ELECTRIC POWER RESEARCH INSTITUTE

Grid Operations and Planning Challenges with Decarbonized Future

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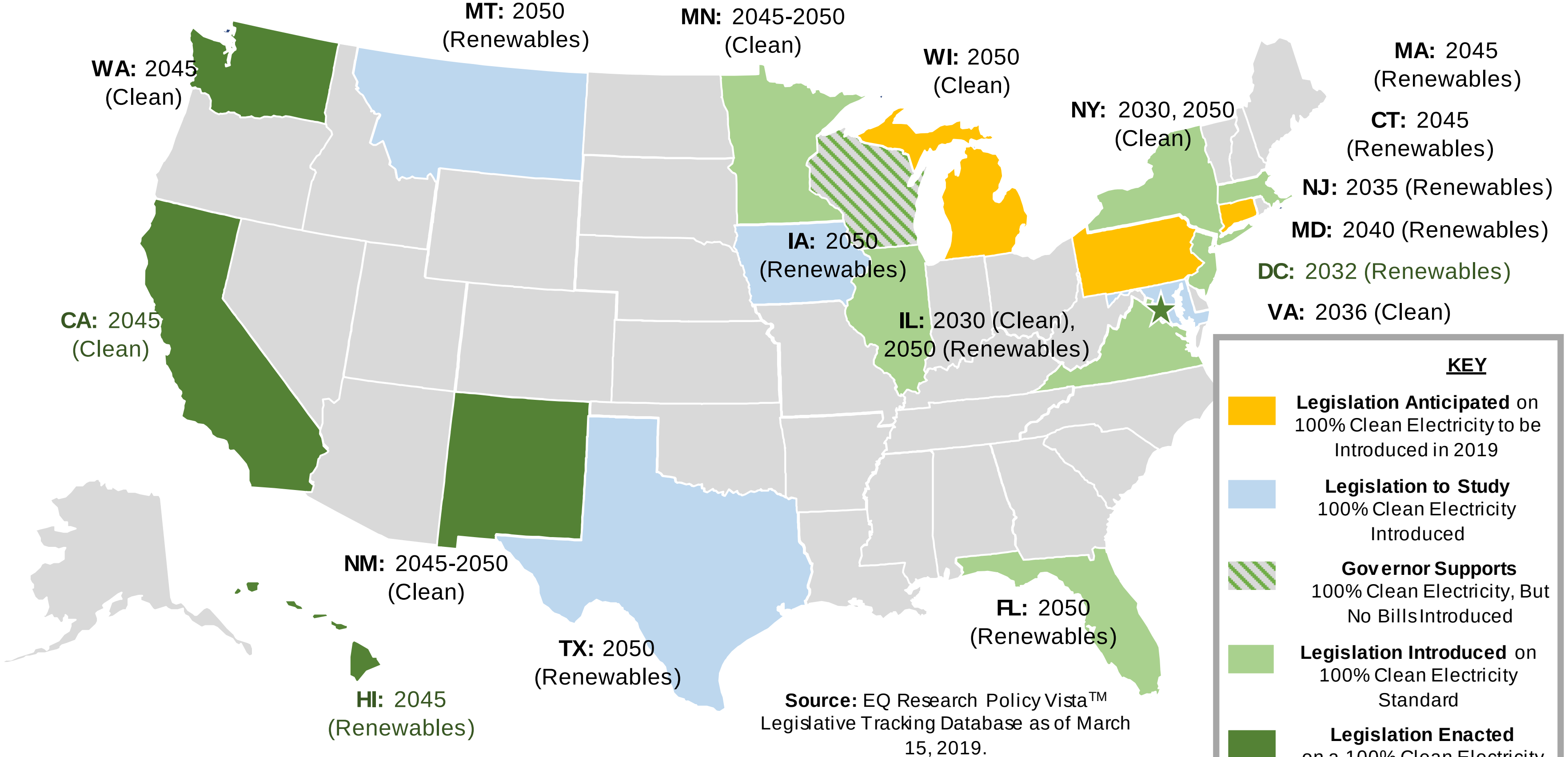
100% Clean or Renewable Energy Targets

Anticipated, Proposed or Enacted 100% Standards and Studies



Source: EQ Research Policy Vista™ Legislative Tracking Database as of March 15, 2019.

