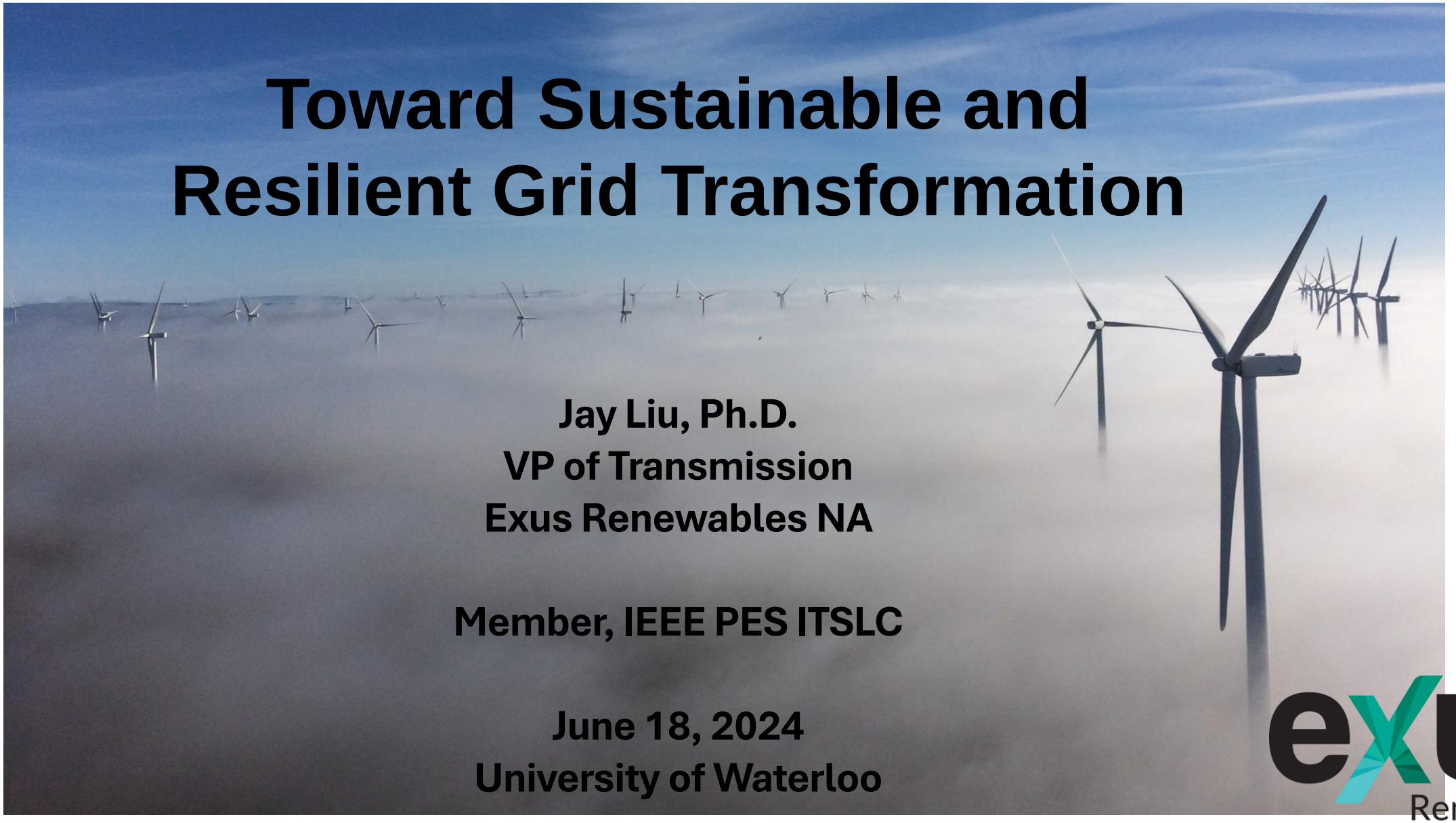
Toward Sustainable and Resilient Grid Transformation



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June 18, 2024
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- Power Grid **Transformation** has been an evolving process globally, starting from fuel mix change with renewable resources to more advanced sustainable, economical, and resilient infrastructure.
- **Advanced Transmission and Distribution technologies** will play critical roles in the next decades to address challenges on excessive amount of new generation interconnection requests, rapid growth of Data Center/AI loads, large scale Off-Shore Wind interconnection, and reliability and resilience threats under climate changes.
- **Regulatory and publicity impacts** on energy technology development are also gaining more attentions from engineers and leaders in the industry.
- How to be prepared for the next generation power grid from **core** technology development perspectives.

