BERKELEY LAB
LAWRENCE BERKELEY NATIONAL LABORATORY

Queued Up:

Characteristics of Power Plants Seeking Transmission Interconnection As of the End of 2021

Joseph Rand, Ryan Wiser, Will Gorman, Dev Millstein, Joachim Seel, Seongeun Jeong, Dana Robson

Lawrence Berkeley National Laboratory

April 2022

This work was funded by the U.S. Department of Energy under Contract No. DE-AC02-05CH11231.

Contents

What are interconnection queues?

Utilities and regional grid operators (a.k.a., ISOs or RTOs) require projects seeking to connect to the grid to undergo a system impact study before they can be built. This process establishes what new transmission upgrades may be needed before a project can connect to the system and then estimates and assigns the costs of that equipment. The lists of projects in this process are known as "interconnection queues".

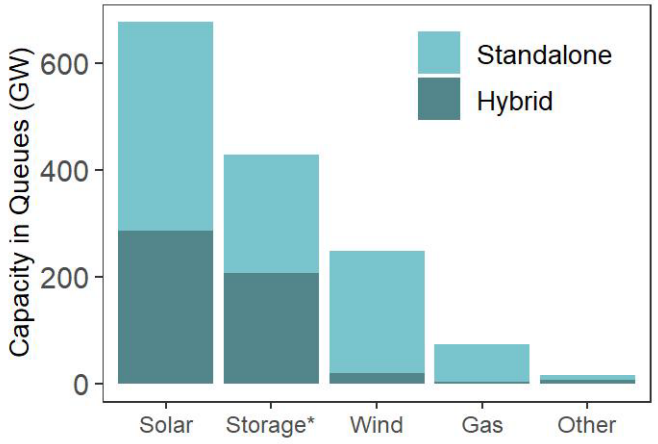
Visit https://emp.lbl.gov/queues to download the data used for this analysis and to access an interactive data visualization tool

BERKELEY LAB

High-Level Findings

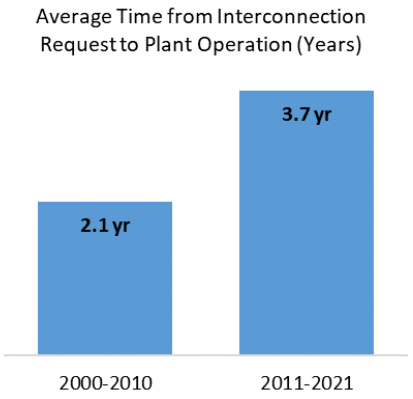
Developer interest in solar, storage, and wind is strong

- Over 1 TW (1000 GW) of generator capacity and 420 GW of storage currently seeking interconnection
- Most (~930 GW) proposed generation is zero-carbon
- Hybrids now comprise a large – and increasing – share of proposed projects



Completion rates are generally low; wait times may be increasing

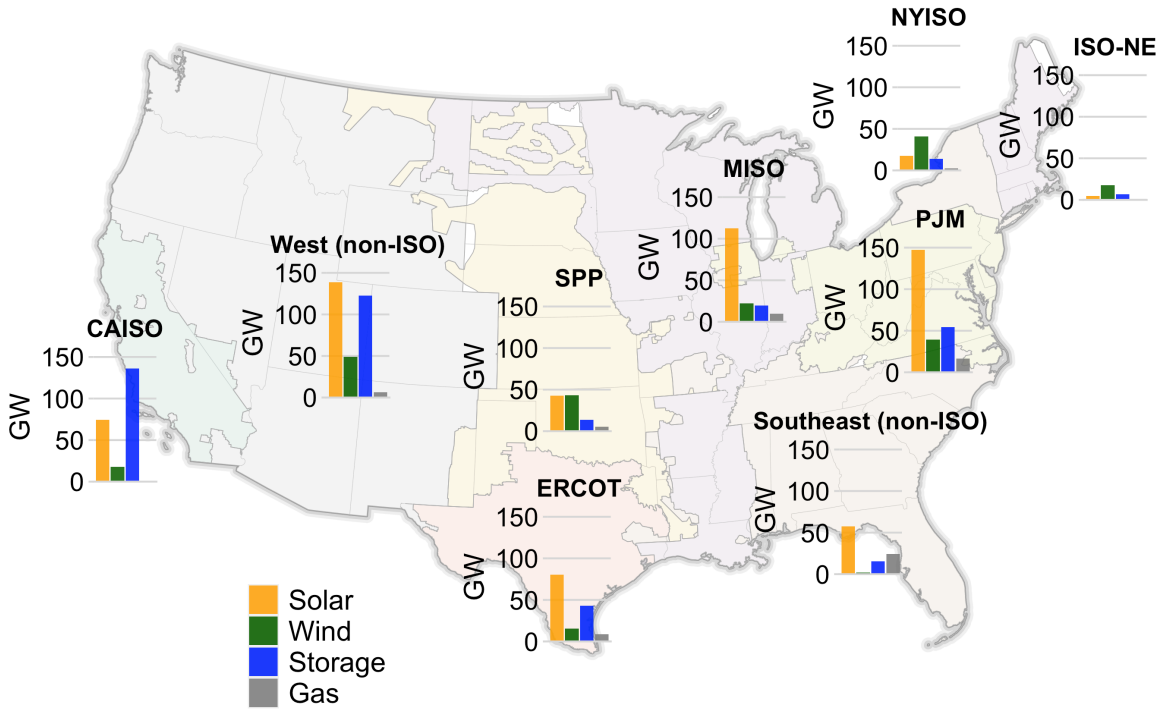
- Only ~23% of projects that requested interconnection from 2000-2016 have reached commercial operations; 72% have withdrawn



- Completion rates are even lower for wind (20%) and solar (16%)
- For five regions[1] where data were available, the time projects spent in queues before being built increased from ~2.1 years for projects built in 2000-2010 up to ~3.7 years for those built in 2011-2021

Proposed capacity is widely distributed across the U.S.

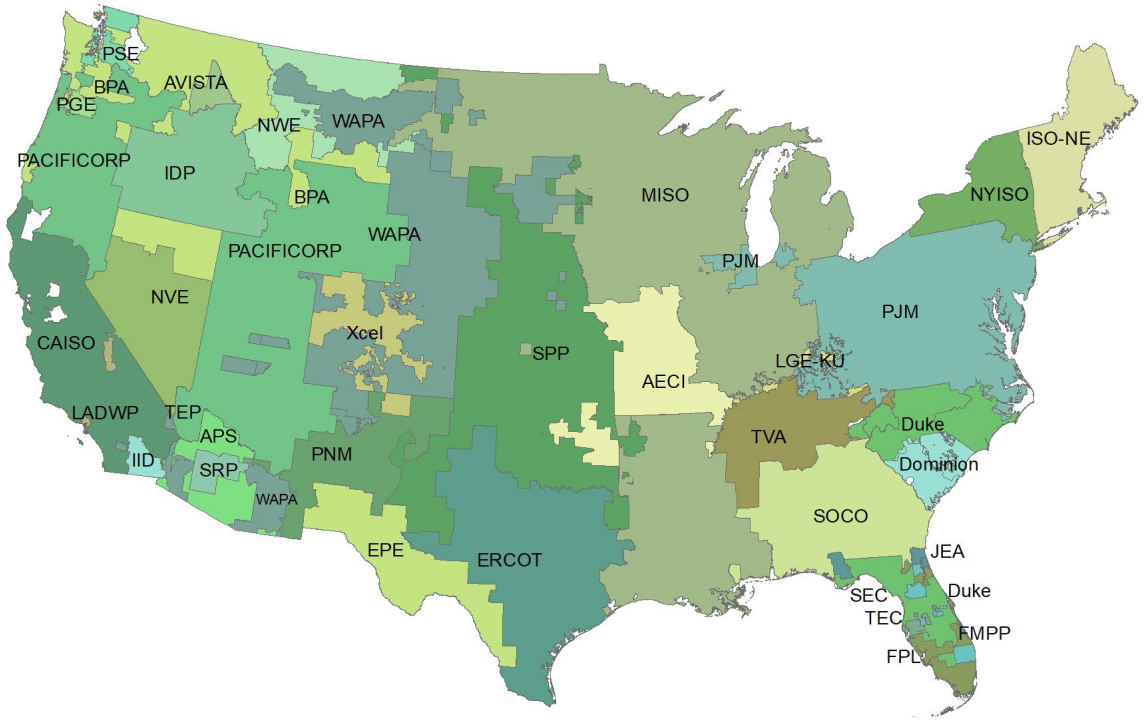
- Substantial proposed solar capacity exists in most regions of the U.S.
- Wind capacity is highest in the non-ISO West and SPP, with increasing share of East Coast offshore projects
- Storage is primarily in CAISO and the West, but also strong in PJM
- Proposed gas is primarily in the Southeast and PJM



1. *In-service date was only available for 1,570 operational projects from 4 ISO/RTOs (CAISO, ERCOT, NYISO, PJM) and one utility (APS).*

Methods and Data Sources

- Data collected from interconnection queues for 7 ISOs / RTOs and 35 utilities, which collectively represent >85% of U.S. electricity load
  - Projects that connect to the bulk power system: not behind-the-meter
  - Includes all projects in queues through the end of 2021
  - The full sample includes:
    - 8,133 “active” projects
    - 12,585 “withdrawn” projects
    - 3,439 “operational” projects
    - 229 “suspended” projects
- Hybrid / co-located projects were identified and categorized
  - Storage capacity in hybrids (separate from generator capacity) was estimated based on available data for some projects
- Note that being in an interconnection queue *does not guarantee* ultimate construction

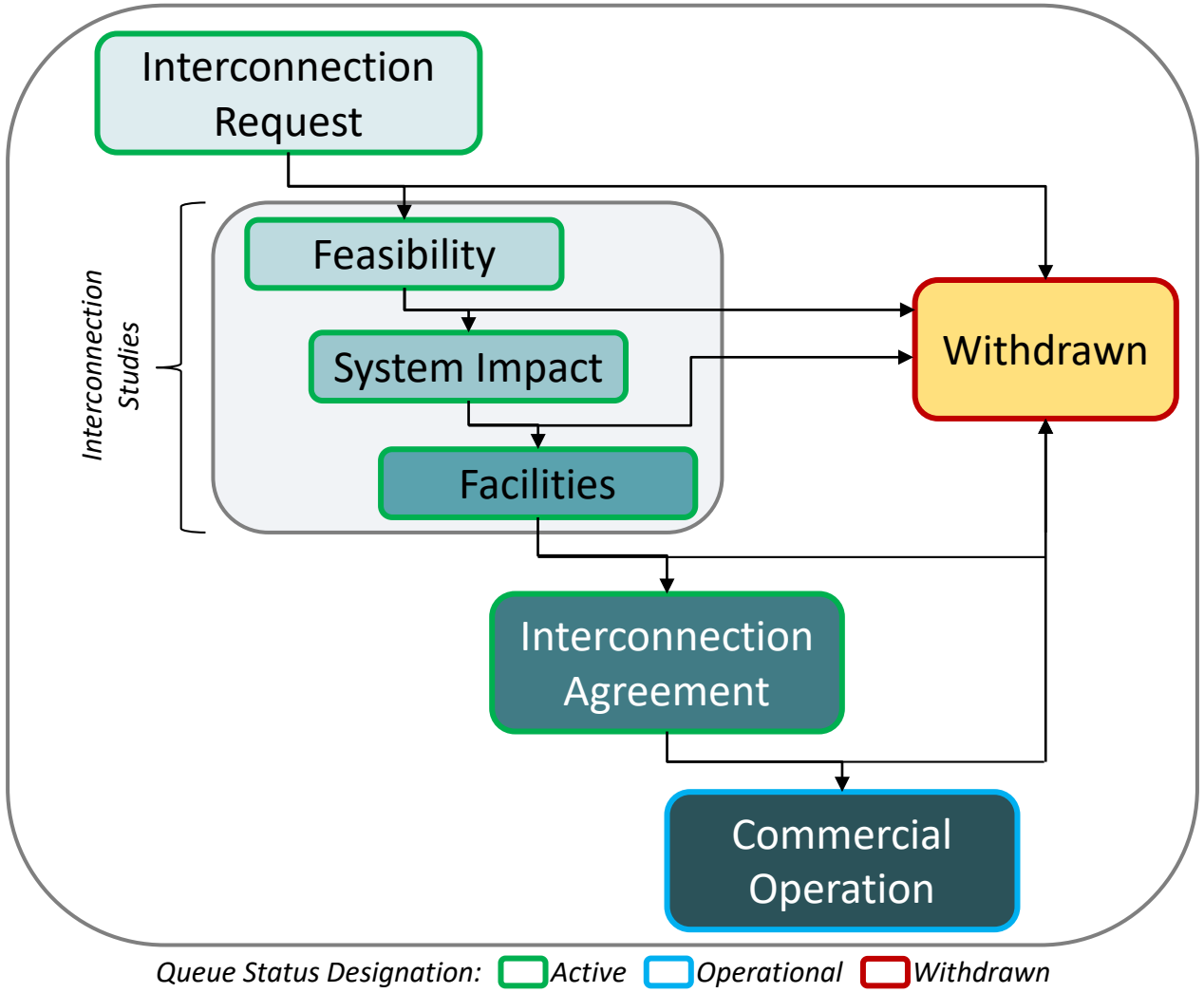


Coverage area of entities for which data was collected
Data source: Homeland Infrastructure Foundation-Level Data (HIFLD)
A full list of included balancing areas can be found in the Appendix
Note that service areas can overlap
No data collected for Hawaii or Alaska