Note: Map assumes New Mexico SB 489 is enacted.

GridLAB

ESIG ENERGY SYSTEMS INTEGRATION GROUP

As of May 2019

RE 100 ABOUT RE100 PARTNERS GOING 100%

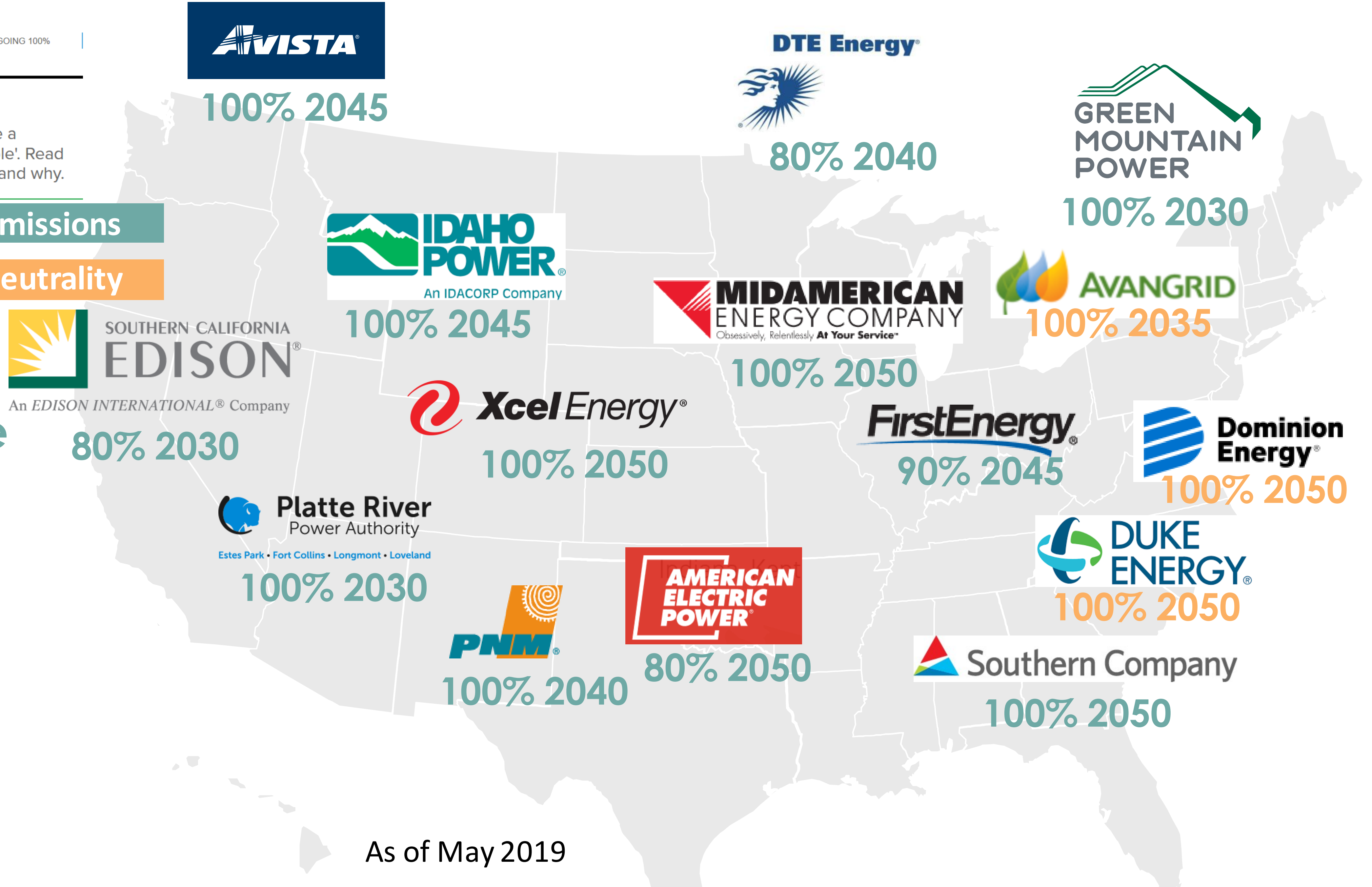
Companies

226 RE100 companies have made a commitment to go '100% renewable'. Read about the actions they are taking and why.