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Grid Transformation

- **A few commonly used terms for changes in Power Grids -**
  - Power System Planning
  - (Backbone) Development
  - Aging Infrastructure Replacement
  - Power System Hardening

Copilot
***Transformation** refers to a **complete change** in the appearance or character of something or someone. It can be a radical alteration, resulting in an improved state. … In mathematics, **transformation** involves changing one configuration or expression into another according to a mathematical rule[2]. Overall, it signifies a **shift**, whether in form, nature, or character[3].*

- **Common characteristics of legacy power grid infrastructure development:** *Long time constant, High investment with long return period, Long operational life and reliability impact…*
  - **Passive, Expensive, Inflexible, Heavily Regulatory Dependent**
- **Power Grid Transformation**
  - **Adaptive, Economical, Flexible, Competitive**

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Grid Transformation

- **IEEE Grid Operator Survey in 2021**

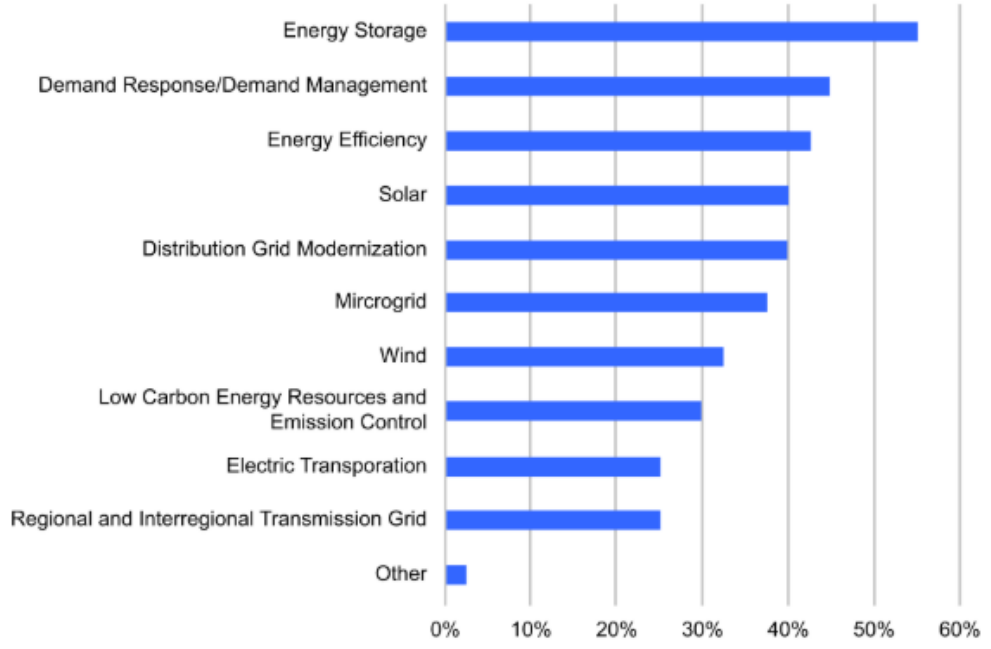

Figure 1: Survey results; business areas with a strategic plan regarding sustainable energy

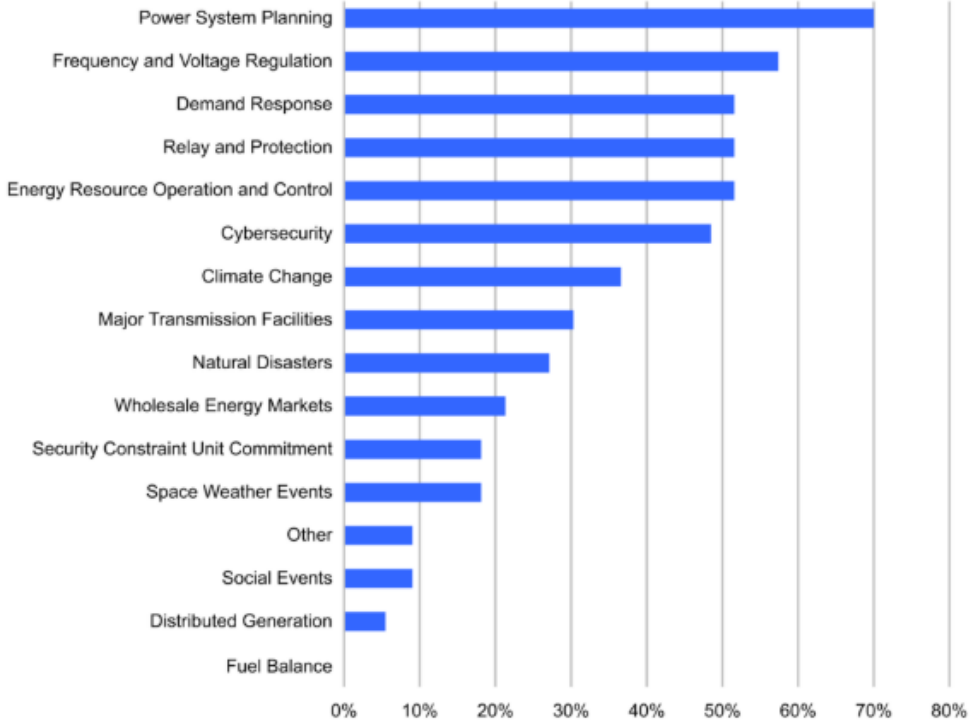

Figure 2: Survey results; business areas with a strategic plan

https://resourcecenter.ieee-pes.org/publications/white-papers/pes_tp_wp_gpstc_011121?check_logged_in=1

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Advanced Transmission and Distribution Technologies in Grid Transformation