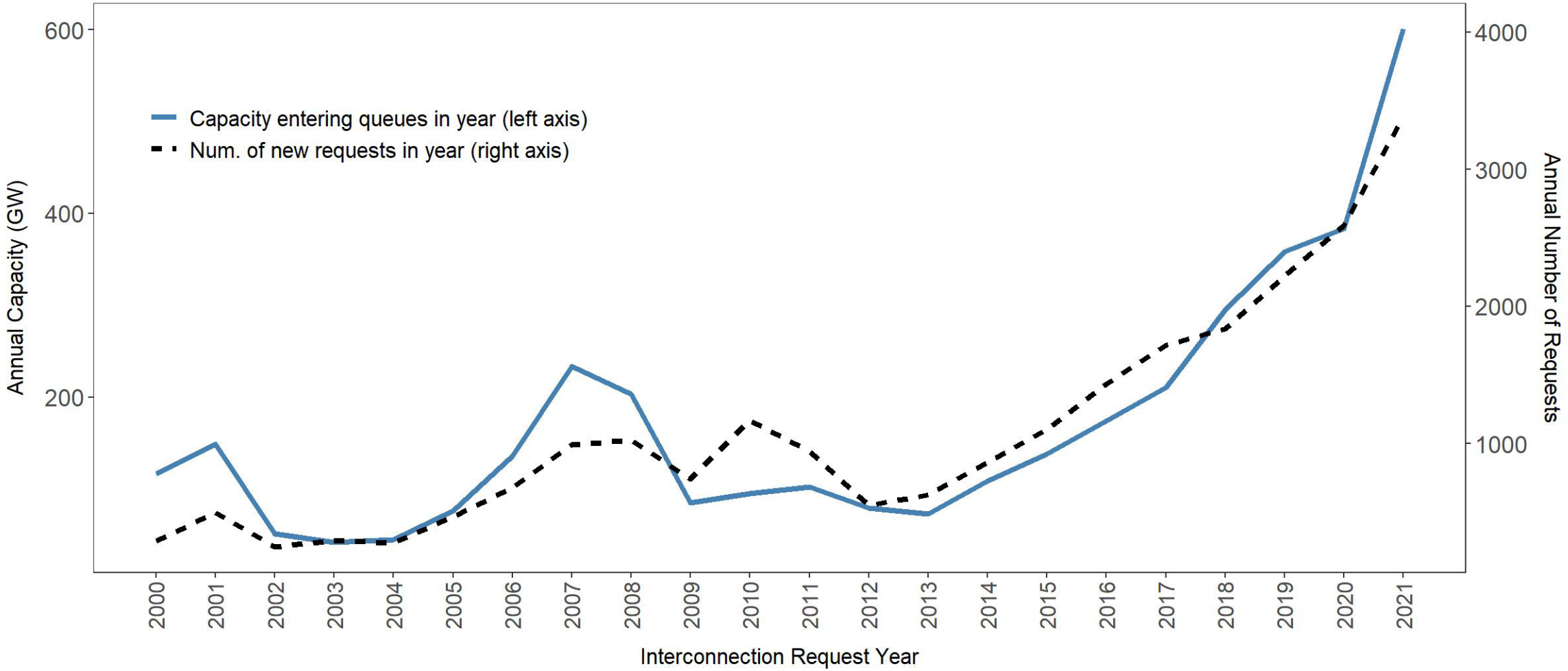
Typical Interconnection Study Process and Timeline

- A project developer initiates a new ***interconnection request (IR)*** and thereby enters the ***queue***
- A series of ***interconnection studies*** establish what new transmission equipment or upgrades may be needed and assigns the costs of that equipment
- The studies culminate in an ***interconnection agreement (IA)***: a contract between the ISO or utility and the generation owner that stipulates operational terms and cost responsibilities
- Most proposed projects are ***withdrawn,*** which may occur at any point in the process
- After executing an IA, some projects are built and reach ***commercial operation***

Simplified Interconnection Study Process



There has been a substantial increase in annual interconnection requests (both in terms of number and capacity) since 2013; over 600 GW added in 2021 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.

Commercially Operational & Withdrawn Projects: Volume and Completion Rates

Operational project data were collected from all 7 ISO/RTOs, and 25 non-ISO utilities, totaling 3,439 projects.

Region	*n* (Operational)
CAISO	194
ERCOT	320
ISO-NE	325
MISO	438
NYISO	85
PJM	1,036
SPP	229
Southeast (non-ISO)	203
West (non-ISO)	609

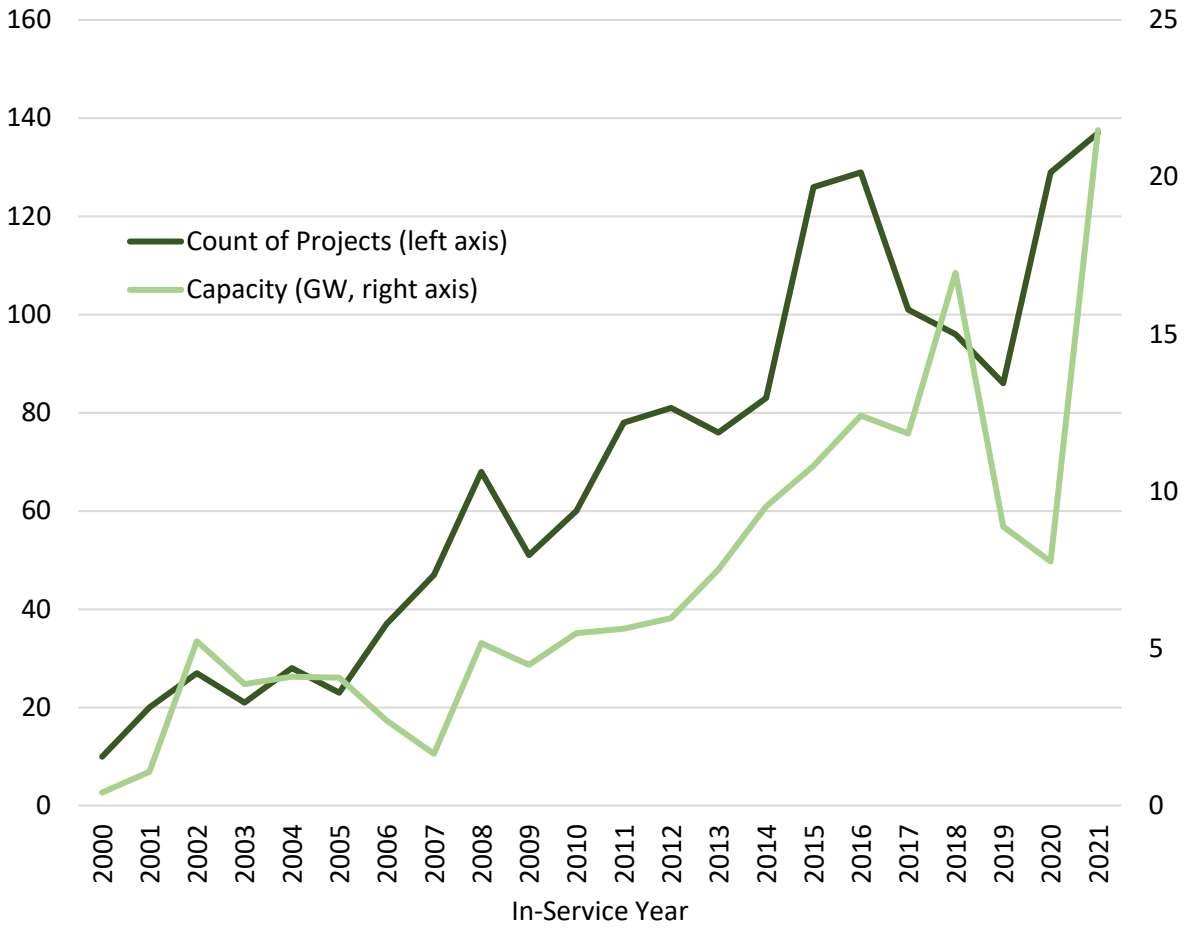
Withdrawn project data were collected from 6 ISO/RTOs, and 32 non-ISO utilities, totaling 12,585 projects.

Region	n (Withdrawn)
CAISO	1,472
ERCOT	689
ISO-NE	567
MISO	1,825
NYISO	653
PJM	3,352
SPP	0
Southeast (non-ISO)	1,071
West (non-ISO)	2,956