Emissions

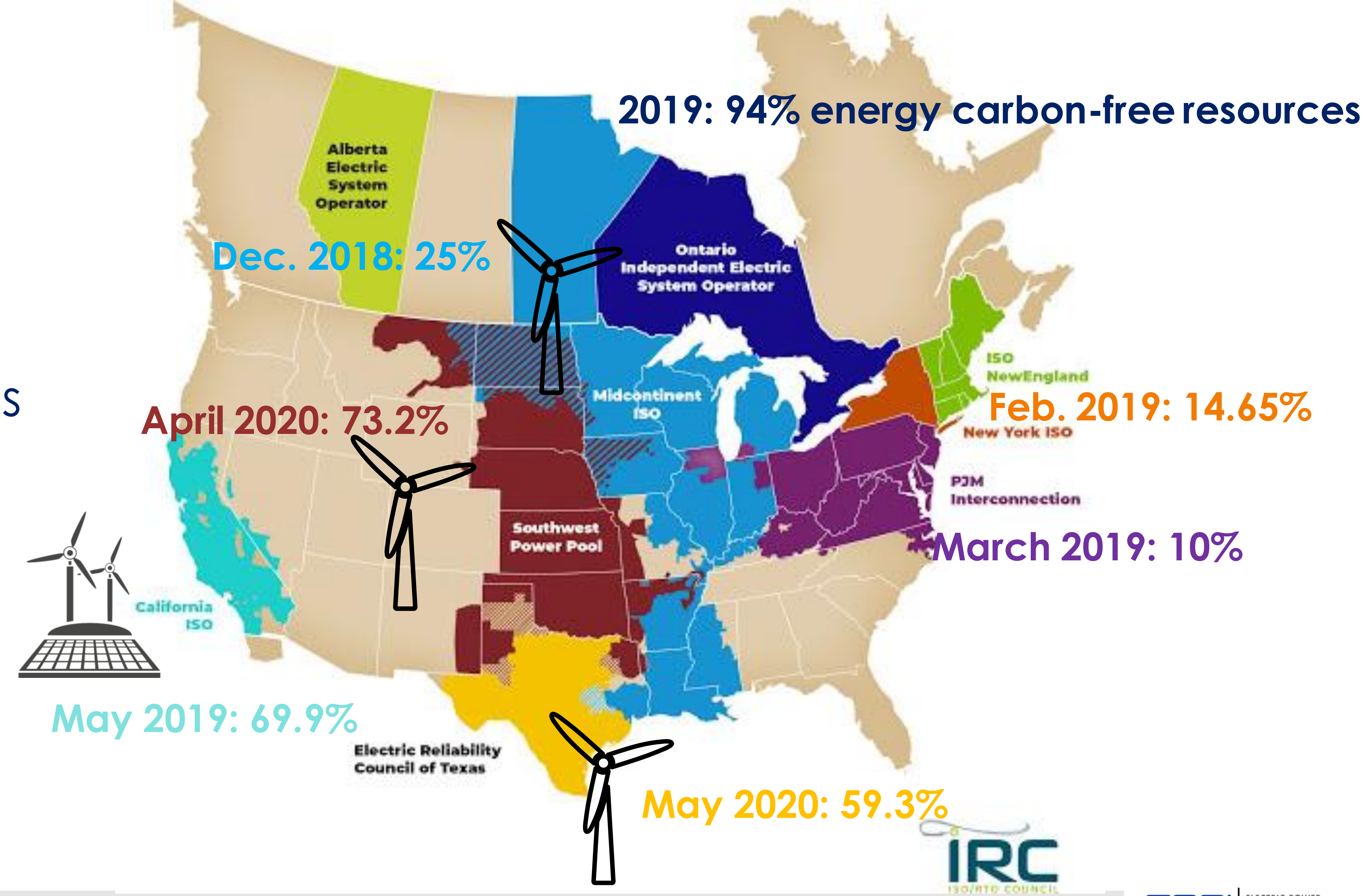
Neutrality

Utilities commit to 100% carbon free or renewable energy standards



As of May 2019

Variable Renewable instantaneous penetration records



ESIG
ENERGY SYSTEMS
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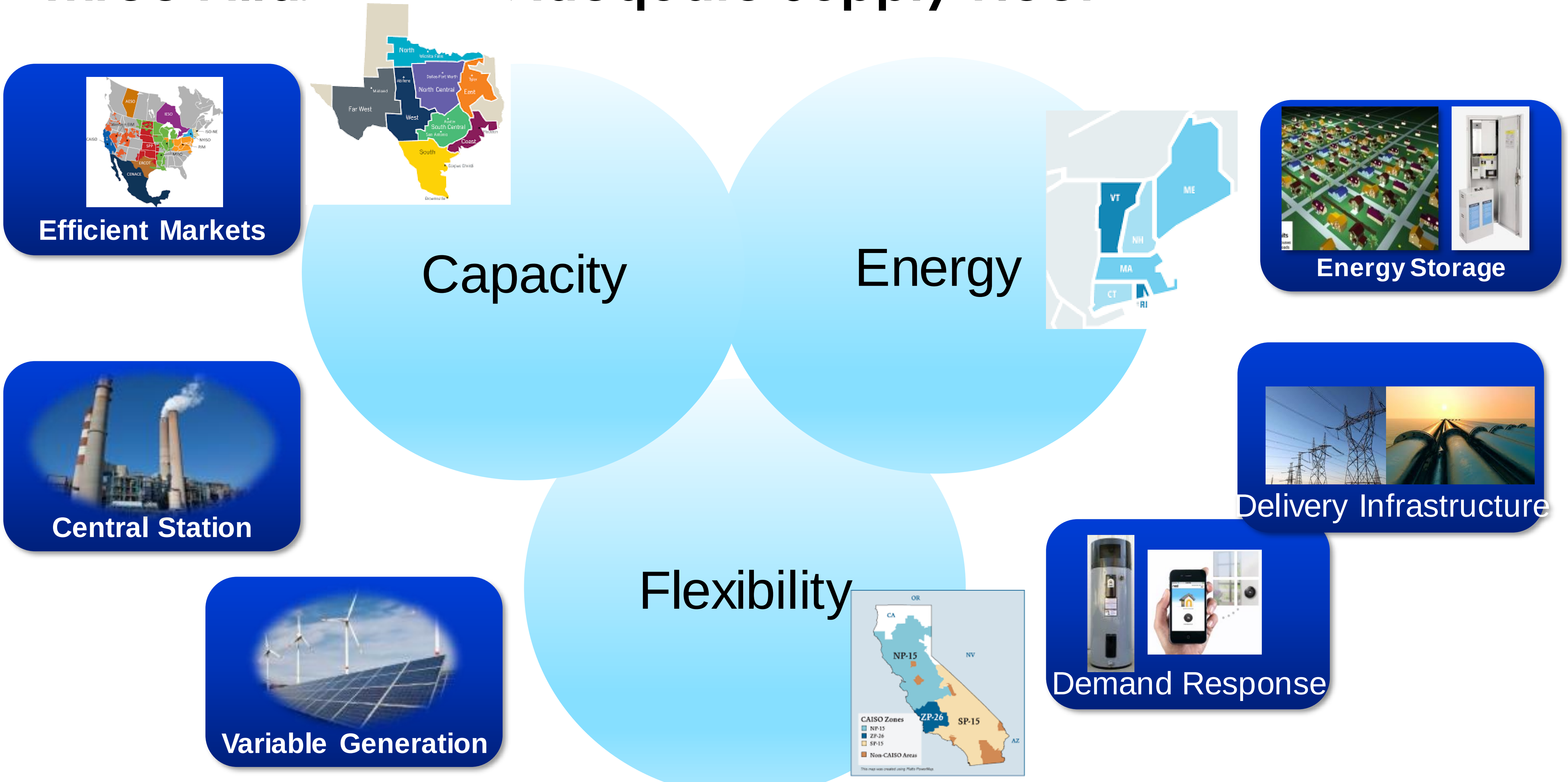
Variable Energy Resources – Key Characteristics

- Variability
- Uncertainty
- Inverter-based interface
- Location of connection (T&D)
- Capital and operating costs distribution

How do we plan for and operate a power system with nearly all energy supplied by variable renewable generation?