- Next Generation FACTS and HVAC/UVAC
- Next generation transformer, DC circuit breaker, Off-shore grid, etc.
- HVDC and Hybrid DC/AC
- Digital Transmission and Substation
- System Operation technologies – From reliability preventive operation toward predictive economical/sustainable energy service
- Energy Storage as Transmission and Distribution Service
- Generation interconnection friendly T&D technologies
- T&D technologies and operation method for resilience

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Regulatory and Publicity Impacts through Grid Transformation

- A few recent major FERC Orders
- NERC's recommendation and coming compliance requirements on IBRs interconnection, Grid Forming Technologies and so on…
- Policies and local support/reactions toward renewable energy integration and major T&D infrastructure

FERC Order 1920

- 1000+ pages “Landmark” rulemaking on new transmission and cost allocation
- Aiming for long-term planning for regional transmission facilities and determine how to pay for them
- 20-year horizon vs. 10-, 15-year Long-Term Regional Transmission Planning
- Encourage new Grid Enhancing Technologies
- Policies and local support/reactions toward renewable energy integration and major T&D infrastructure

Long-Term Regional Transmission Planning in FERC Order 1920

- Produce a **long-term (20+ years**) regional transmission plan to identify needs and the facilities to meet them.
- Conduct this long-term planning at least **once every five years … three scenarios** …use **best available data**.
- Apply **seven specific benefits** to determine whether any identified regional proposals will **efficiently and cost-effectively** address long-term transmission needs.
- Include an **evaluation process** to identify long-term regional transmission facilities for potential selection in the regional plan.
- Include a process giving **states** and **interconnection customers** the opportunity to fund all, or a portion, of the cost of a long-term regional transmission facilities …
- In the **event of delays or cost overruns, reevaluate …**
- Consider transmission facilities that **address interconnection-related needs (if)** identified multiple times in existing generator interconnection processes, but that have not been built.
- Consider the use of **Grid Enhancing Technologies** such as dynamic line ratings, advanced power flow control devices, advanced conductors and transmission switching.
- Identify opportunities to **modify in-kind replacement** …as **"right-sizing,"** when needed.

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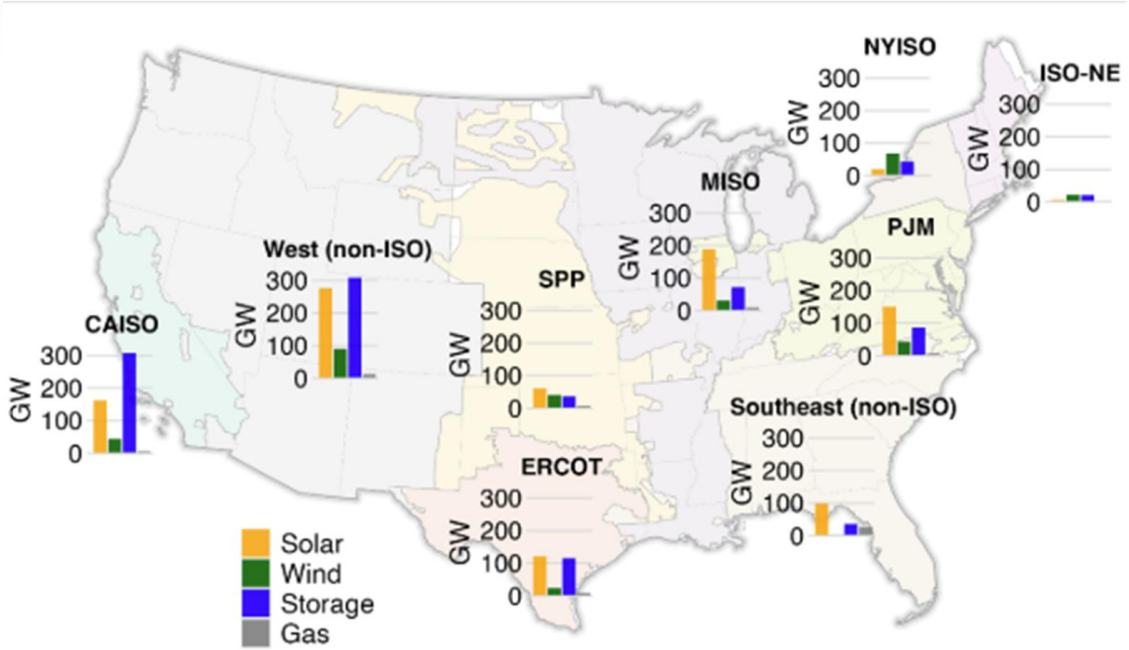
Queue Reform and FERC Order 2023

- Huge Queue request Pipelines in US
  - 1,570 GW Gen
  - 1,030 GW Storage
- Increasing waiting time
- Historical Low Success rate - ~20% requests (~14% capacity) reached COD by the end of 2023
- ~300GW New Energy, ~120GW Energy Storage by 2030 or beyond – Would that be feasible?