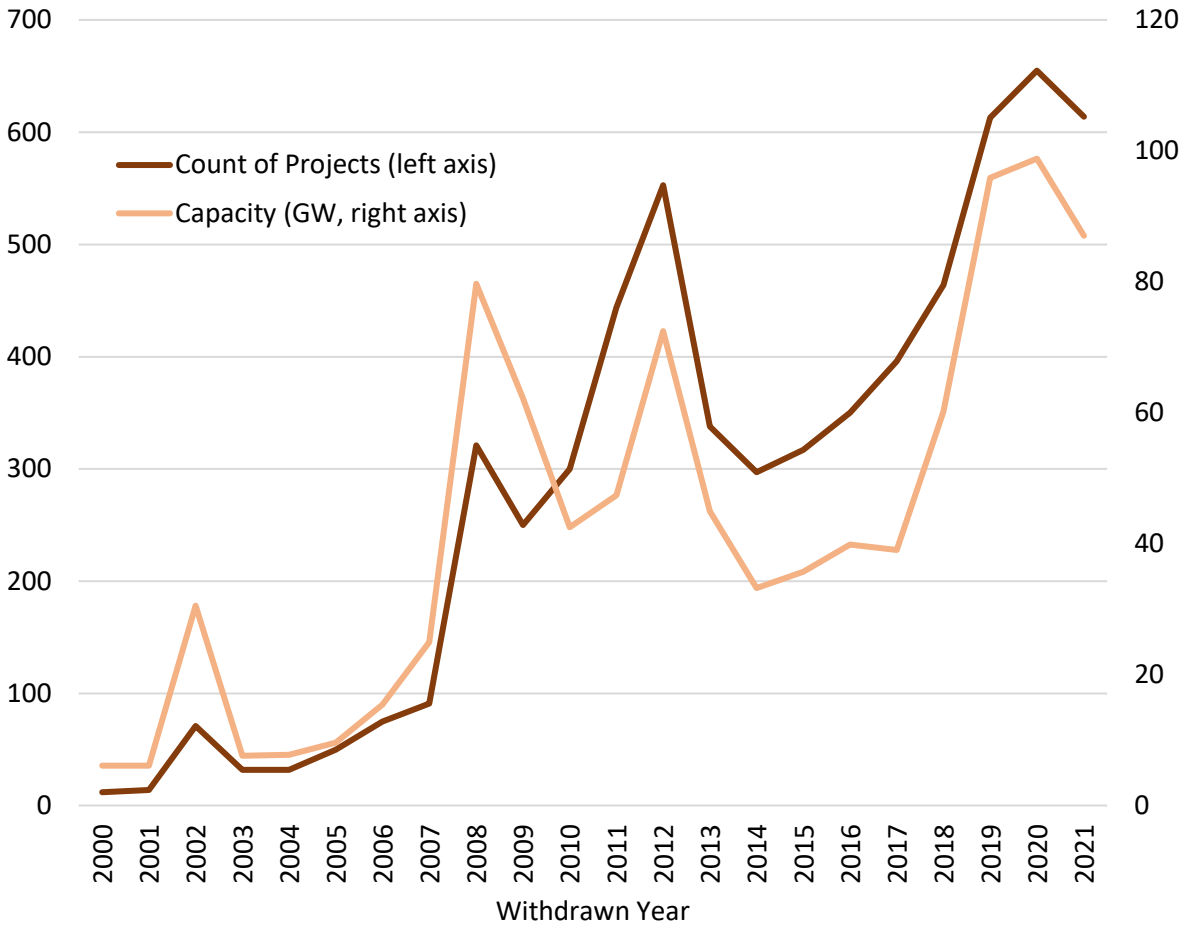
Notes: (1) The number of operational and withdrawn projects with available data may be fewer than the total number of operational or withdrawn projects for each entity. (2) Data were sought from 7 ISO/RTOs and 35 utilities; operational and withdrawn project data are not always available.

Volume (number and capacity) of operational and withdrawn projects are increasing year-over-year

Volume of Operational Projects by In-Service Year



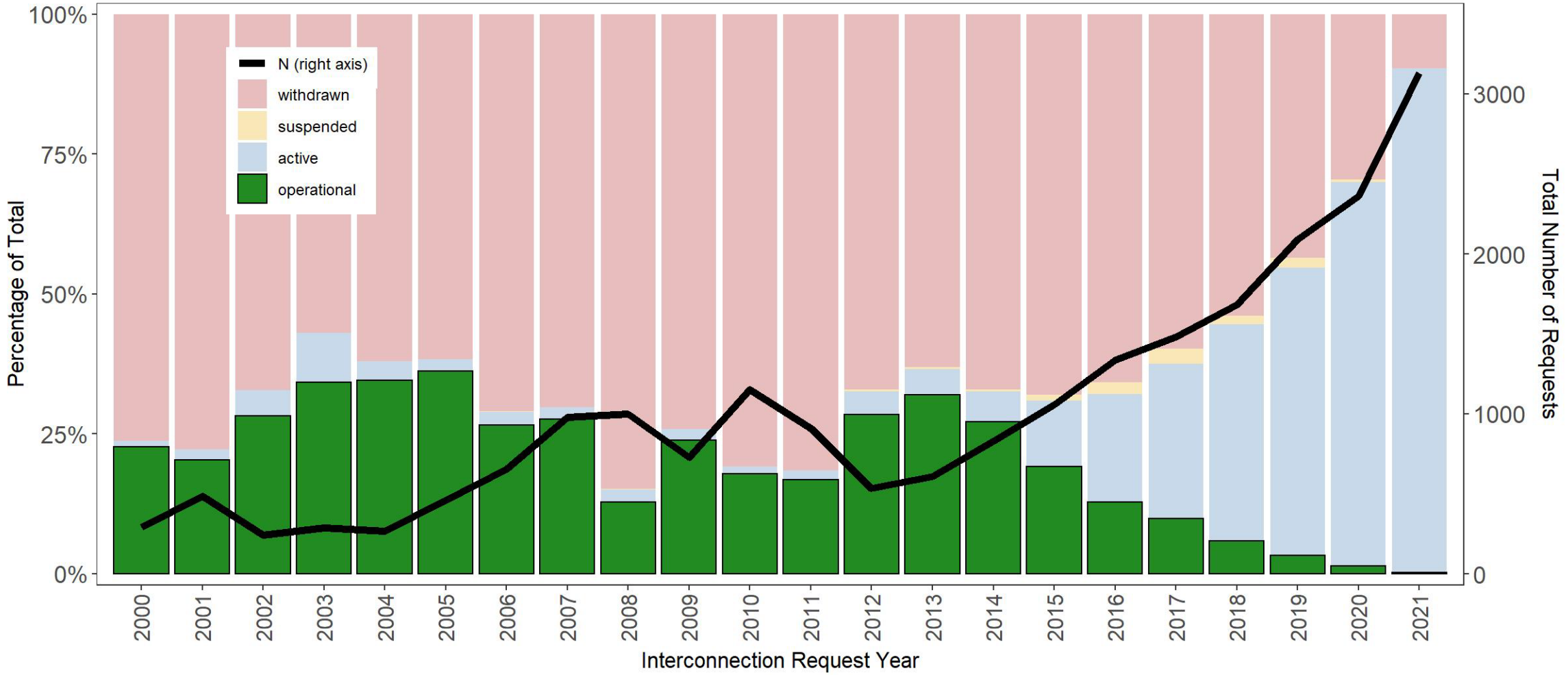
Volume of Withdrawn Projects by Withdrawn Year



Note: In-service year only available for 44% of the "operational" project sample; withdrawn year only available for 50% of the "withdrawn" project sample. These figures therefore only include a subset of total data.

Less than 23% of all projects proposed from 2000-2016 have reached commercial operations – 72% have withdrawn from queues

The completion rate may have increased temporarily after 2010-2012 queue reforms[1] but appears to be declining for projects proposed since 2013. Trends for projects proposed in 2017 and after cannot yet be determined.

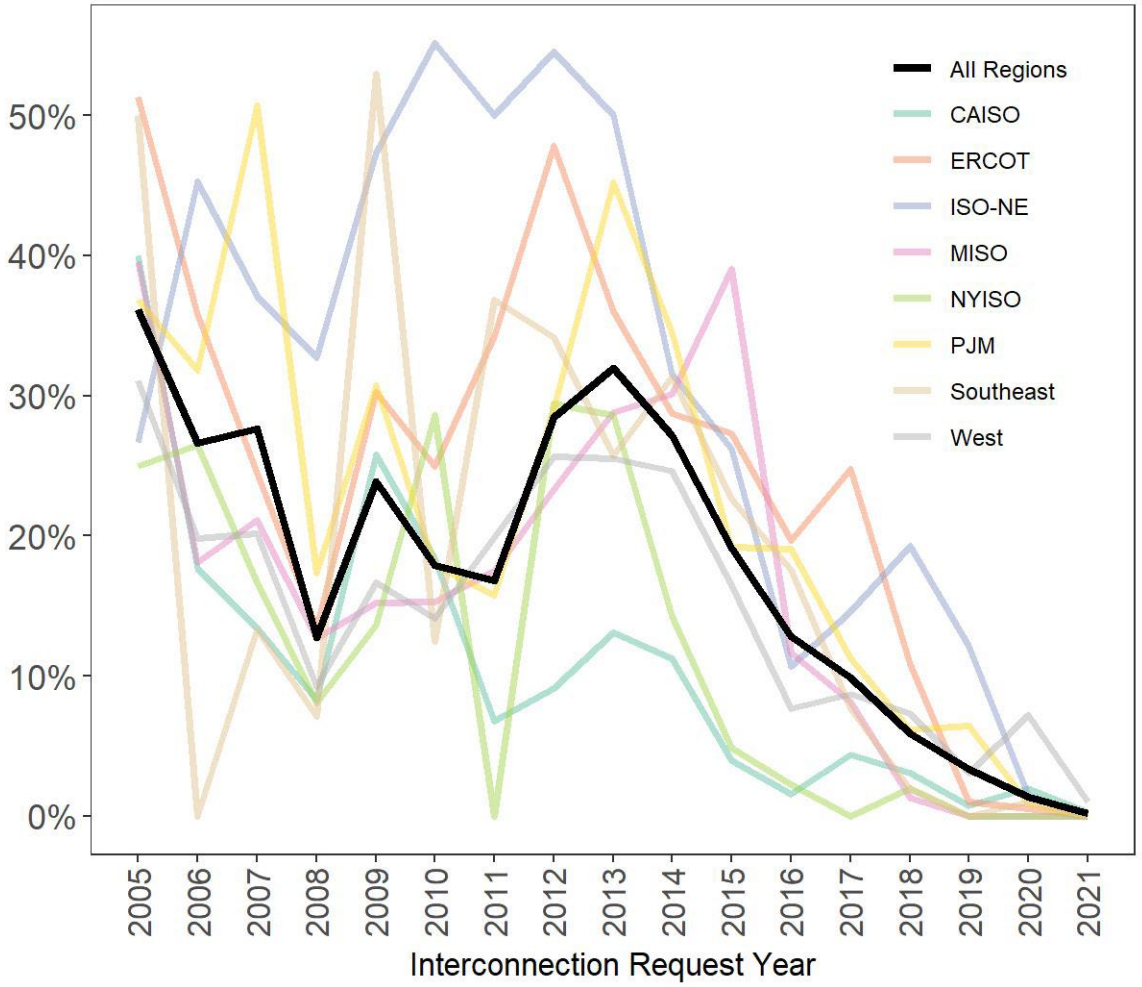


1. Americans for a Clean Energy Grid. *Disconnected: The Need for a New Generator Interconnection Policy.* January, 2021.

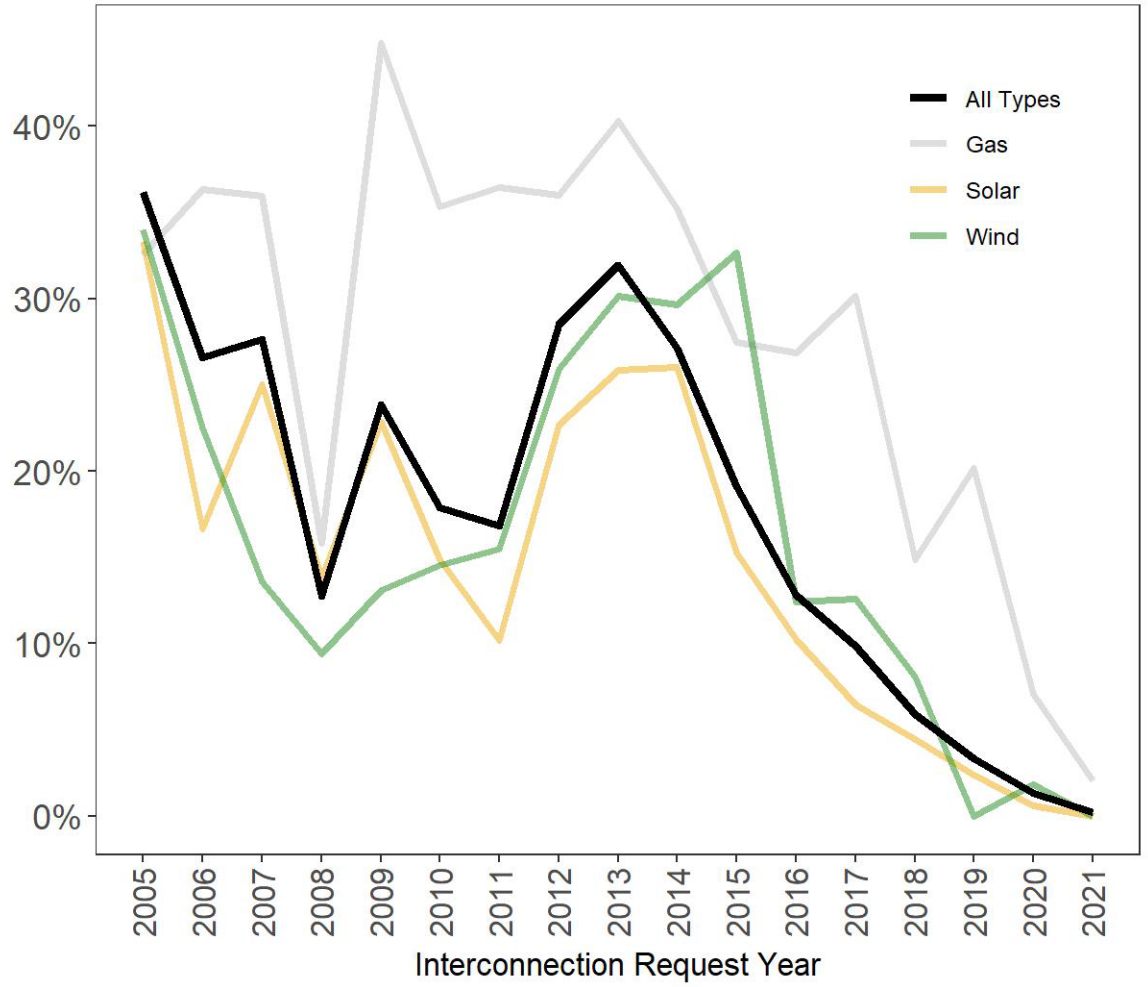
Notes: (1) Completion rate is calculated by number of projects, not capacity-weighted. (2) Limited to data from 6 ISO/RTOs and 25 utilities.