Three Pillars of an Adequate Supply Fleet



Key Areas of Focus for High Renewable Assessment

Planning

- What resources are still needed to fill in the gaps when wind is not blowing and it is dark?
- If majority of demand is responsive to price, how do we set a planning target?
- Are we sure we are building the right types of resources?
- What infrastructure (T/D, pipeline, transport) will be required for energy systems integration?

Operations

- How much and what type of essential reliability services are needed?
- Will we be able to maintain reliability without synchronous machines?
- How do we dispatch resources that do not have operating costs or require start-up directions?
- How much coordination between T & D operators will be necessary?

Electricity Markets

- Will resources that continue to supply energy have sufficient revenue to remain in service?
- Will resources providing reliability services with lower energy sales have incentives to do so?
- What other market designs may need evaluation?

If all zero variable cost resources have the same variable cost, what else do we desire?

- ↓capital costs including O&M costs
- Location – ability to deliver, ↓T&D losses
- Location – ↓need for additional infrastructure
- Provide the most energy (↑capacity factor)
- Provide the energy as anticipated (↓forecast error)
- Provide energy at times when needed
  - ↑aggregate capacity value, ↑Geographic diversity,)
- Provide quality reliability services when needed
- Provide energy during extreme conditions when needed

100% Renewable Integration Workshop

Key Findings

- ESIG released a summary report on the workshop
  - https://www.esig.energy/esig-releases-toward-100-renewable-energy-pathways-key-research-needs-report/
- Grid forming inverter technology exists, but needs further evaluation
- Level of demand-side participation may require significant changes
  - Digitization and automation key
- Innovative technologies that are becoming cost-effective to provide flexibility and store energy across different time frames
  - Ex: Short-duration storage combined with long-duration (e.g., days to seasons)
- Changes to operations and market structures still unclear
  - How will a more decentralized paradigm impact operations and planning?

Ancillary Services* (Bulk Power System)

Those services that are necessary to support the transmission of capacity and energy from resources to loads while maintaining reliable operation of the Transmission Service Provider's transmission system in accordance with good utility practice. (FERC/NERC)

****Terms and categorizations differ substantially by region and authority. This is simply one way of categorizing using terms that are most common or most descriptive.***

- **Operating Reserve**
  - **Event**
    - **Contingency Reserve** — *Instantaneous events (contingencies)*
      - Inertia** — Reduce ROCOF; maintain stability
      - Fast Freq. Resp. — Reduce Nadir, Avoid UFLS
      - Primary — Stabilize Frequency
      - Secondary — Return Frequency to nominal and/or ACE to zero
      - Tertiary — Bring back to n-1 secure state
    - **Ramping Reserve** — *Longer duration events*
      - Secondary — Return Frequency to nominal and/or ACE to zero
      - Tertiary — Bring back to secure state
  - **Non-Event**
    - **Flexibility / Following Reserve** — Correct the anticipated ACE. Manual (Part of Optimal Dispatch)
    - **Regulating Reserve** — Correct the current ACE. Automatic (Within Optimal Dispatch)

Operating Reserve can be further categorized by direction (upward, downward), online status (spin, non-spin), and horizon (day-ahead, hour-ahead) among other characteristics.

- **Planning Reserve**
  - ICAP
  - Flexible Capacity
- **Volt/Reactive Control/Reserve**
  - Static
  - Dynamic
- **Black Start Restoration**
- **Short circuit Contribution**

***Inertia is not a reserve but part of the*

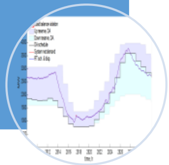
Adapted from Ela et al., *An Enhanced Dynamic Reserve Method for Balancing Areas*, EPRI, Palo Alto, CA: 2017. 3002010941.

