Overview of Large Loads

ESIG
ENERGY SYSTEMS INTEGRATION GROUP

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ESIG Background

1989
UWIG Established

ESIG started as the Utility Wind Interest Group (UWIG) in 1989, a group of six utilities interested in learning more about wind energy

Early 2000's
Understanding Improves

Wind integration understanding rapidly improved, and was helped by consolidation of balancing areas and growth of larger market operators (ISO/RTOs) in early 2000's

2011
UWIG becomes UVIG

Solar energy emerged at scale and with similar integration issues, and UWIG became the Utility Variable Generation Integration Group (UVIG) in 2011

2018
UVIG becomes ESIG

With renewables, storage and decarbonization as mainstream pathways to the future, UVIG merged with the International Institute for Energy Systems Integration (iiESI) and became the Energy Systems Integration Group (ESIG) in March 2018

ESIG Differentiators and Mission

ESIG

DIFFERENTIATORS

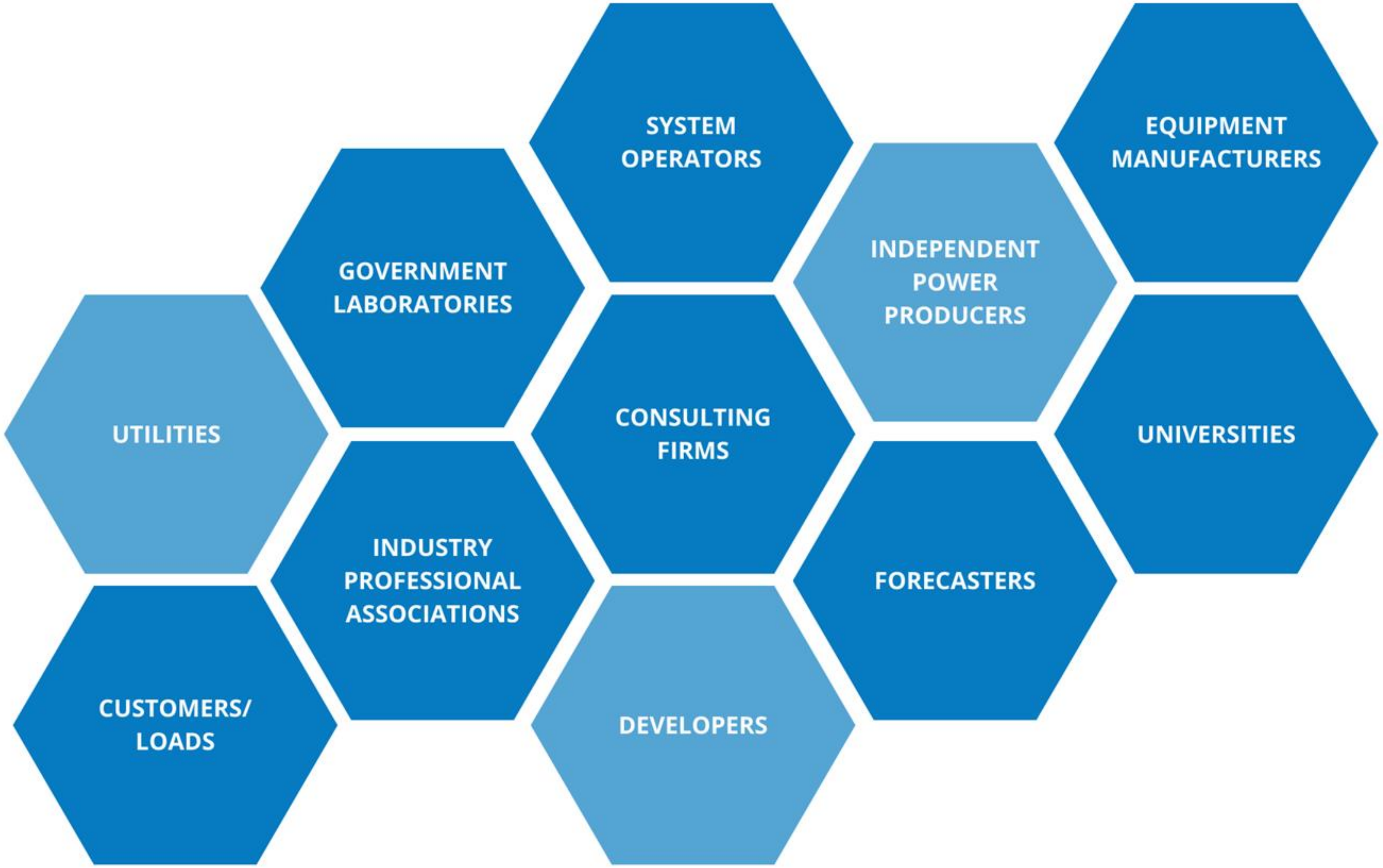
Stellar Technical Reputation | Best in Class, Global Reach | Independent and Trusted

MISSION

- Address the technical challenges for transforming energy systems through collaboration, education and knowledge sharing
- Work with all industries, energy vectors and applications globally
- Forward leaning, but not advocating, keeping everyone at the table
- Working at the cutting edge of the technical pathways toward 100%
- Pragmatically progressive—reliable, economic and sustainable transformation