US DOE Report https://emp.lbl.gov/sites/default/files/2024-04/Queued%20Up%202024%20Edition_R2.pdf

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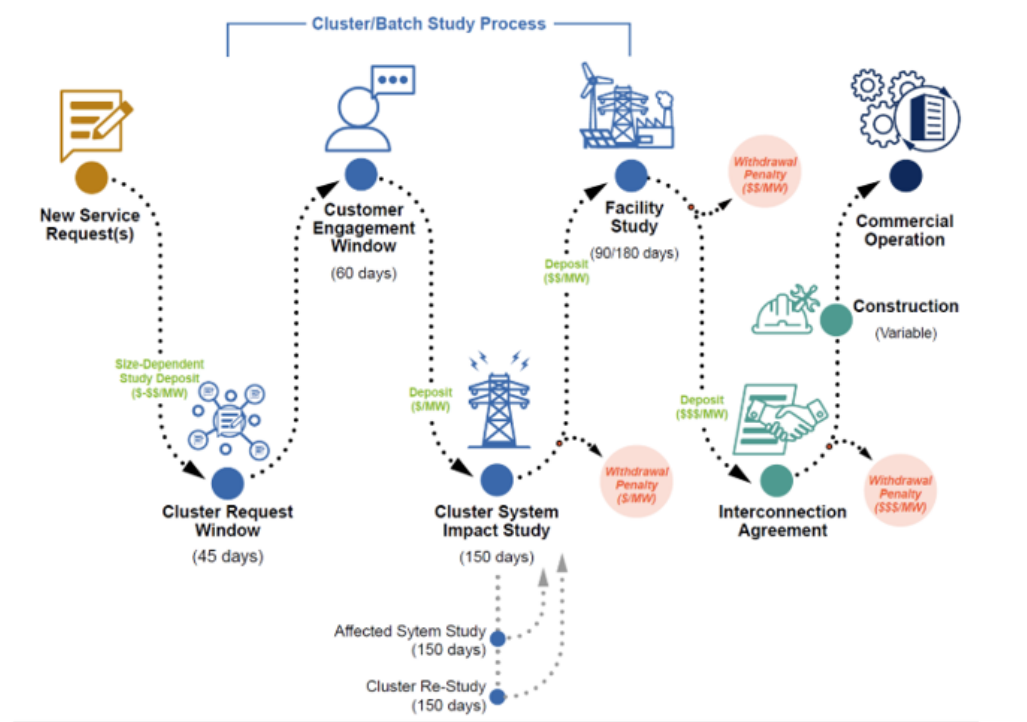
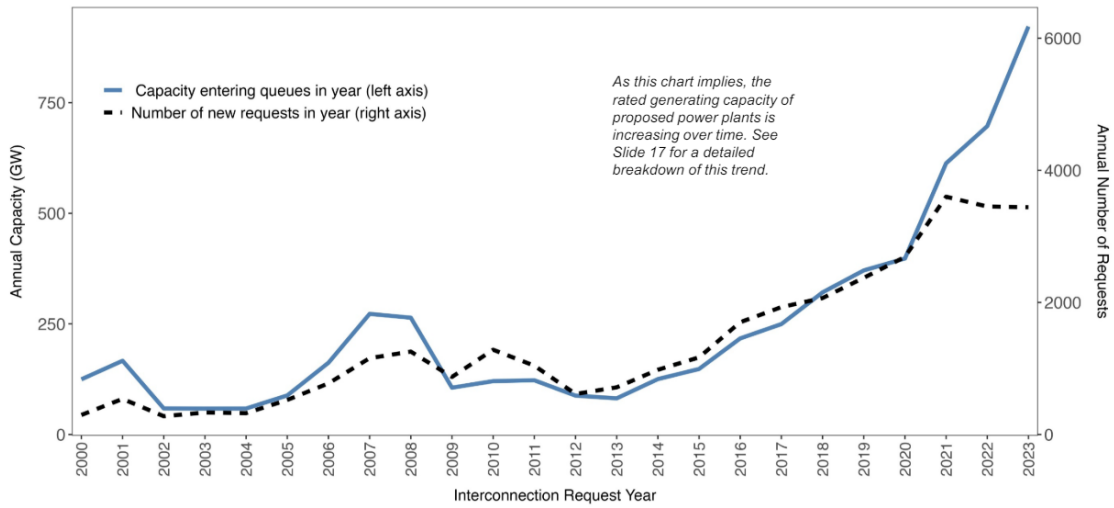
Queue Reform and FERC Order 2023



Annual interconnection requests have surged since 2013 (both in terms of number and capacity); over 900 GW added in 2023 alone



Notes: (1) This total annual volume includes projects with a queue status of "active", "suspended", "withdrawn", or "operational".
(2) All values – especially for earlier years – should be considered approximate.