There is considerable variation in completion rates across ISOs and regions; wind (20%) and solar (16%) have lower completion rates from 2000-2016 than other types

Completion percentage by region:

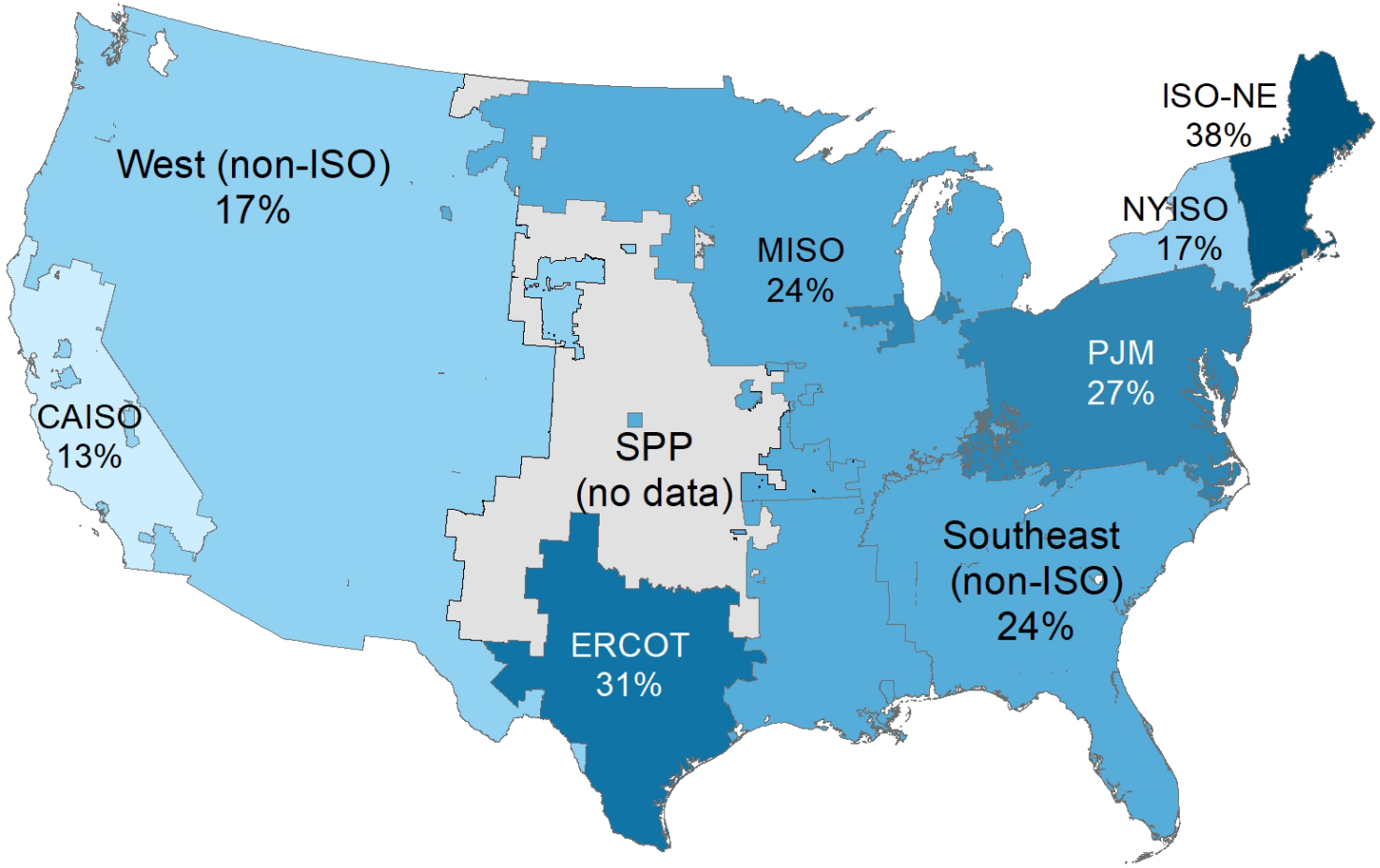


Completion percentage by generator type:



Note: Completion rate is calculated by number of projects, not capacity-weighted. Includes data from six ISOs and 25 utilities.

The share of projects that entered the queues from 2000-2016 and have reached COD is relatively low across regions: Only ISO-NE and ERCOT exceed 30% completion



- The share of queued projects that reach COD is relatively low
- For interconnection requests from 2000-2016, ISO-NE (38%) and ERCOT (31%) had the highest project completion percentages, with CAISO (13%) and NYISO (17%), and the non-ISO West (17%) lower on average
- These rates are variable by year, and trends may be shifting as queue volumes and reforms evolve
- The difference between regions, temporal trends, and the implications of these low rates on electric-sector decarbonization, are important areas for future research

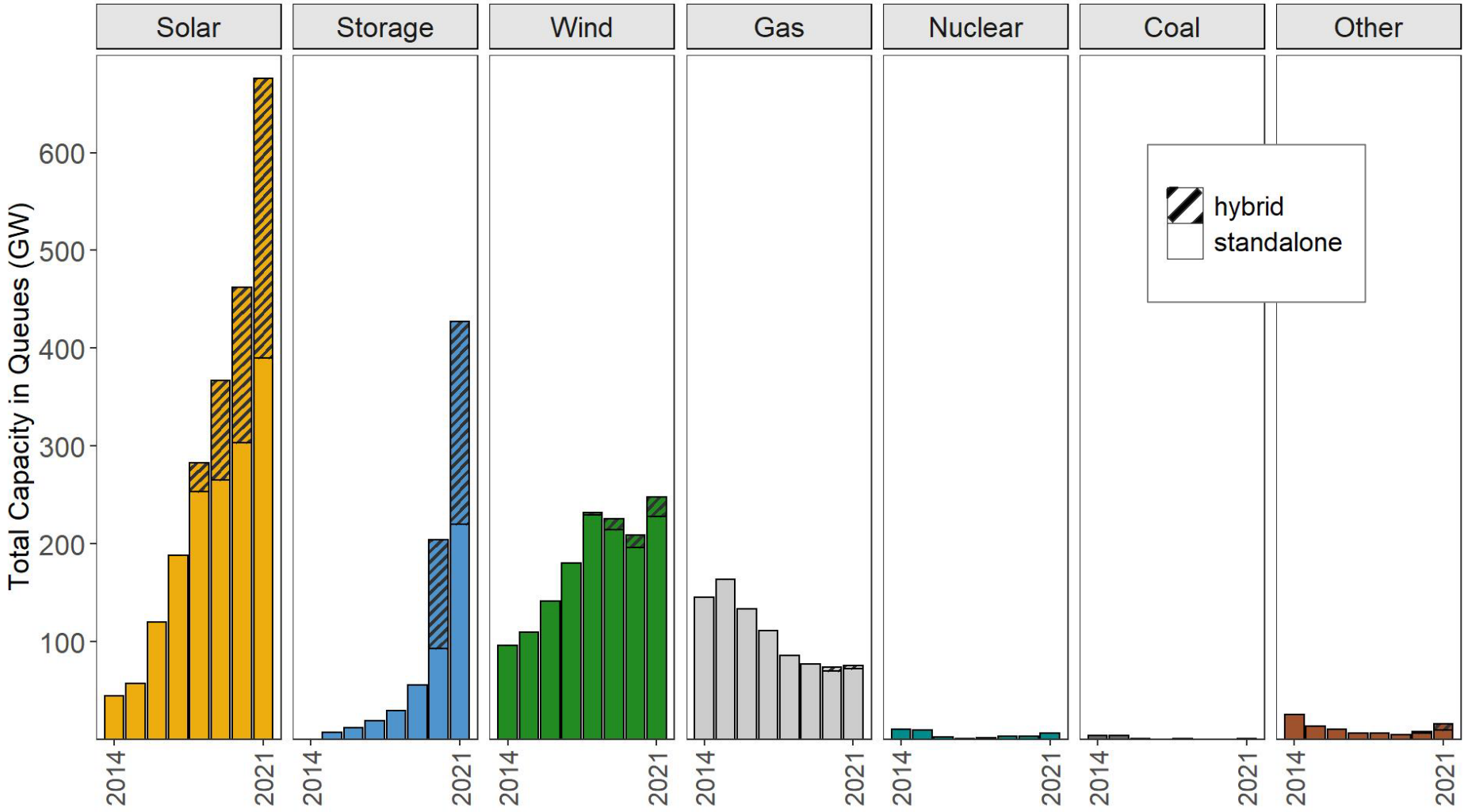
Note: Completion rate is calculated by number of projects, not capacity-weighted. Includes data from six ISOs and 25 utilities.