ESIG Membership

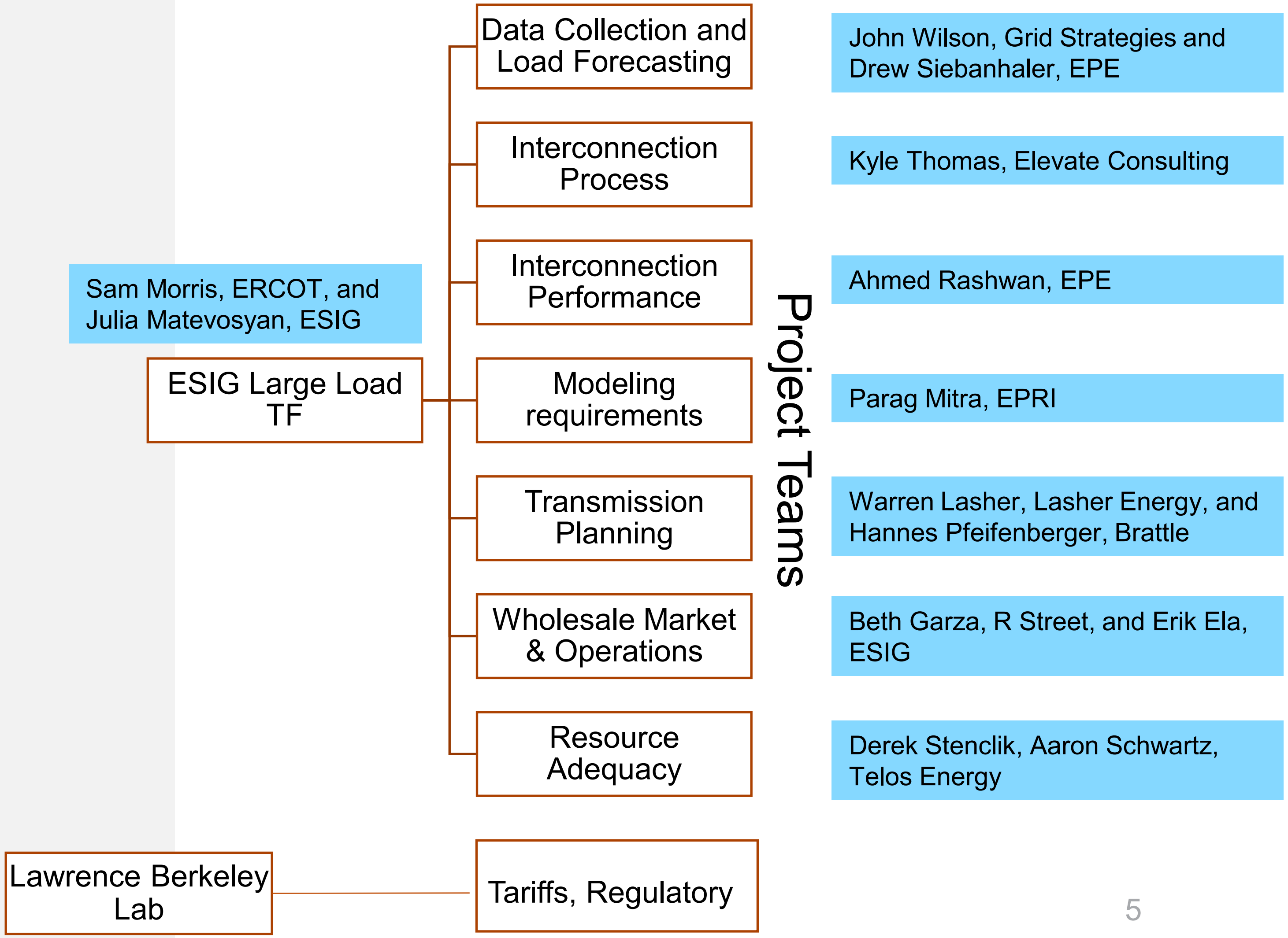
250+ Members Globally



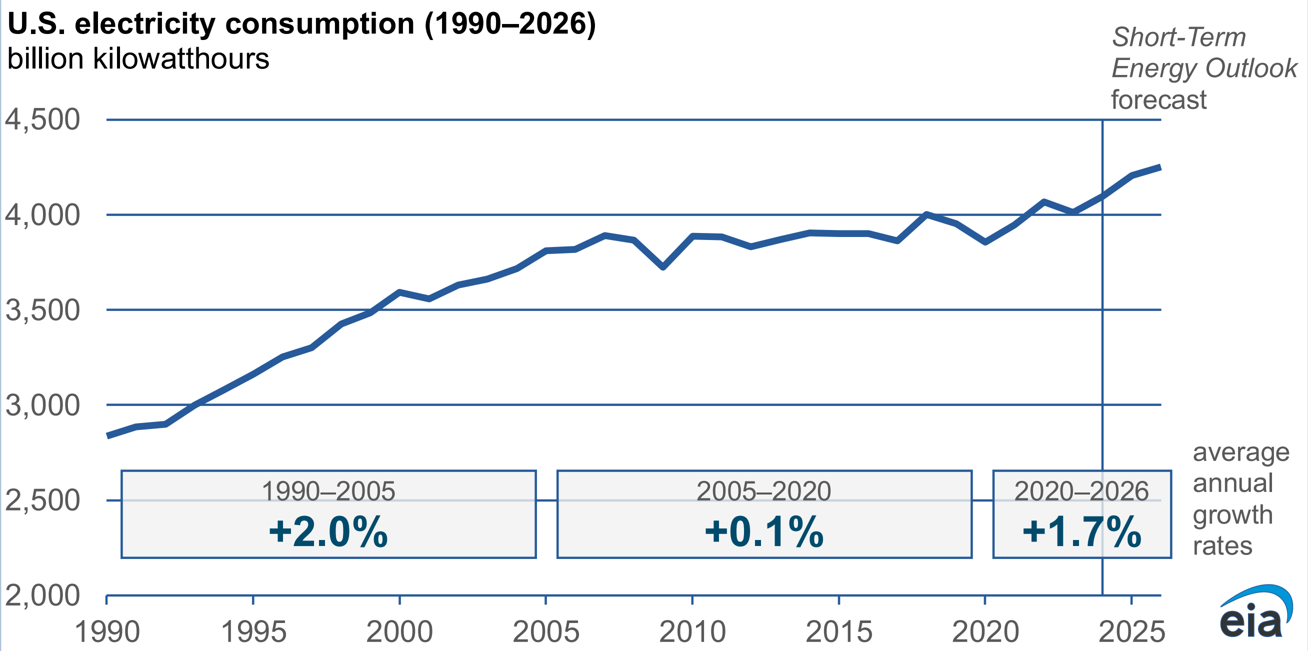
ESIG’s Large Load Task Force

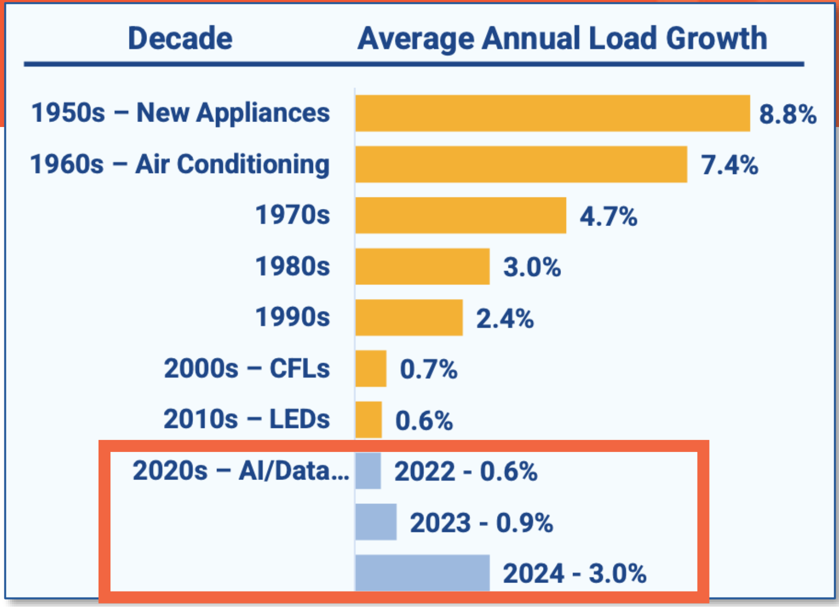
- The goal is to bring together members across the energy industry to
  - Share perspectives
  - Summarize the existing state-of-the-art
  - Identify existing or future gaps
  - Identify practical solutions