8

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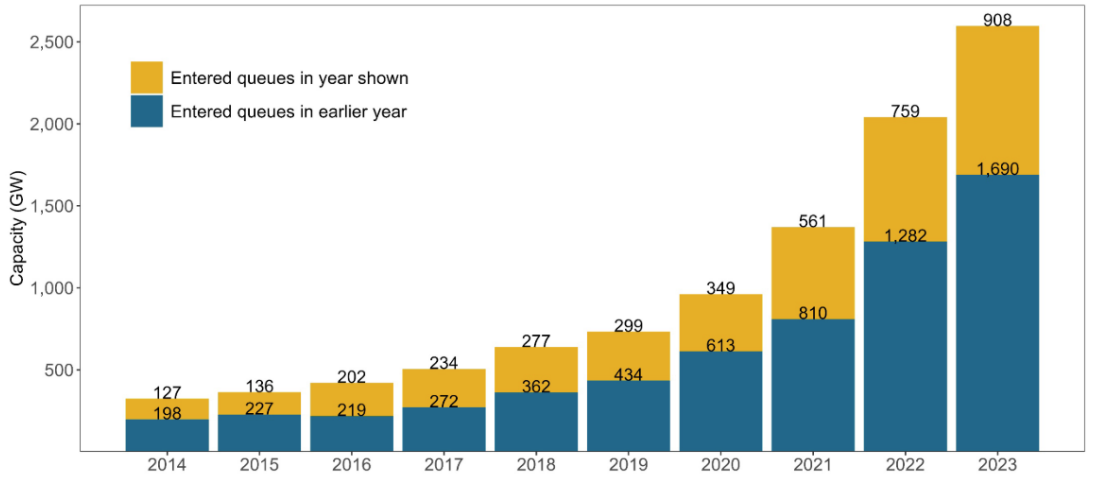
Queue Reform and FERC Order 2023

Total (cumulative) active capacity in queues is now nearly 2,600 GW (2.6 TW); New (annual) capacity entering the queues has increased every year since 2014



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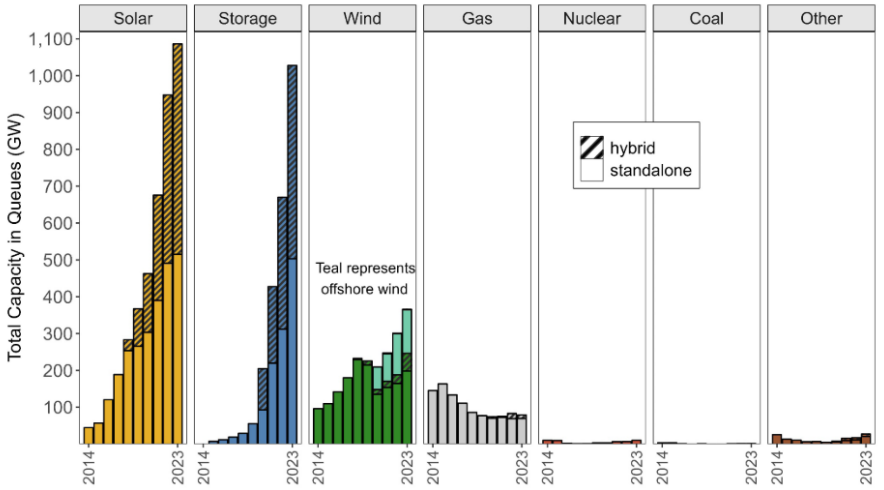
Solar (1,086 GW) , Storage (1,028 GW), and Wind (366 GW) make up 95% of active capacity in queues, with 3% (79 GW) from Gas. Most solar and storage capacity is in hybrid plants



- "**Wind**" includes both onshore and offshore.
- "**Other**" includes
  - Hydropower
  - Geothermal
  - Biomass/biofuel
  - Landfill gas
  - Solar thermal
  - Oil/diesel
- "**Storage**" is primarily (99%) battery, but also includes pumped storage hydro, compressed air, gravity rail, and hydrogen.

See https://emp.lbl.gov/queues to access an interactive data visualization tool.
Notes: (1) Hybrid storage capacity is estimated for some projects using storage:generator ratios from projects that provide separate capacity data, and that value is only included starting in 2020. Storage duration is not provided in interconnection queue data. (2) Wind capacity includes onshore and offshore for all years, but offshore is only broken out starting in 2020. (3) Hybrid generation capacity is included in all applicable generator categories. (4) Not all of this capacity will be built.