Active Projects in Interconnection Queues: Volume, Time Trends, Regional Trends, and Hybrids

Includes data from all 7 ISOs and 35 non-ISO utilities, totaling 8,133 proposed projects

Region	n (Active)
CAISO	604
ERCOT	673
ISO-NE	310
MISO	963
NYISO	385
PJM	2,734
SPP	555
Southeast (non-ISO)	708
West (non-ISO)	1,201

Interconnection queues indicate that commercial interest in Solar and Storage has grown, including via hybridization; Wind and Gas relatively stable in recent years

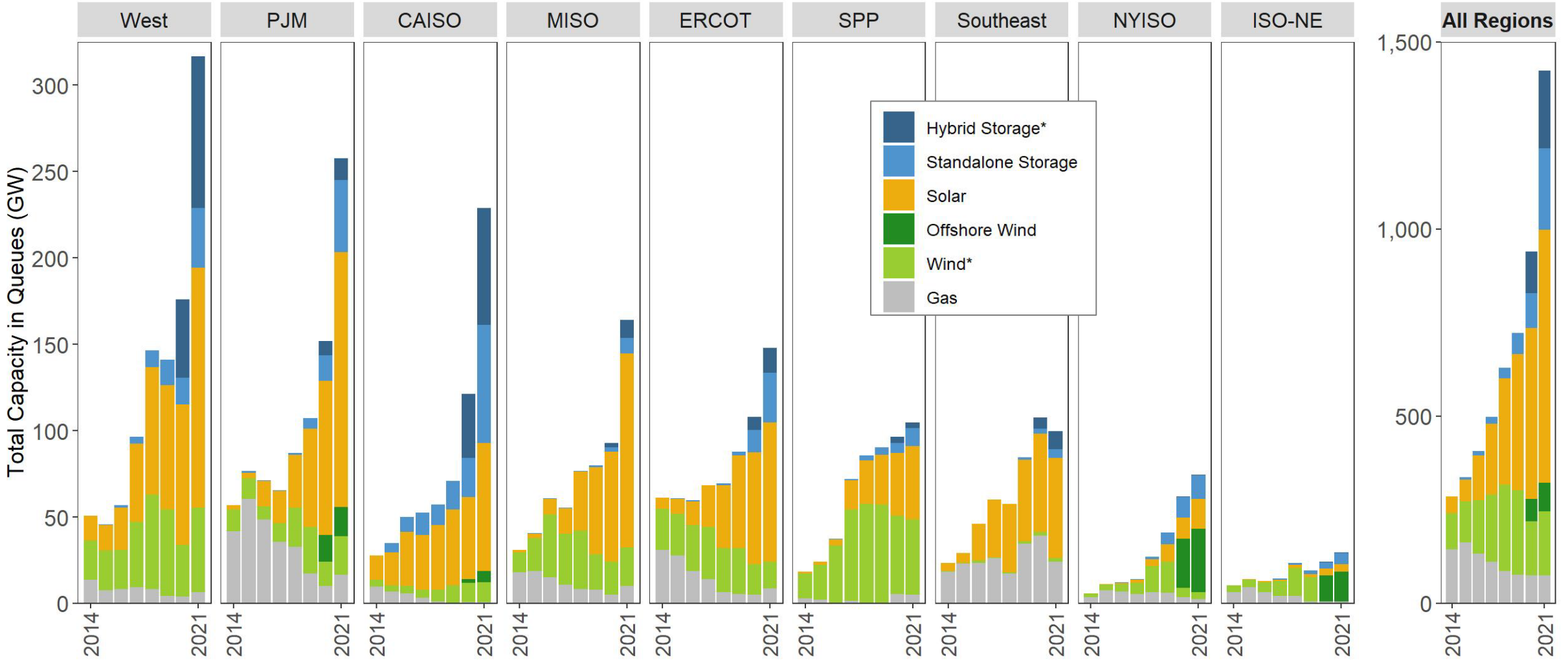


- "**Wind**" includes both onshore and offshore.
- "**Other**" includes
  - Hydropower
  - Geothermal
  - Biomass/biofuel
  - Landfill gas
  - Solar thermal
  - Oil/diesel
- "**Storage**" is primarily (98%) battery, but also includes pumped storage hydro, compressed air, gravity rail, and fuel cell projects.

**Hybrid storage capacity is estimated using storage:generator ratios from projects that provide separate capacity data*
Storage capacity in hybrids was not estimated for years prior to 2020.
Note: Not all of this capacity will be built

BERKELEY LAB

Solar and Storage booming in most regions, especially the West, PJM, and CAISO. Wind growing in the West and offshore, with slight declines in ERCOT, SPP, MISO.

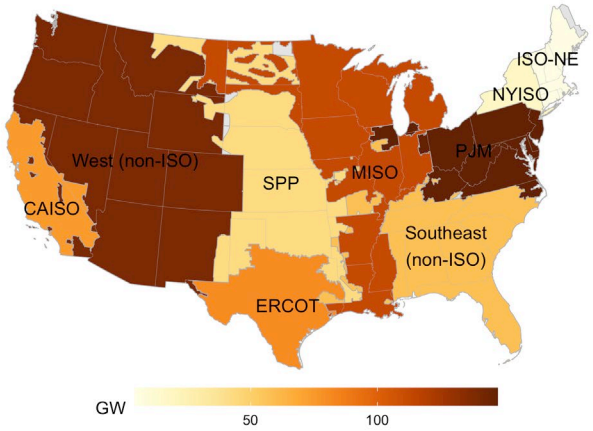


**Hybrid storage capacity is estimated for some projects, and that value is only included starting in 2020. Wind capacity includes onshore and offshore for all years, but offshore is only broken out starting in 2020.*
Notes: (1) Hybrid generation capacity is included in all applicable generator categories. (2) Not all of this capacity will be built.

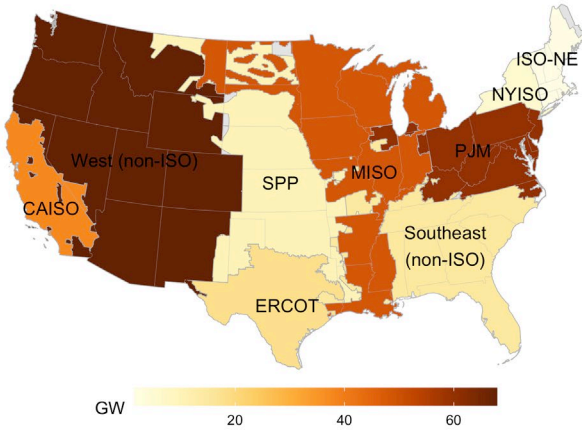
BERKELEY LAB

Regional trends: Proposed solar is widespread, with less in SPP and Northeast; Most wind in the West and SPP with new offshore in NY; Most storage in CAISO, West, and PJM; Gas is largely in the Southeast

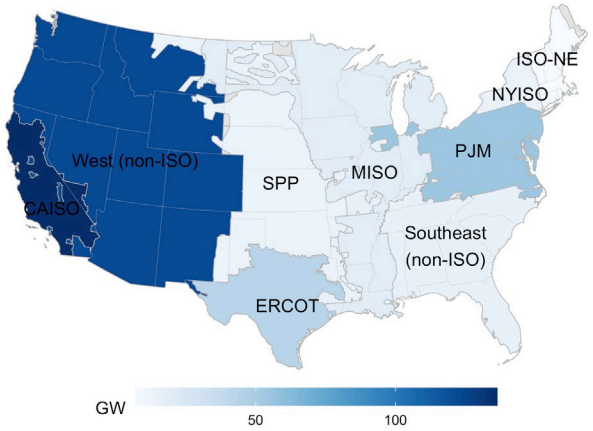
Total Solar Capacity in Interconnection Queues at the end of 2021



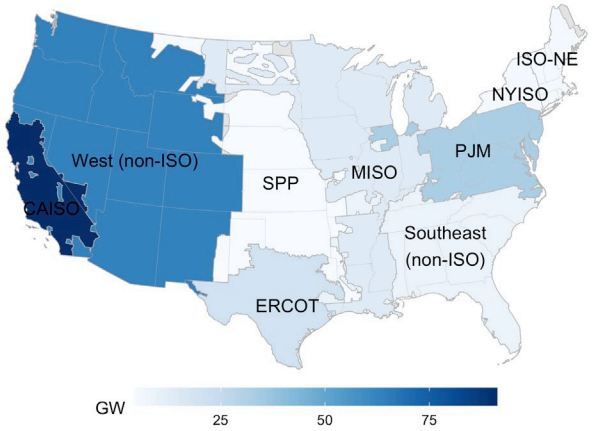
New Solar Capacity Added to Interconnection Queues in 2021



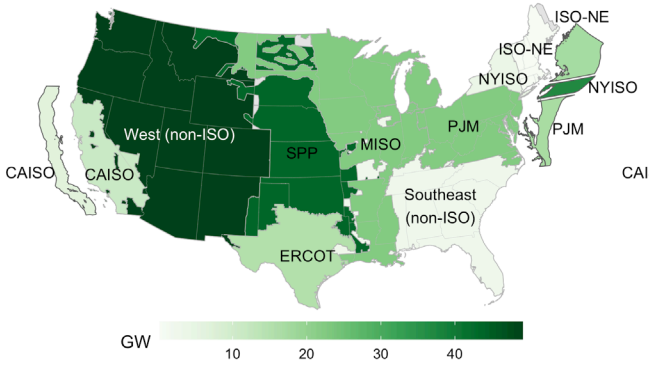
Total Storage Capacity in Interconnection Queues at the end of 2021



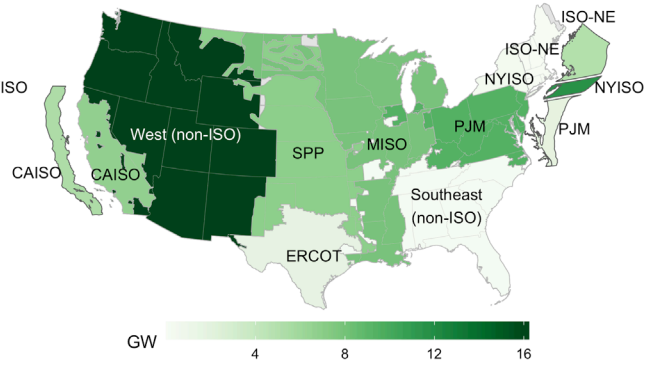
New Storage Capacity Added to Interconnection Queues in 2021



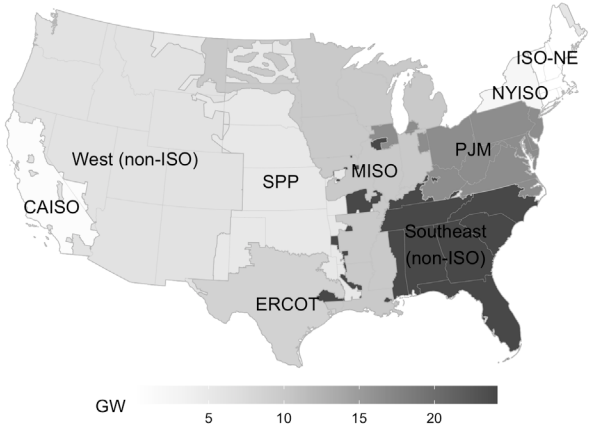
Total Wind Capacity in Interconnection Queues at the end of 2021



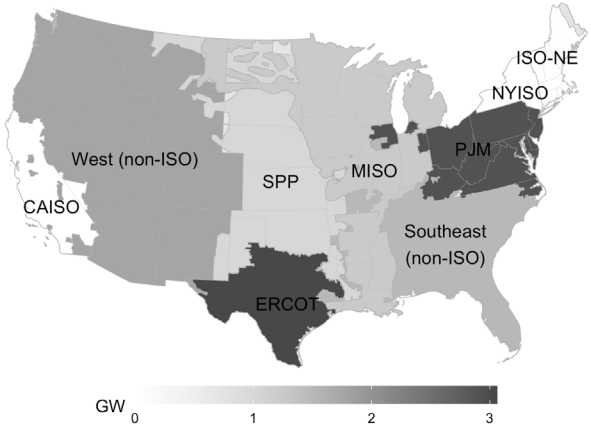
New Wind Capacity Added to Interconnection Queues in 2021



Total Gas Capacity in Interconnection Queues at the end of 2021



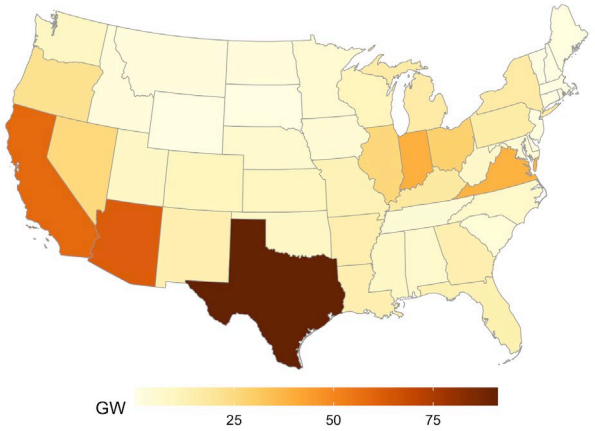
New Gas Capacity Added to Interconnection Queues in 2021



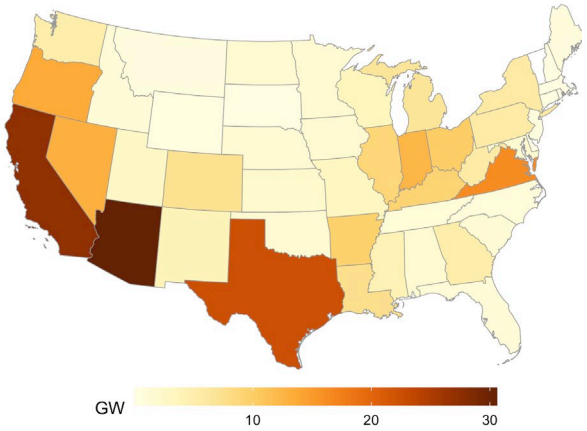
Note: Queue capacity mapped by county can be found in appendix slides.