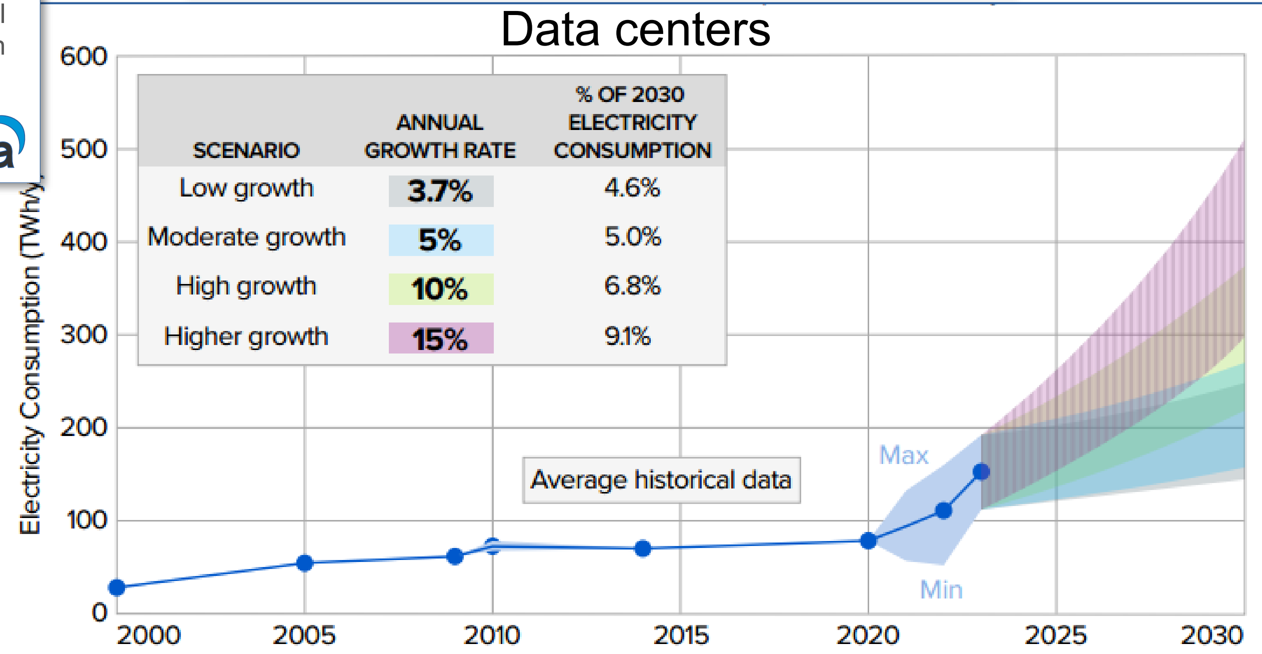
Acknowledgement: The U.S. Department of Energy Office of Energy Efficiency and Renewable Energy and Meta are supporting this effort as are ESIG members.



Load is increasing after many years of flat growth







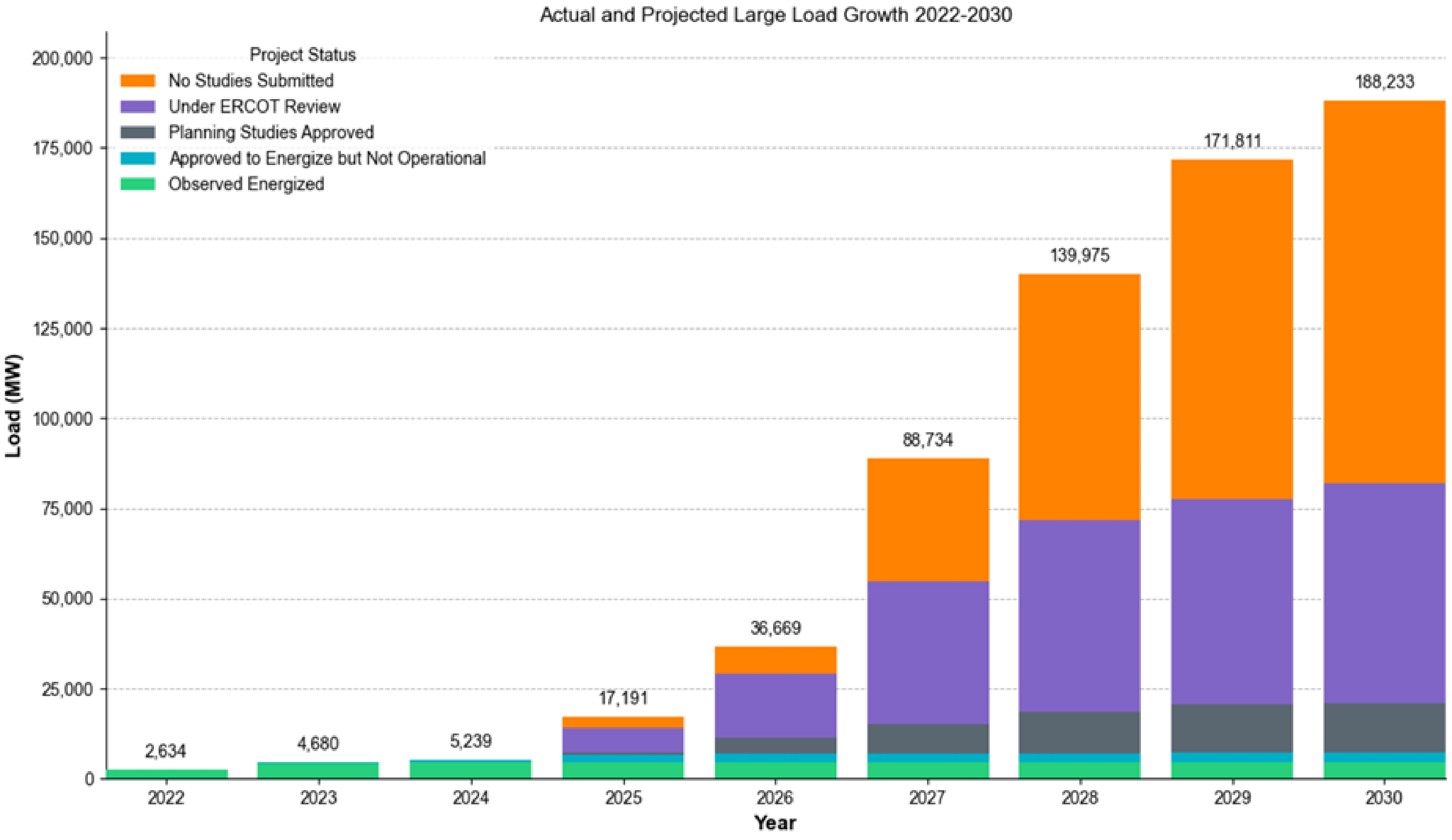
SCENARIO	ANNUAL GROWTH RATE	% OF 2030 ELECTRICITY CONSUMPTION
Low growth	3.7%	4.6%
Moderate growth	5%	5.0%
High growth	10%	6.8%
Higher growth	15%	9.1%