11

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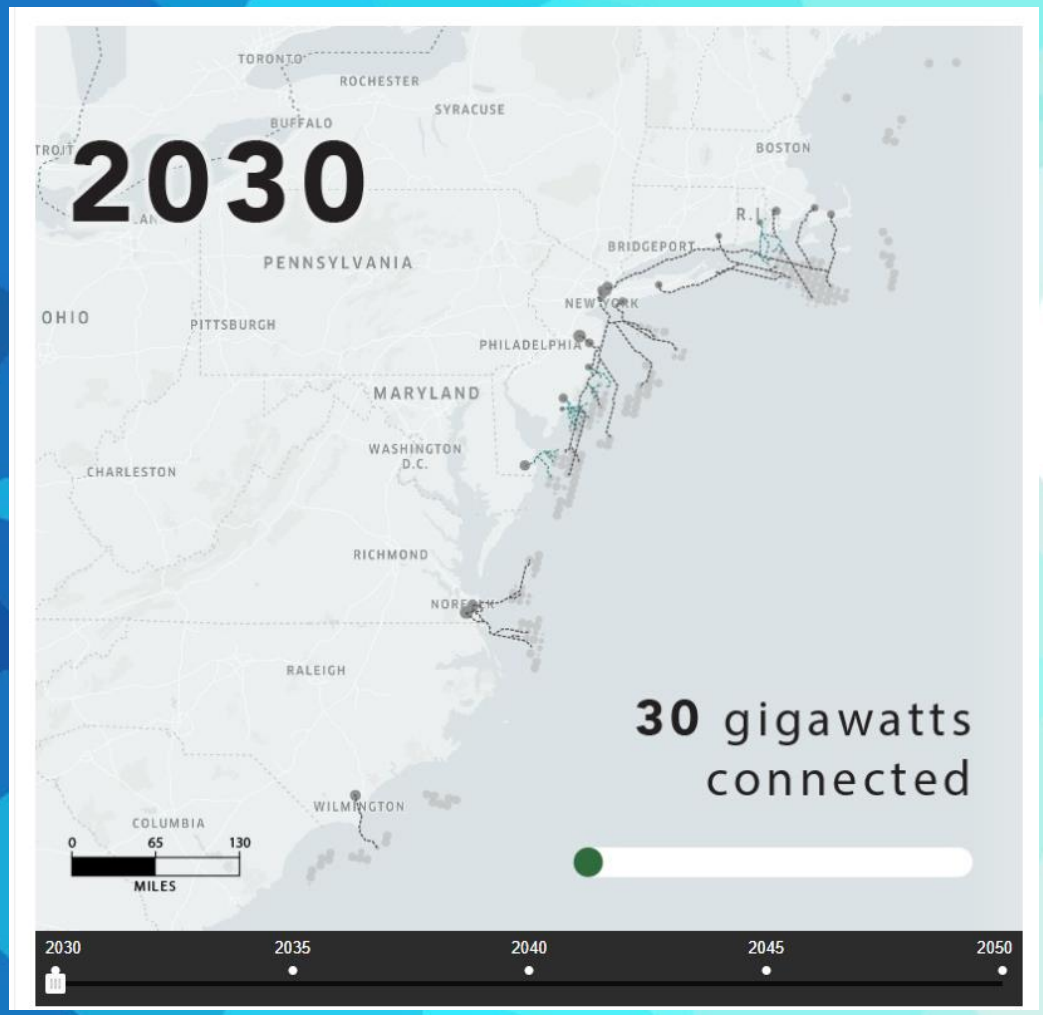
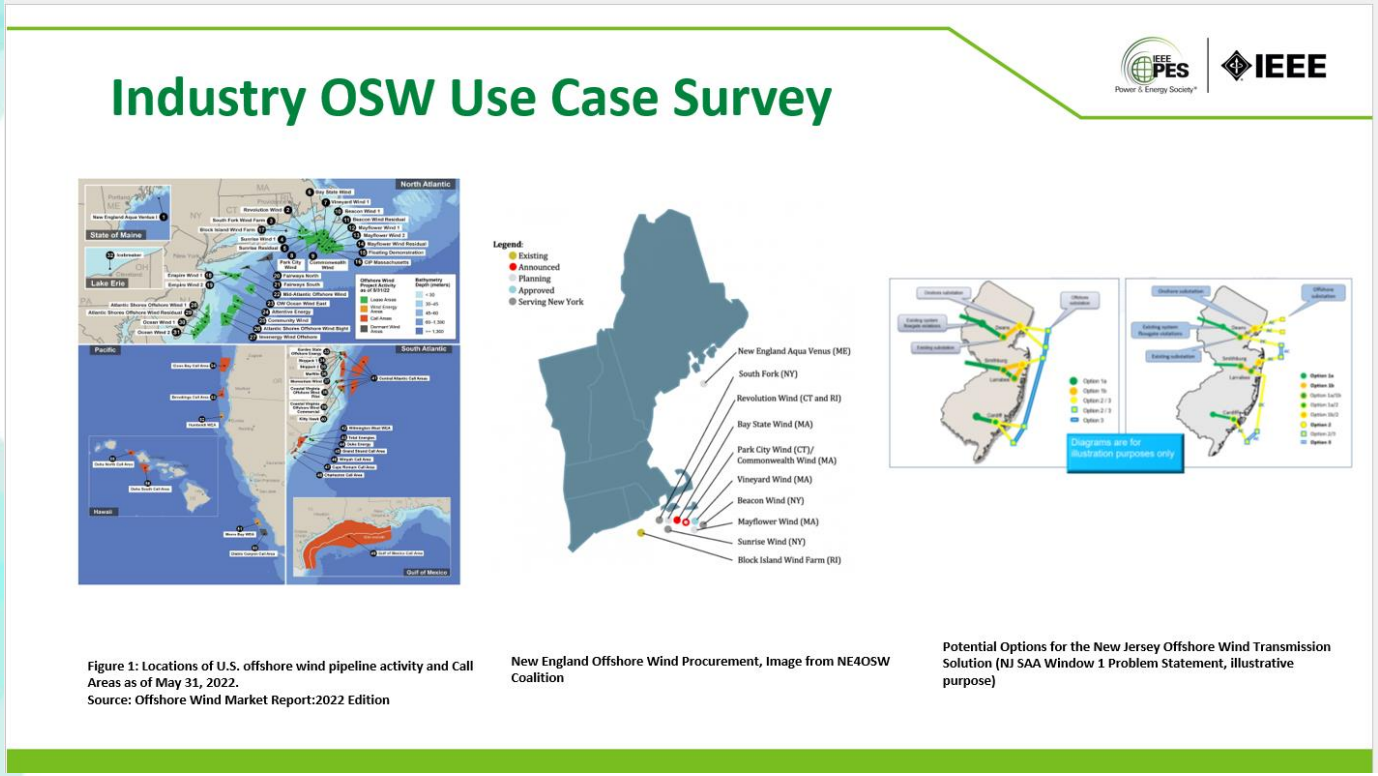
Offshore Wind Integration in US