The needs, types, and providers of grid services may all be evolving on future systems!

Mechanisms to Ensure Flexibility Provided Reliably and Cost-Effectively

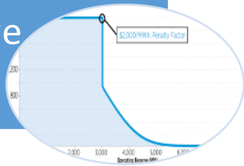
Address uncertainty and ramp with commitment and dispatch

Uncertainty and ramp reserve product



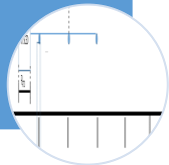
Value reserve above minimum requirements

Operating Reserve Demand Curve



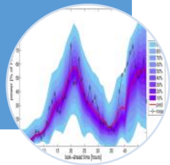
Price opportunity costs of ramp

Multi-interval settlement



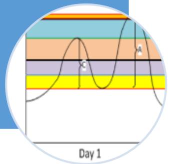
Represent uncertainty explicitly

Stochastic multi-scenario market scheduling



Make sure flexibility is built

Forward Flexible Capacity Attribute Procurement



Let demand provide flexibility inherently

Real-time demand pricing

Flatten the curve with correct incentives

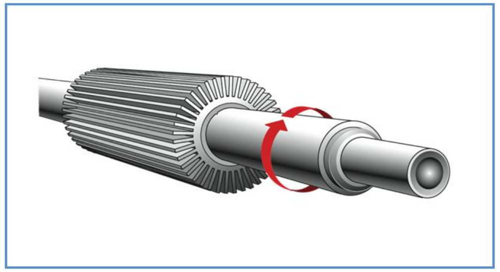
Energy Storage

Reduce uncertainty directly

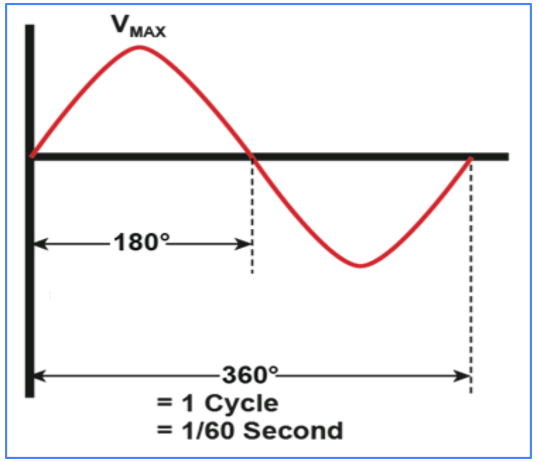
Enhanced Forecasting

Conventional System Frequency vs. All-Inverter System Frequency

Conventional System



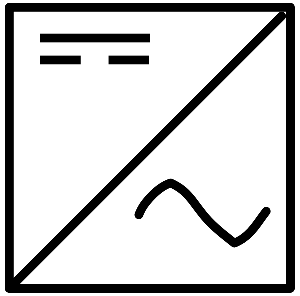
Mechanical Frequency



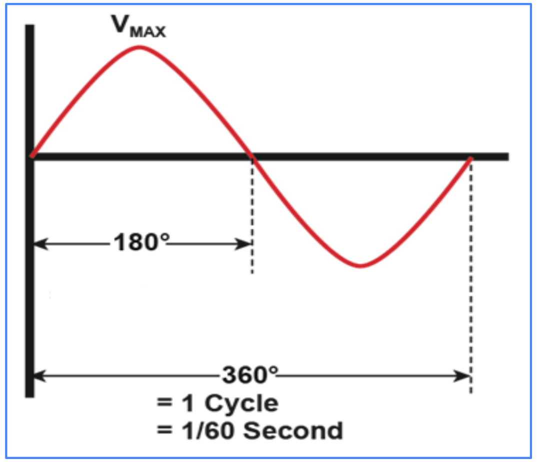
Electrical Frequency

VS

100% IBR System



System Impedance



Electrical Frequency

Conventional System

- **Frequency deviation: inertia and supply/demand balance**
- **Stability: rotor angle**

100% IBR System

- **Frequency deviation: rate of change of system angles**
- **Stability: inverter controls**

100% IBR System Is Fundamentally Different System

Together…Shaping the Future of Electricity