Source: EPRI, Powering Data Centers 2024; https://www.eia.gov/todayinenergy/detail.php?id=65264; Grid Strategies, National Load Growth Report, 2024

Planning: Load forecasting issues

- Many utilities/ISOs have low bars to entry.
  - Load developers file (multiple) requests in multiple regions for 1 project, to see which is cheapest or fastest. Utilities/ISOs are swamped with requests.
- Increasing levels of commitment with each step in the process can help:
  - Study fees, material collateral, site control
- Certify whether the request is duplicative of others at the same company.
- **Large load interconnection queue data is not public**

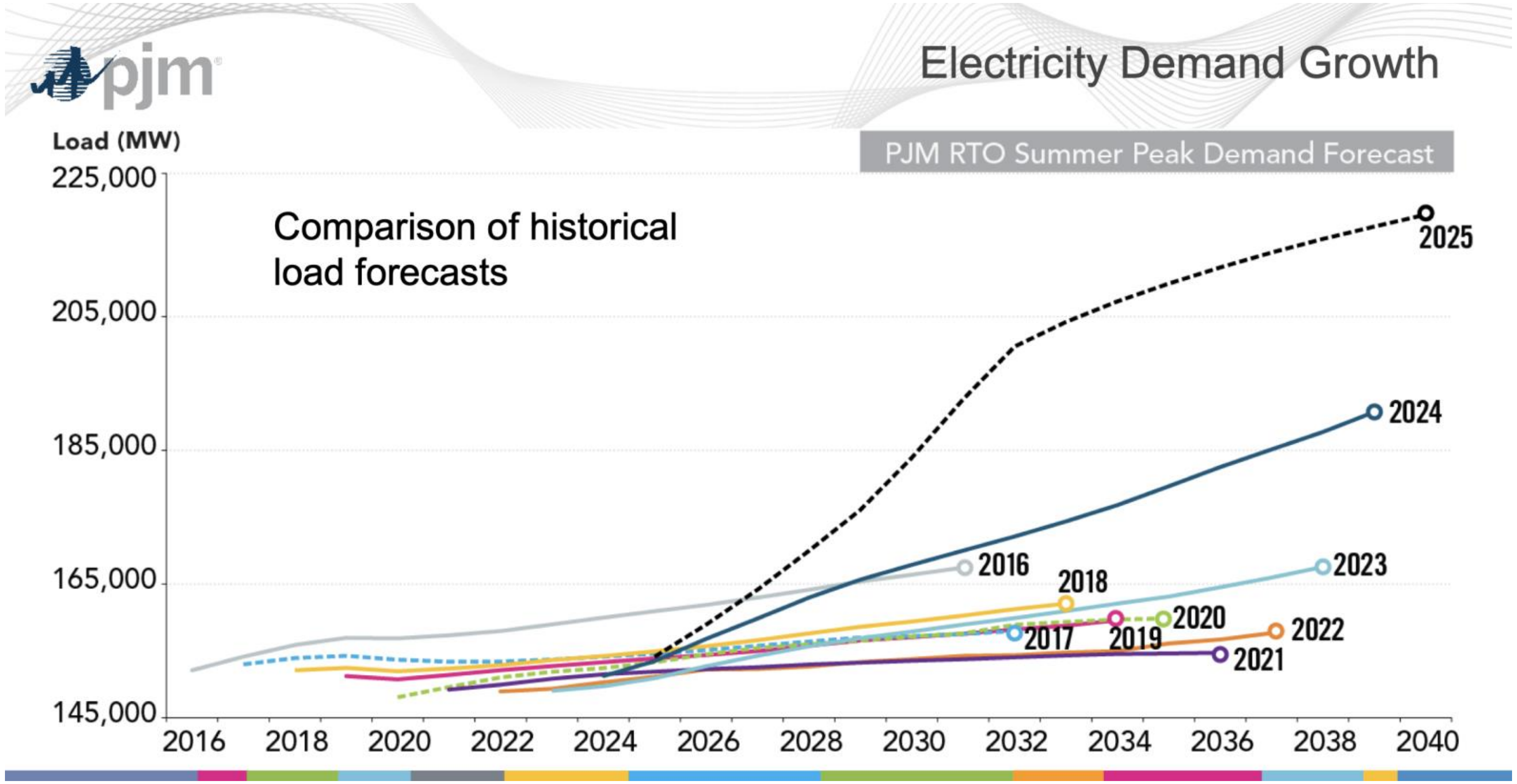
ERCOT Large Load Interconnection Queue (end of July 2025)