https://www.energy.gov/gdo/atlantic-coast-offshore-wind-transmission-planning

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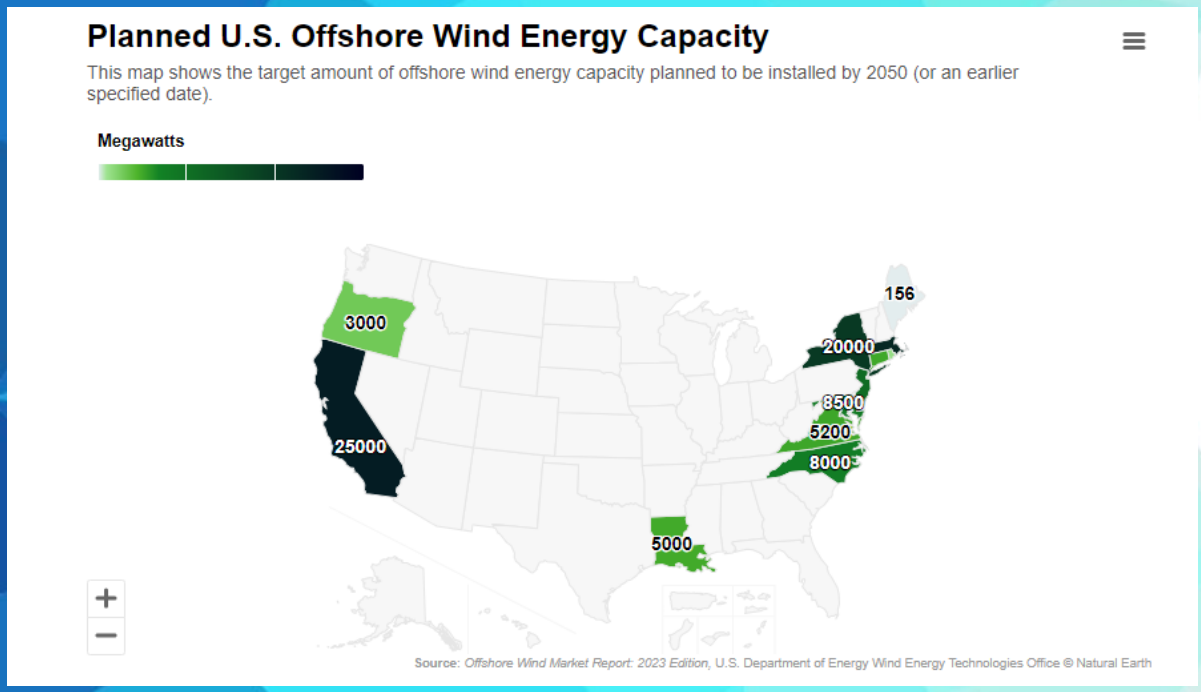
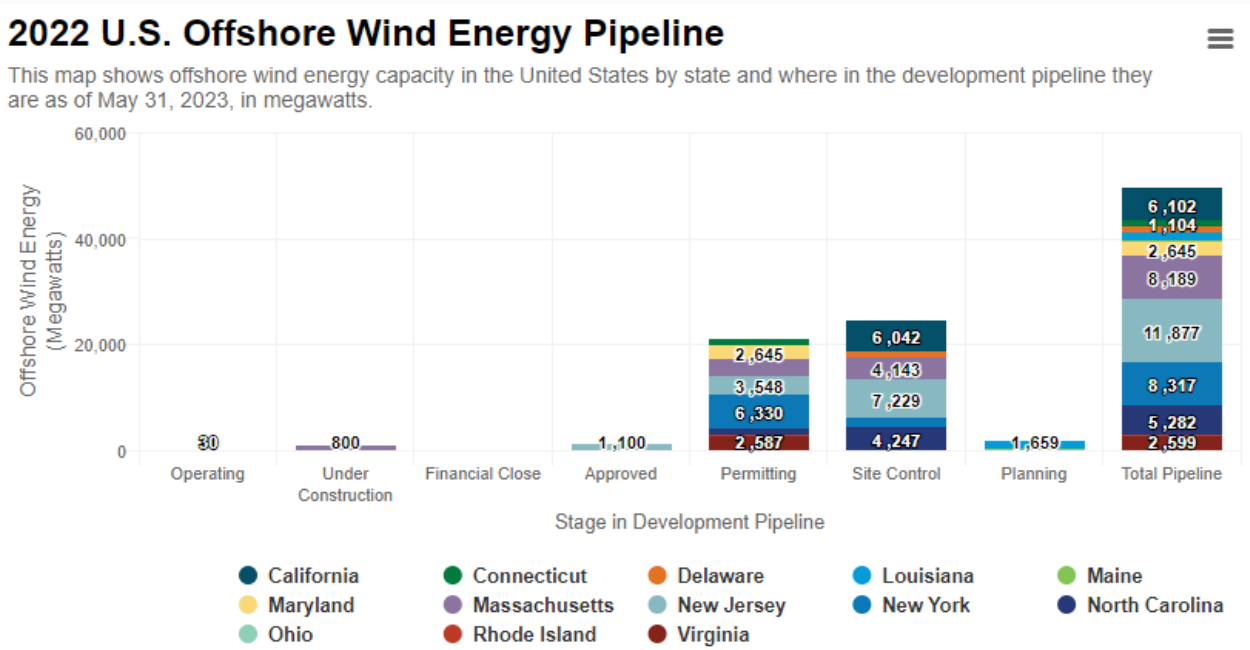
Offshore Wind Integration in US