State Level: Most proposed solar TX, AZ, CA; proposed wind is offshore, TX, and “wind belt”; storage is mainly proposed in CA, TX, AZ; Proposed gas in TX and Southeast

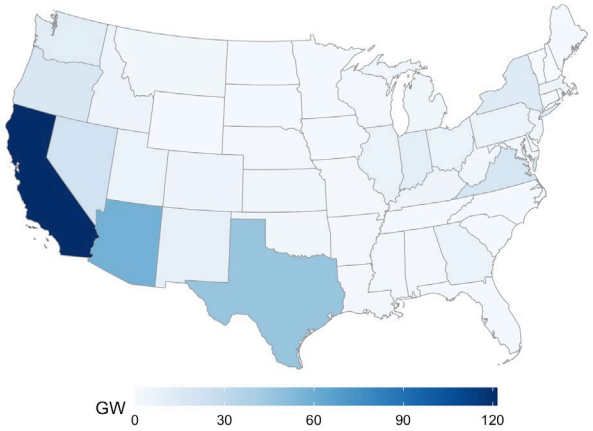
Total Solar Capacity in Interconnection Queues at the end of 2021



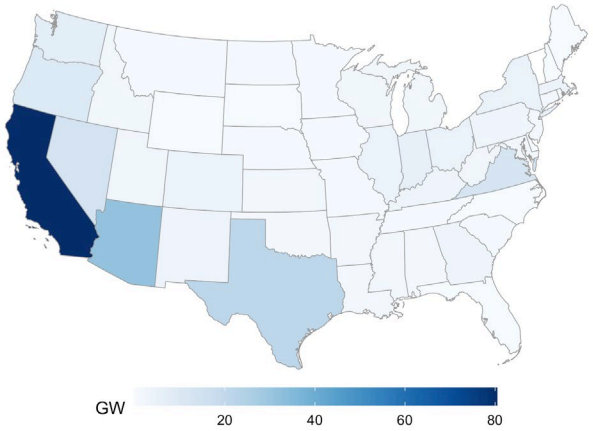
New Solar Capacity Added to Interconnection Queues in 2021



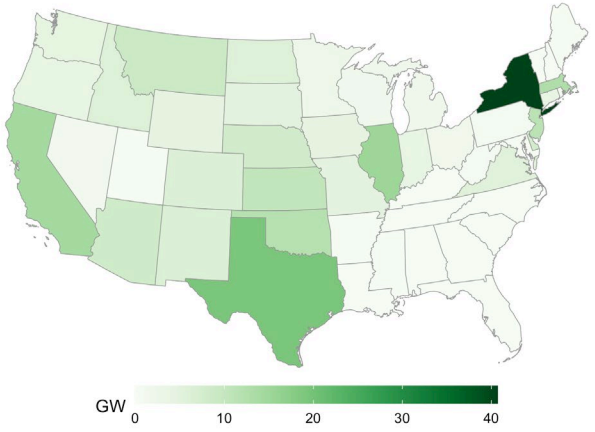
Total Storage Capacity in Interconnection Queues at the end of 2021



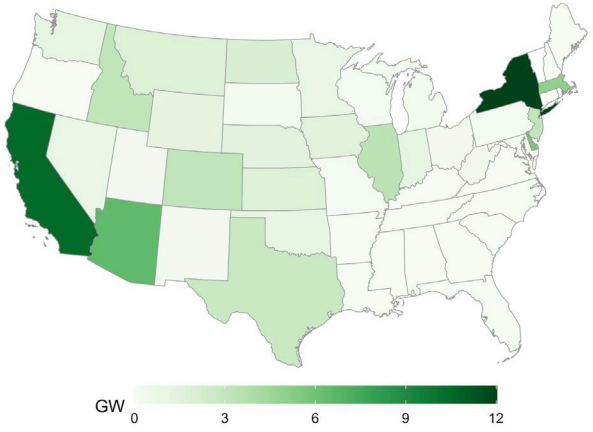
New Storage Capacity Added to Interconnection Queues in 2021



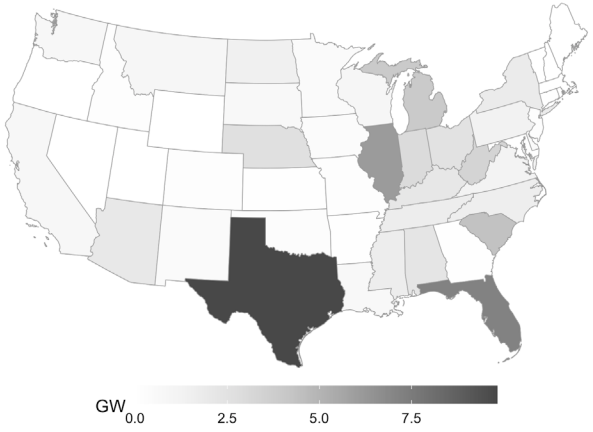
Total Wind Capacity in Interconnection Queues at the end of 2021



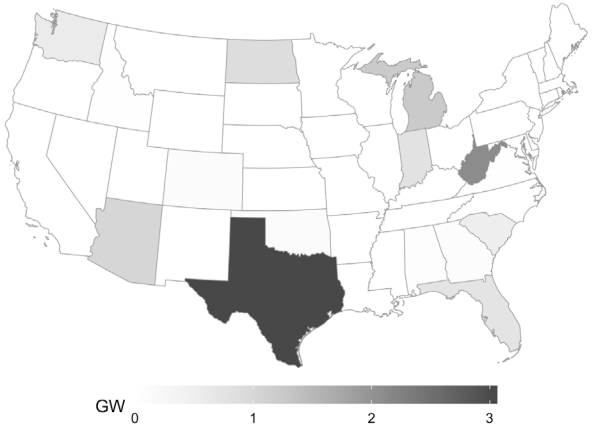
New Wind Capacity Added to Interconnection Queues in 2021



Total Gas Capacity in Interconnection Queues at the end of 2021



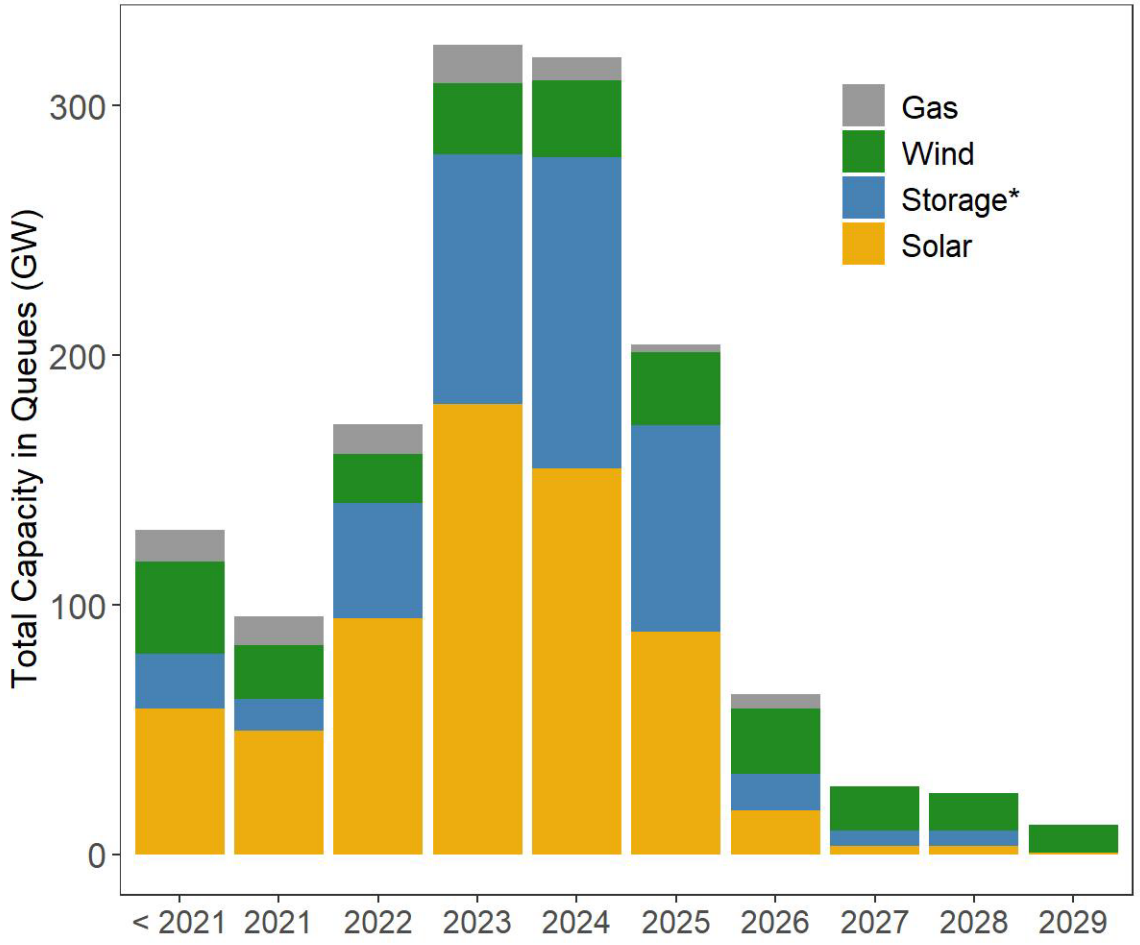
New Gas Capacity Added to Interconnection Queues in 2021