Source: ERCOT Monthly Operational Overview, July 2025

Uncertainty in Large Load Forecasts

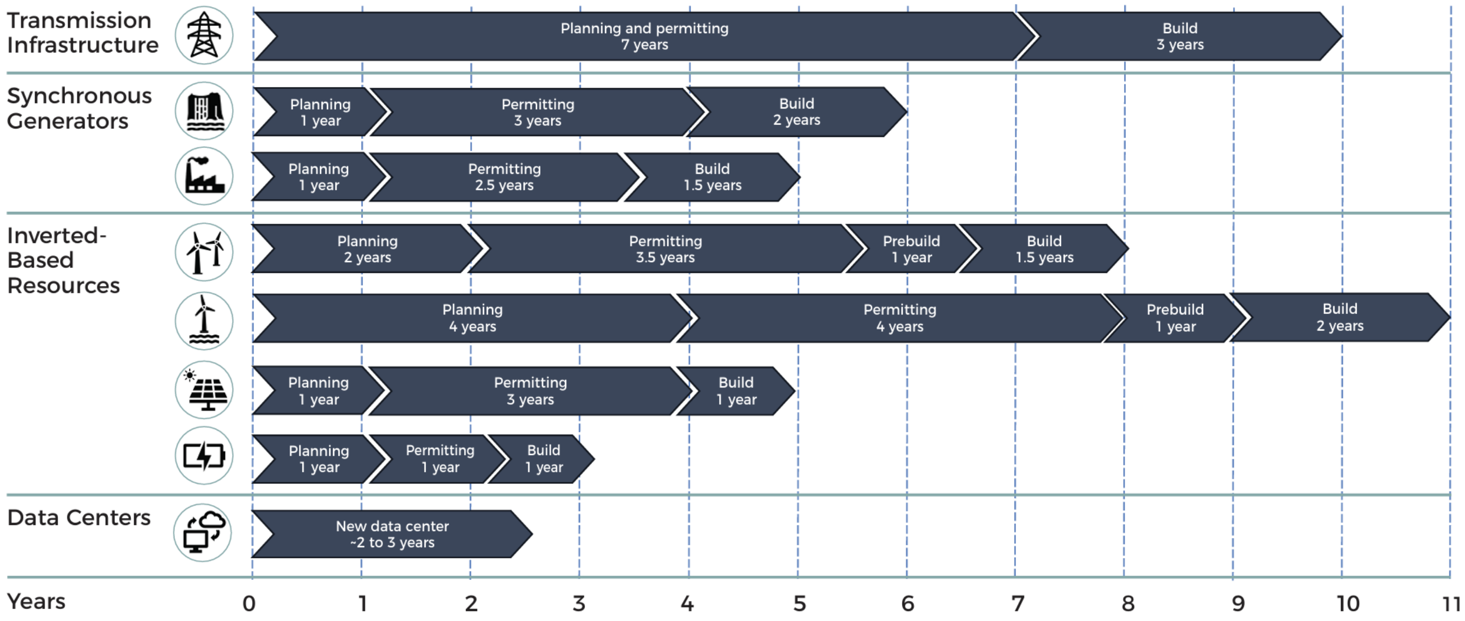
- Driven by **non-public** large load interconnection information
- **Experience** from IBR interconnections is key
- Efforts need to be made to **classify large loads appropriately** to allow for necessary performance and data requirements



Source: [Large Load Additions Workshop](), May 9, 2025

Planning Generation, Loads, and Transmission

- Today, large loads want to interconnect faster and they are unprecedentedly large
- Significant, fast load growth puts pressure on generation capacity prices.
- Generation may take longer to build and the generation interconnection queues are slow and backlogged.
- Transmission requires even more time to build.
- **Industry struggles with today's timelines**



Timelines for grid infrastructure are not aligned with those for large load development, creating bottlenecks for grid supply of electricity. SOURCE: ADAPTED FROM S&P GLOBAL.

Source: Practical Guidance and Considerations for Large Load Interconnections GridLab and Elevate Energy, May 2025

How Do Moden Large Loads Differ (from today's large loads)

- **Scale** – Individual facilities (e.g., hyperscale data centers, hydrogen plants) now reach 100s of MW to GW scale, far beyond past industrial loads.
- **Interconnection** – Connect at transmission level (instead of distribution) due to size/reliability needs
- **Clustering** – Concentrated in grid-constrained regions (e.g., Northern Virginia, Texas industrial corridors) creating local demand spikes.
- **Power electronics** – Converter-dominated interfaces bring new challenges: power quality, protection, and sensitivity to disturbances.
- **Fault behavior** – Many switch-over to backup during routine faults, risking cascading grid impacts from simultaneous large load losses.
- **Dynamic profiles** – AI clusters, electrolyzers, EV charging, and heat pumps cause rapid swings and new peak risks.
- **Opaque to operators** – Private developers often limit data sharing, complicating forecasting and operational planning.
- **Growth vs. infrastructure** – Loads materialize in 2–3 years; new grid build-out takes 7–10 years, causing backlog and bottlenecks.

System-Level Implications

- **Planning:** Load growth far outpaces connection request processing ability, transmission & generation buildout; forecasts highly uncertain.
- **Operations:** Short-term forecast errors drive inefficient unit commitment & higher reserve needs.
- **Reliability:** Risks to stability, load-shedding, and restoration from large, concentrated loads.
- **Power Quality:** Harmonics, flicker, and reactive swings from converter-based systems.
- **Observability:** Need for PMUs/DFRs as loads now require high-speed monitoring.
- **Markets:** Drive congestion, price impacts, and incentive shifts.
- **Transmission:** Load siting often mismatched with available transmission capacity.

Large Load Characteristics and Impact

Components of Grid Planning & Operations

	Large Facility Size	Geographic Concentration	Development Uncertainty	Profile & Flexibility Uncertainty	Co-located Resources	Power Electronics Interface
Interconnection Process	●	◔	●	◕	◑	◕
Load Forecasting	●	◔	●	◑	◑	◔
Transmission Planning	●	●	◕	◕	◕	◔
Resource Planning & Adequacy	●	◕	◕	●	◕	◔
Operations & Markets	●	◑	◔	●	◕	◔
Operational Reliability	●	◕	◔	◑	◕	●

● = must consider

◕ = should consider

◑ = may consider

◔ = keep track

Source: DRAFT ESIG Large Load Introduction Report

Reliability Impacts of Large Loads

- Voltage Stability
  - Transient
    - Extremely fast LL response can cause stability issues
    - May exacerbate disturbances
- Steady-state
  - LL loss due to poor ridethrough can result in additional stress on the system

- Frequency Stability
  - LL are extremely power dense
  - Subject to many of the same causes of reduction as IBR
  - Normally cleared disturbances can cause large frequency fluctuations

"OLD"

"NEW-er"

- Resonance
  - LL controls may interact with natural modes
    - SSCI/SSR/SSTI
- Forced Oscillations
  - AI learning looks like forced oscillations to the grid
    - Impact worsens with system strength
- Risks to Sync Gens