- **Challenges associated with large scale OSW integration**
  - **High interconnection cost**
  - **Coordination with on-shore grid and operation**
  - **Off-shore Grid – HVDC network**
  - **Legacy planning process vs Long duration OSW development cycle**

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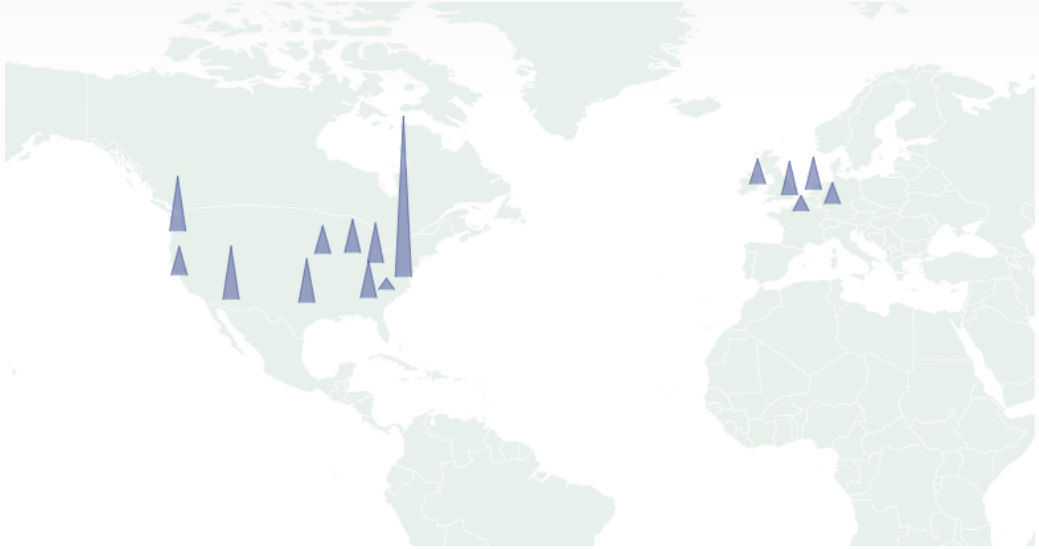
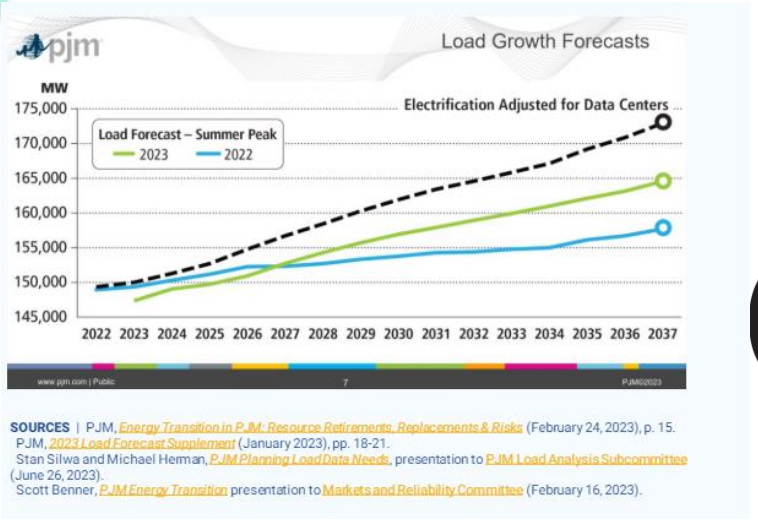
Data Center Load Growth

- Data centers Load Growth :
  - 19GW (2023), 21GW (2024)
  - 35GW by 2030 (9% total Load, per EPRI)
  - $50 + billion new generation capacity needed

- Data Center Load Profile and Data Center Load Management
  - Transmission Services
  - Renewable Energy PPAs
  - Energy Storage





SOURCES | PJM, Energy Transition in PJM: Resource Retirements, Replacements & Risks (February 24, 2023), p. 15.
PJM, 2023 Load Forecast Supplement (January 2023), pp. 18-21.
Stan Silwa and Michael Herman, PJM Planning Load Data Needs, presentation to PJM Load Analysis Subcommittee (June 26, 2023).
Scott Benner, PJM Energy Transition presentation to Markets and Reliability Committee (February 16, 2023).

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Final Words

- How to be prepared for the next generation power grid
  - Enhance academia and industry collaborations
  - Reduce the time constant of power technology commercialization
  - Out-of-box thinking especially in fundamental material and design in power applications
  - Beyond engineering

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