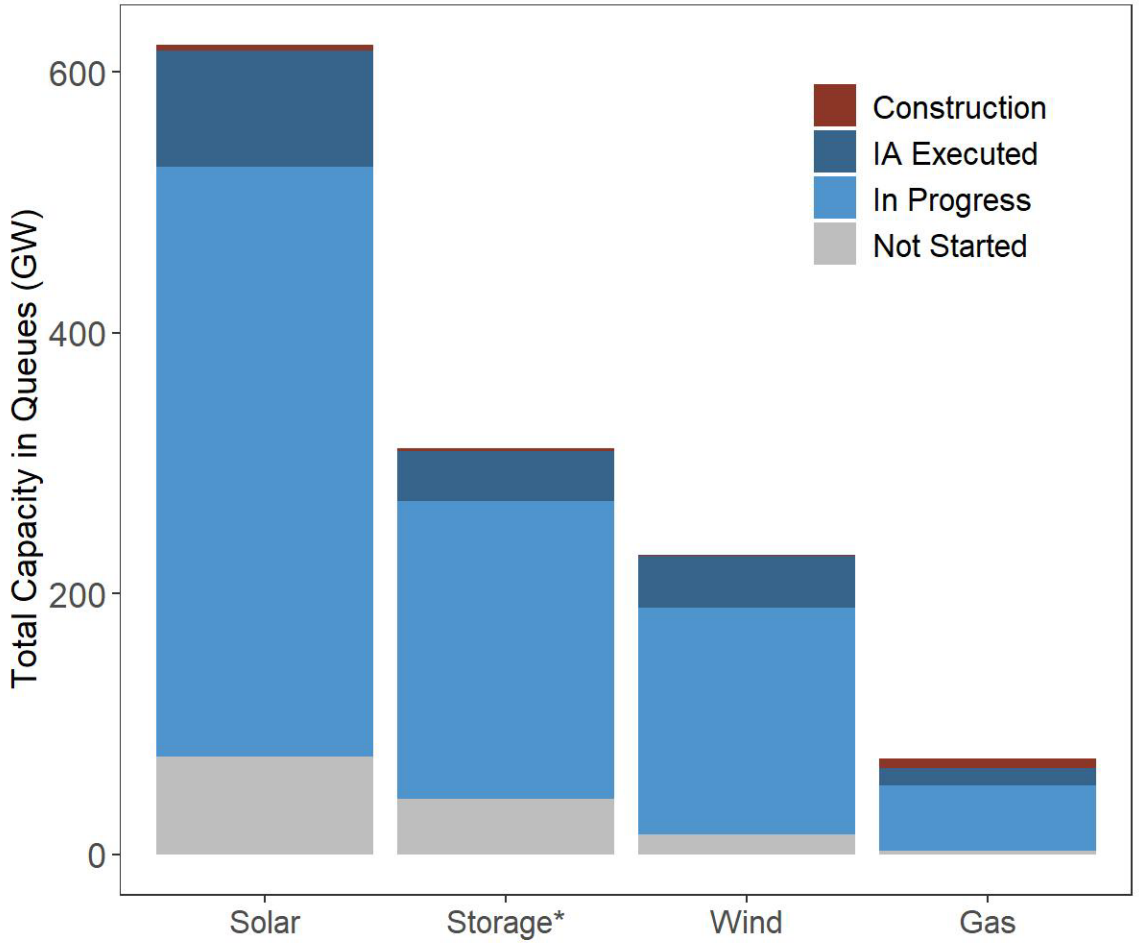


Note: Queue capacity mapped by county can be found in appendix slides.

73% (998 GW) of total capacity in queues has proposed online date by end of 2024; 13% (183 GW) already has an executed interconnection agreement (IA)

80% of solar (537 GW) is proposed to come online by the end of 2024, compared to 72% of storage (307 GW) and only 56% of wind (138 GW). 13% of solar projects have an IA, compared to 16% of wind and 9% of storage.

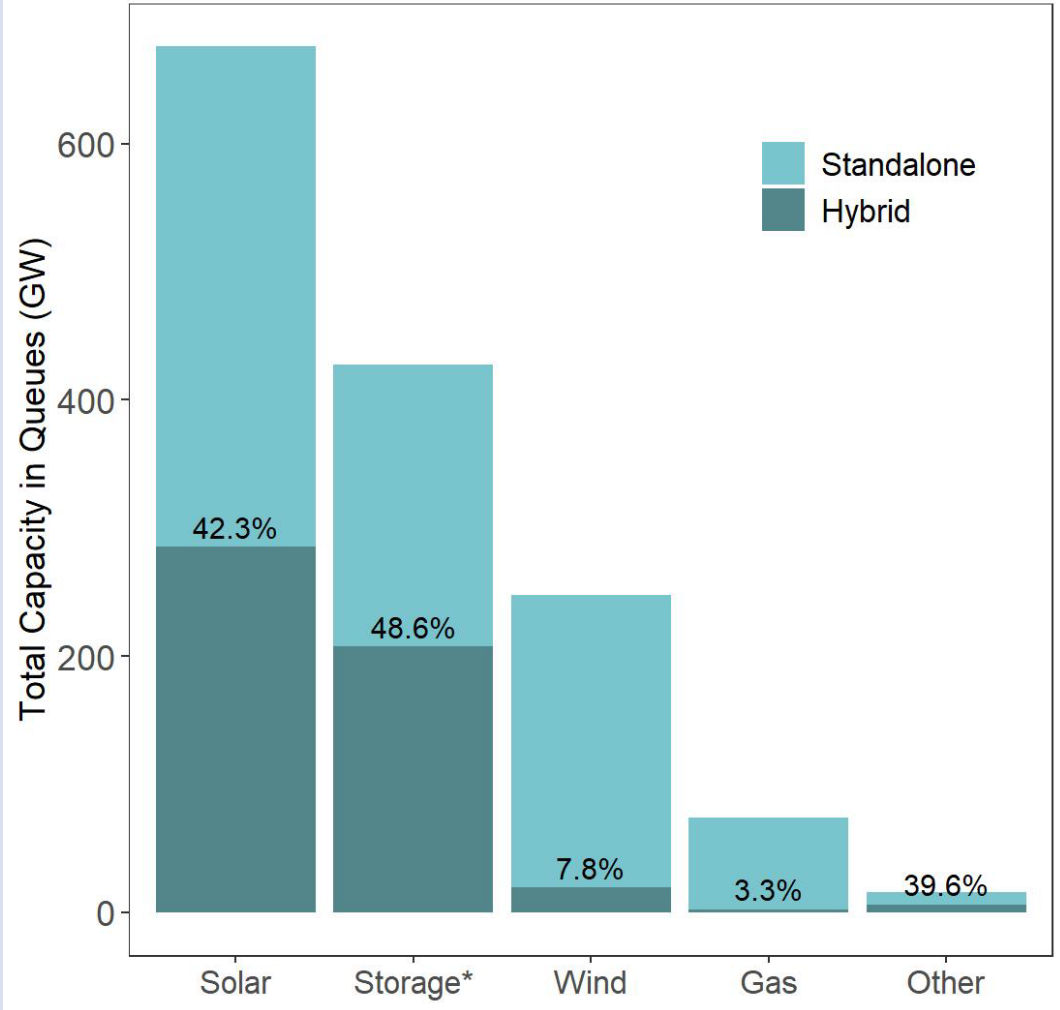




**Hybrid storage capacity is estimated for some projects*

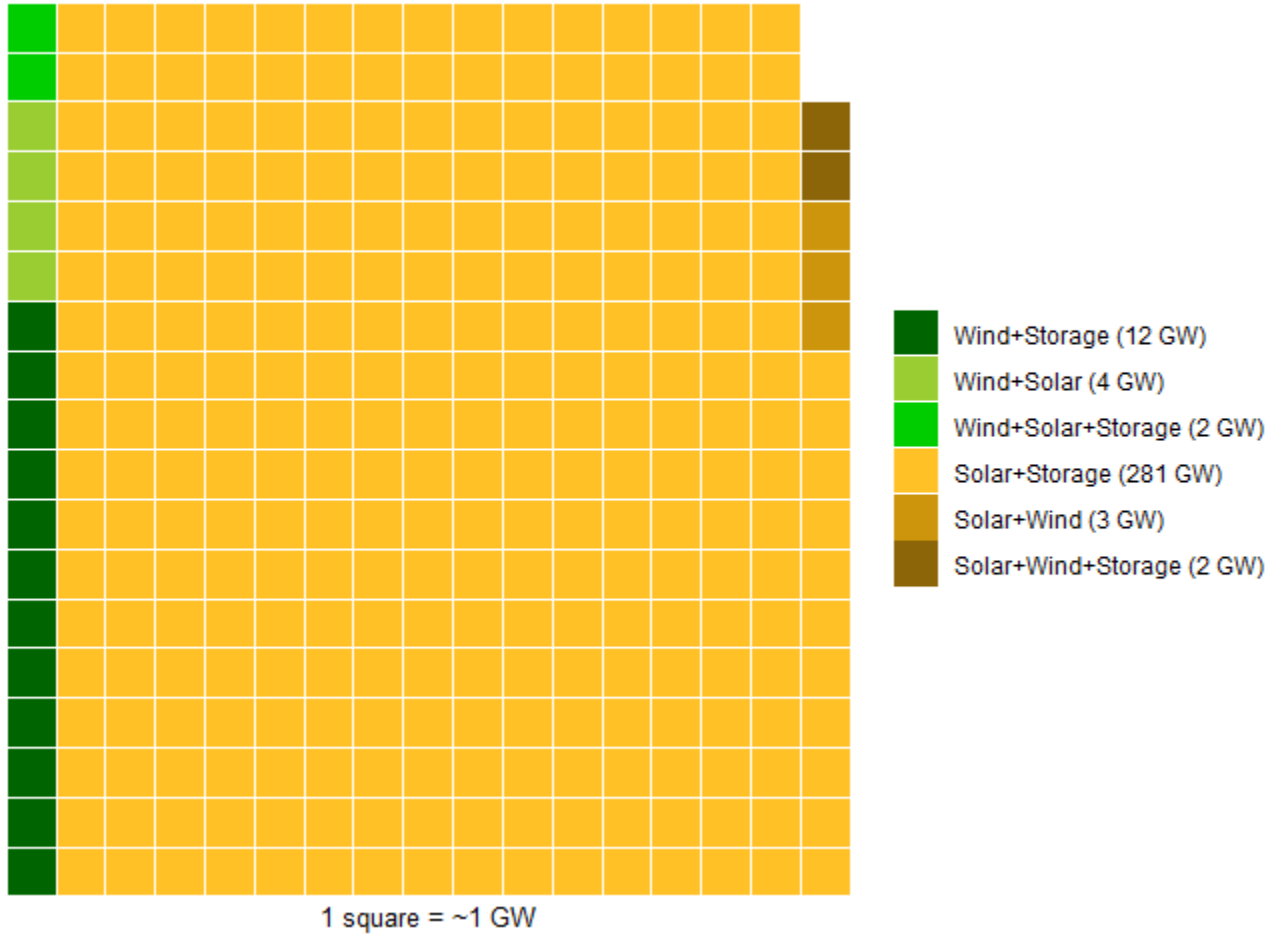
Note: Not all of this capacity will be built. Study status categories are simplified, and not all queues identify projects under construction

Interest in hybrid plants has increased: 42% of solar (285 GW) proposed as hybrids, 8% of wind (17 GW) proposed as hybrids (up from 34% and 6% in 2020, respectively)



*Hybrid storage capacity is estimated using storage:generator ratios from projects that provide separate capacity data

Solar+Storage (281 GW) is by far the largest hybrid configuration



*Only the **generator** capacity is illustrated here (not storage); for hybrid configurations with multiple generator types, each color represents **only the first generator** type.*

Notes: (1) Some hybrids shown may represent battery capacity added to existing generation; only the net increase in capacity is shown; (2) Hybrid plants involving multiple generator types (e.g., wind+PV+storage, wind+PV) show up in all generator categories, presuming the capacity is known for each type.