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ESIG

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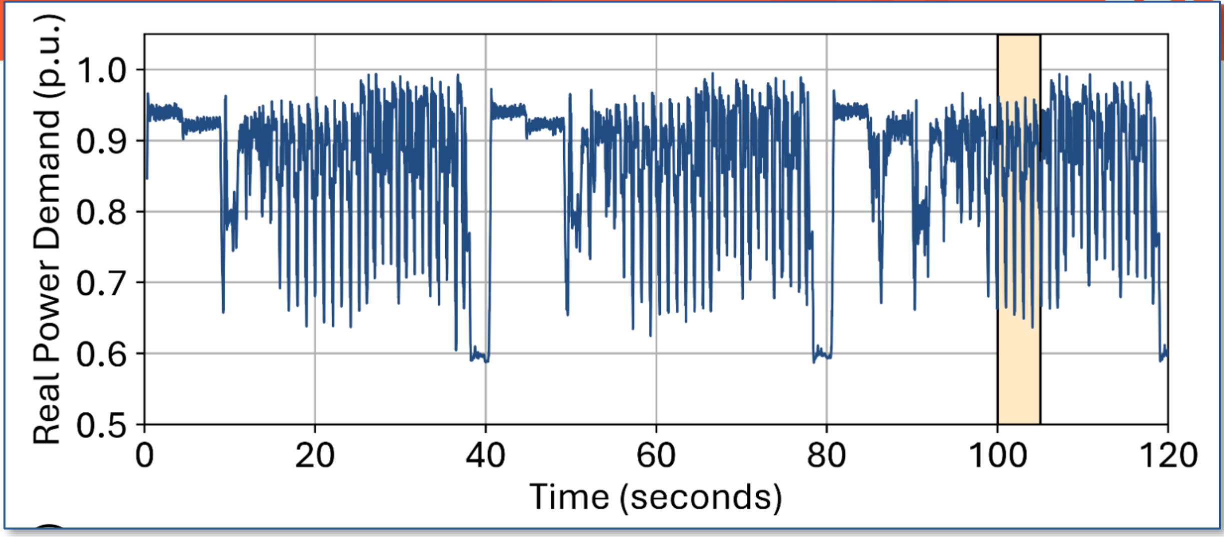
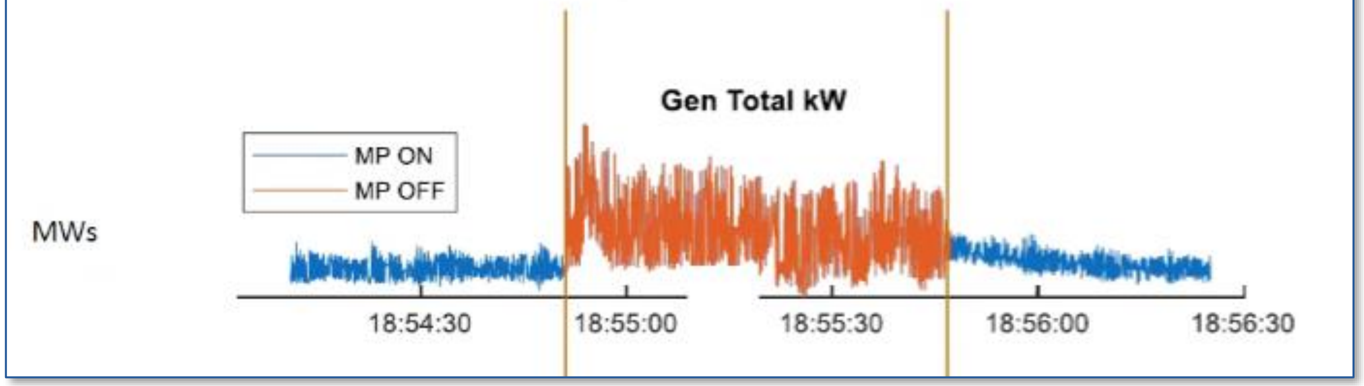
IB MAX

Reliability Issues: Oscillations

- During AI training, thousands of GPUs can be computing (energy intensive), and then exchanging data (not energy intensive).
- Since they operate in synchronism, it can result in large power fluctuations in which load oscillates rapidly
- If off-grid, the oscillations can damage the generator
- If on-grid, can interact with nearby generators or inter-area oscillations can occur
- Software solutions or battery storage can help to reduce variability
- Even uncontrolled ramping, to chase prices, for example, can create reliability issues.



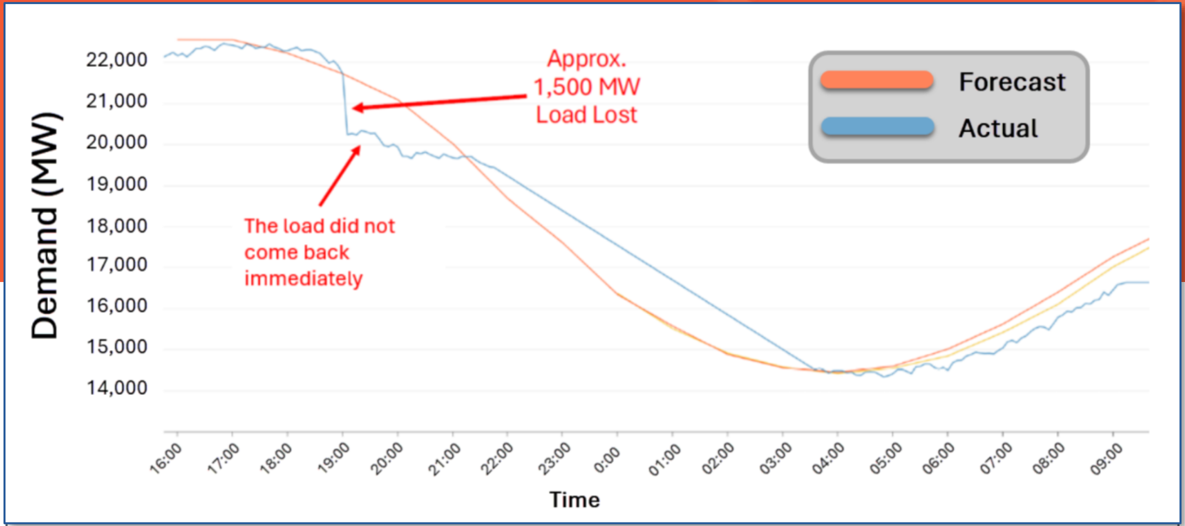
Real-world results of AI training power load smoothing tested beyond 25 MWs

