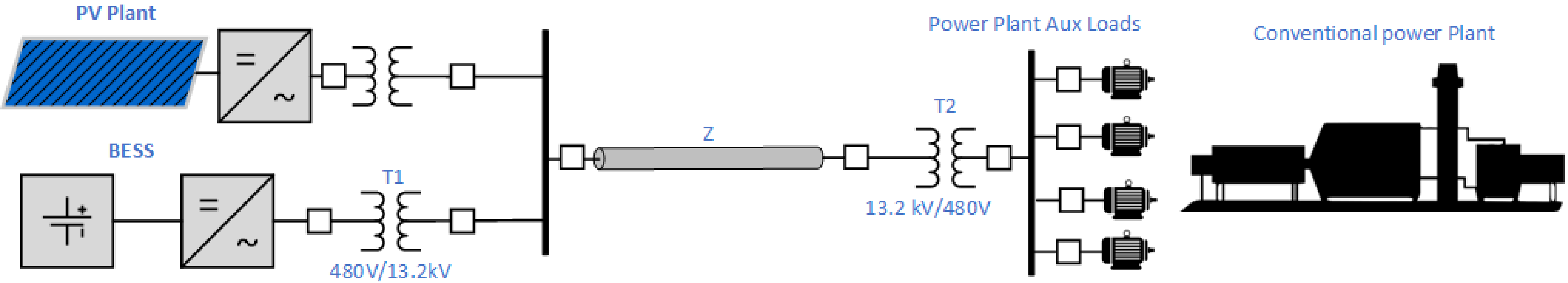
Changing black-start aradigm

Microgrids

Bottom-up approach

Source: NREL

PV-BESS Black-Starting a Gas Turbine Generator



Source: NREL

Main challenge:

- Energizing transformers and feeders
- Midsize gas turbines employ starting motors
- Black-start inverters need to be sized to provide necessary inrush current.

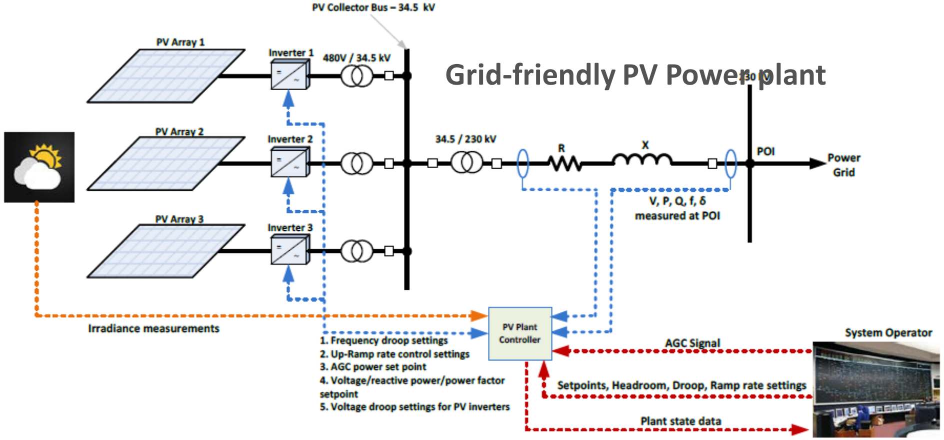
Possible solutions:

- Oversized inverters for inrush current
- Equip all plant motor loads with soft starters of variable-frequency drives
- Partial solution: energize transformers with tap positions at highest number of turns.

Conclusion

- Modern inverter-coupled variable generation and energy storage systems are capable of providing all types of reliability services to the grid.
- Adequate market designs are essential for unleashing such capabilities as an important tool in achieving the broader objective of a resilient, reliable, low-carbon grid.
- Exploring economic and/or contractual incentives to maximize production and not hold back production to provide reliability services
- Markets should incentivize faster and more accurate resources that provide such services.

- Grid forming is important for stability and resilience of future grids.
- What are the optimum ratios between grid-forming and grid-following resources?
- Do we need grid-following resources at all?
- What are the stability impacts of grid-forming operation and how do we identify and mitigate them (small-signal and transient stability, control interactions, subsynchronous oscillations, harmonic resonances, etc.)?



Grid-friendly PV Power plant

Thank you
Eskerrik asko
Gracias

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