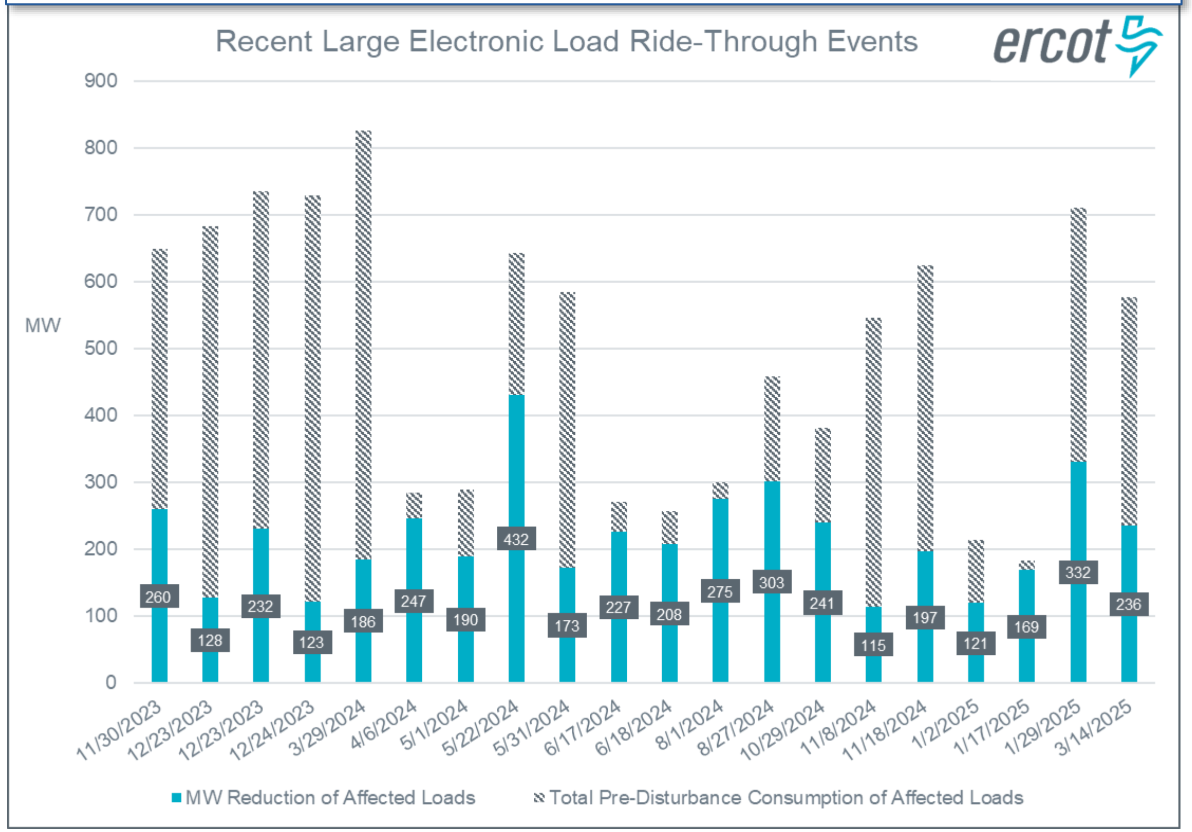


NERC LLTF 6/18/25; Sean Jones, Tesla, NERC LLTF 4/10/25

Reliability issues: Fault Ride-Through

- When there is a transmission fault (lightning, animals, trees, equipment failure, etc) some large loads in that region may trip offline, and transfer to their backup power.
- A fast, unexpected drop of 1500 MW of load can have a similar impact as a 1500 MW nuclear plant tripping offline. It can create a reliability event.
- To avoid this, we need to set up interconnection requirements for large loads so that they don't trip offline for minor disturbances. We may also want to control their ramping so that when they do transfer to backup power it is not abrupt.





Source: ERCOT Large Load Workshop, June 2025

Easy to Get Overwhelmed

Ride Through Capability

Forced Oscillations

Damage to Synch Gen

Rapidly Interconnecting

Frequency Stability

Clustered Geographically

Opaque to Operators

Uncertain Forecasts

Dynamic Profiles

Power Dense

Power Electronic Based

Opaque to Planners

"Immature" Technology

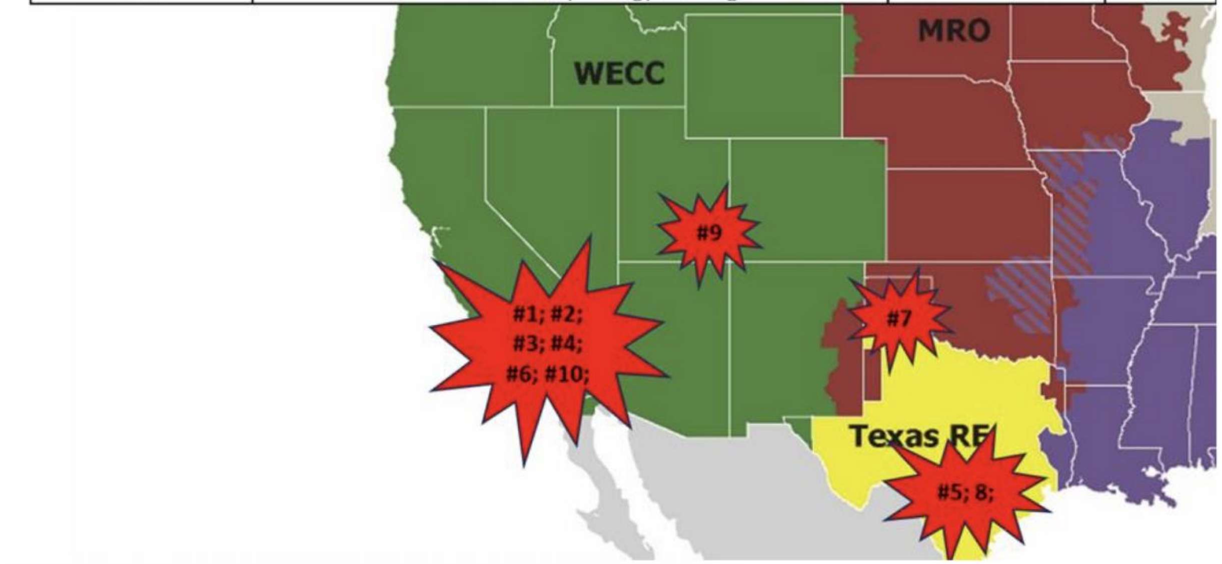
Software Driven

System Balancing

Plenty of History to Start With

- Large Loads and Inverter-based Resources (IBR) share **significant similarities** in performance and reliability
  - Power electronic interface
  - Software-based performance
  - Immature technology
  - Lack of specificity in the regulatory space
- The bulk power system **cannot afford** to repeat IBR mistakes

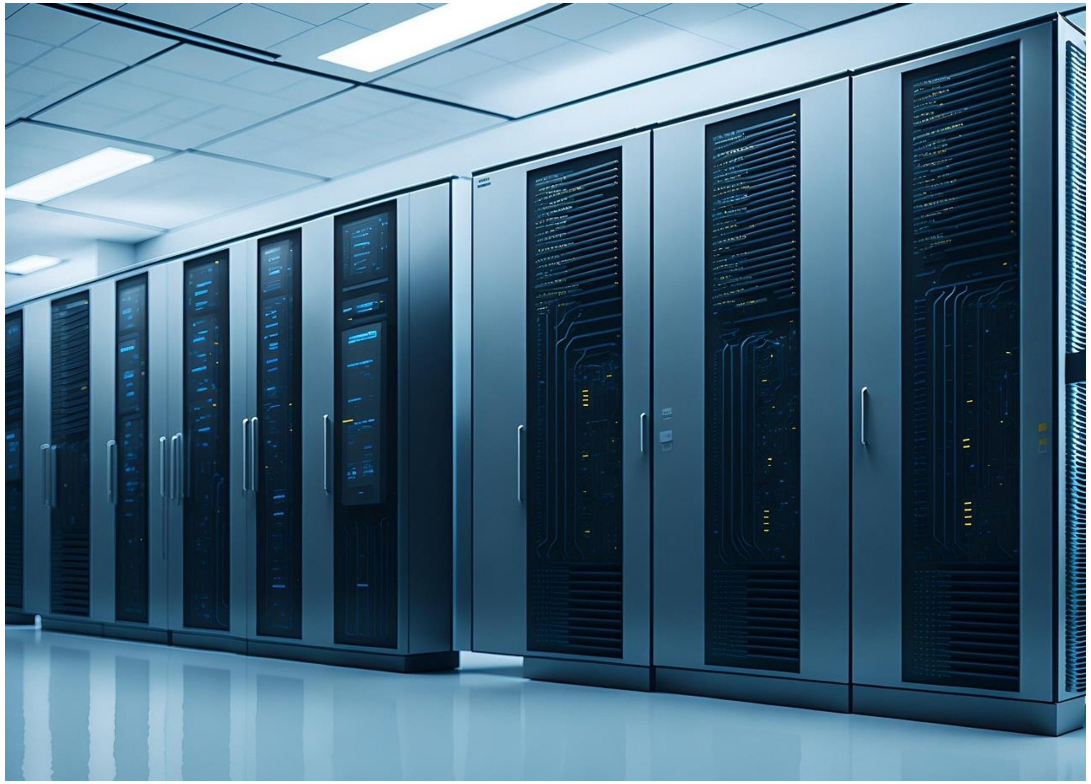
Reference Number	Disturbance	IBR Reduced (MW)	Year
#1	Blue Cut Fire	1,753	2016
#2	Canyon 2 Fire	1,619	2017
#3	Angeles Forest & Palmdale Roost	1,588	2018
#4	San Fernando	1,205	2020
#5	2021 Odessa	1,112	2021
#6	Victorville & Tumbleweed & Windhub & Lytle Creek Fire	2,464	2021
#7	Panhandle Wind	1,222	2022
#8	2022 Odessa	1,711	2022
#9	Southwest Utah	921	2022
#10	California Battery Energy Storage	906	2023



Adapted from NERC Ridethrough Technical Conference, Sep. 4 2024

Lessons We Need to Learn

- Large loads need a **specific regulatory category**
  - Allows for technology specific:
    - Requirement discussion and balloting
    - Interconnection processes
    - Performance and data requirements
    - Modeling requirements
- Advanced controls and performance characteristics must be **transparent** now and **enabled** through **collaborative discussions** between key stakeholders



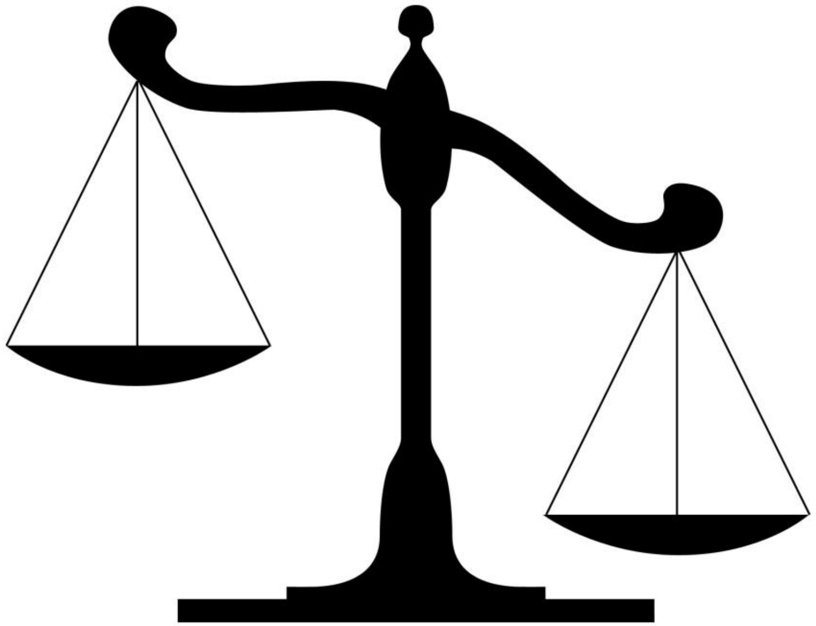
Path to Reliability - Definition of Large Loads (LL)

- At present, no industry consensus on the definition of a Large Load (LL)
- North American Reliability Corporation's (NERC's) Large Load Task Force (LLTF), conducted a survey on size thresholds for "Large Load" for the purposes of development and enforcement of future NERC reliability standards.
  - Most of the 384 respondents suggested > 50 MW, and the single size most commonly suggested was 75 MW.
  - However, NERC LLTF could not reach consensus on a threshold and settled on a high-level definition:

    Commercial or industrial facilities (or aggregations) that can pose BPS reliability risks due to their size, operational behavior, or control systems, e.g., data centers, crypto mining, hydrogen electrolyzers, industrial manufacturing.
- A similar definition is adopted for a new CIGRE Role and Requirements for Large, Inverter Based Loads TF:
  - *Large demand facilities that are interfaced with power electronics and have the capacity, on an individual or aggregated basis, to have material impact on the host grid.*
- The definition adopted by ESIG LLTF:
  - ***A large load is a load that the connecting utility/ISO/RTO identifies as having a material impact on its system either due to its individual size and/or characteristics or on aggregate basis.***

Path to Reliability - Large Loads Can be Resources

- Large loads **can support the grid**
  - Advanced controls
  - Flexibility
  - Co-located generation or storage
- Interconnection process enhancements are needed
  - **Large load specific reliability requirements** are needed
  - Interconnection processes should be **standardized**
    - Regional **variability** is always needed
  - Barriers to entry should be **raised**
  - Processes need to **enable flexibility**
- Market enhancements are needed
  - **Who should pay** for improvements needed for LL?
    - Should consider spreading costs amongst ratepayers?
  - Large loads should be able to participate in wholesale electricity markets just like generators
    - **Incentivizes flexibility**



Conclusions

- When you're big, you have an impact!
- Large loads should not be viewed as a burden but rather as a resource to help the grid.
- We need to ensure the planning processes, interconnection requirements, tariffs and market participation models are designed well.
- This is an opportunity to fix our systems. Large loads reveal shortcomings in our processes
- Ultimately we will likely be trading speed for
  - Flexibility and use of backup generation
  - Interconnection requirements
  - Market participation

Thank You!

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- Get involved in ESIG's Large Load Task Force
- Get involved in other ESIG Task Forces and Working Groups
- Contact for information on ESIG training opportunities!