Hybrids comprise a sizable fraction of all proposed solar plants in multiple regions; wind hybrids are less common overall but still a large proportion in CAISO

Region	% of Proposed Capacity Hybridizing in Each Region			
	Solar	Wind	Nat. Gas	Battery
CAISO	95%	42%	15%	51%
ERCOT	27%	4%	27%	33%
SPP	18%	1%	0%	24%
MISO	27%	8%	0%	n/a
PJM	21%	1%	0%	n/a
NYISO	6%	3%	0%	3%
ISO-NE	24%	0%	0%	n/a
West (non-ISO)	75%	15%	0%	n/a
Southeast (non-ISO)	28%	0%	0%	n/a
TOTAL	**42%**	**8%**	**3%**	**n/a**

- **Solar** hybridization relative to total amount of solar in each queue is highest in CAISO (95%) and non-ISO West (75%), and is above 20% in all but NYISO and SPP
- **Wind** hybridization relative to total amount of wind in each queue is highest in CAISO (42%) and non-ISO West (15%), and is less than 9% in all other regions

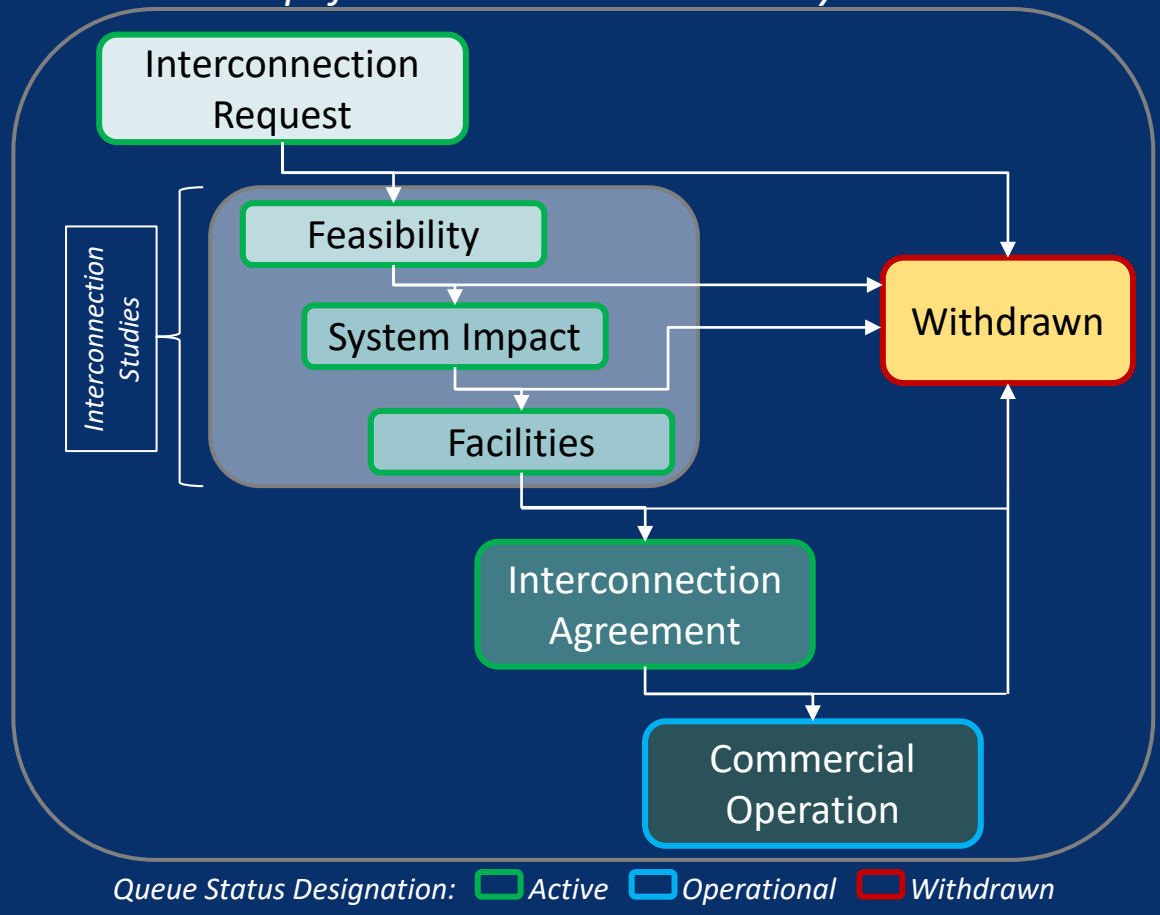
Duration Trends: How Long Do Projects Spend In the Queues?

Active Projects:
- Duration from IR to Interconnection Agreement (IA)

Operational Projects:
- Duration from IR to Commercial Operations Date (COD)
- Duration from IA to COD

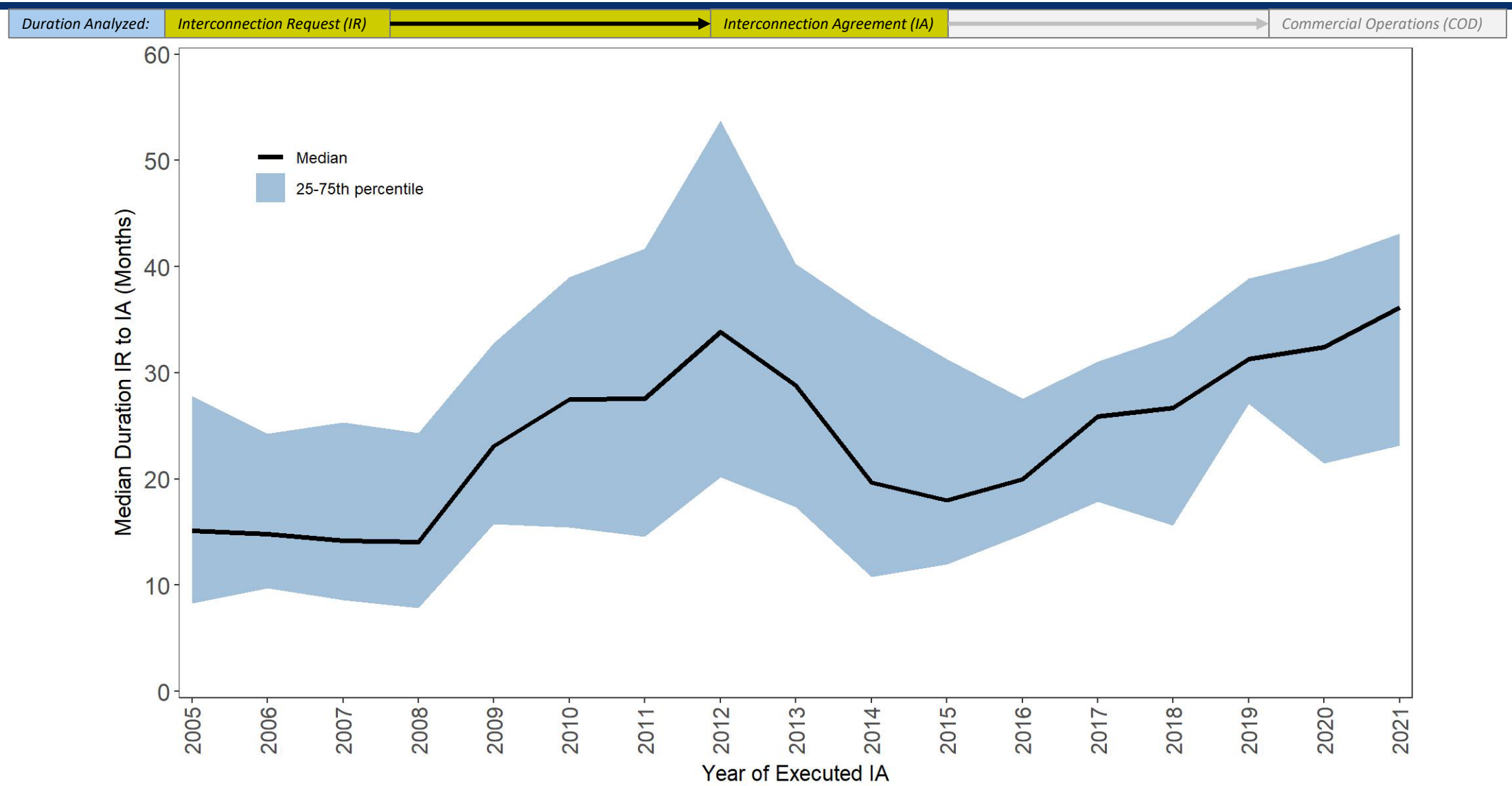
Withdrawn Projects:
- Duration from IR to Withdrawn Date

Simplified Interconnection Study Process



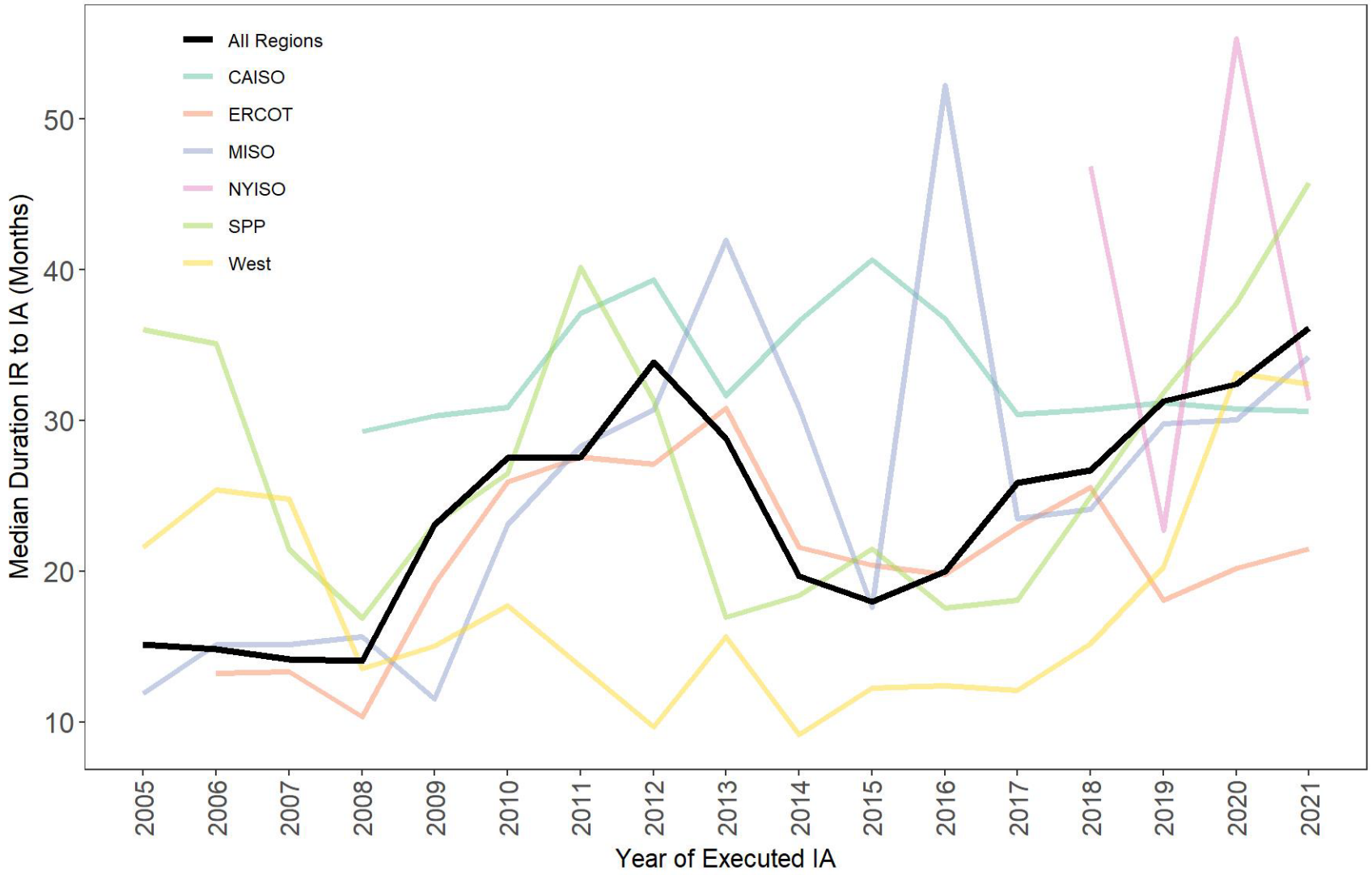
Note: IR to IA duration analysis also included "operational" and "withdrawn" project data, where available

After falling from a 2012 peak, the typical duration from interconnection request to interconnection agreement has increased sharply since 2015, exceeding 3 years in 2021



Notes: (1) Sample includes 2,717 projects from 5 ISO/RTOs and 4 Western utilities with executed interconnection agreements since 2005. (2) Not all data used in this analysis are publicly available.

Recent Increases in IR to IA Durations Are Evident in Some Regions (MISO, SPP, non-ISO West), But Others (CAISO, ERCOT) Have Been Steady Over Time

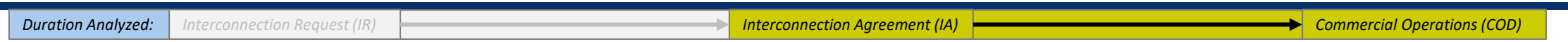


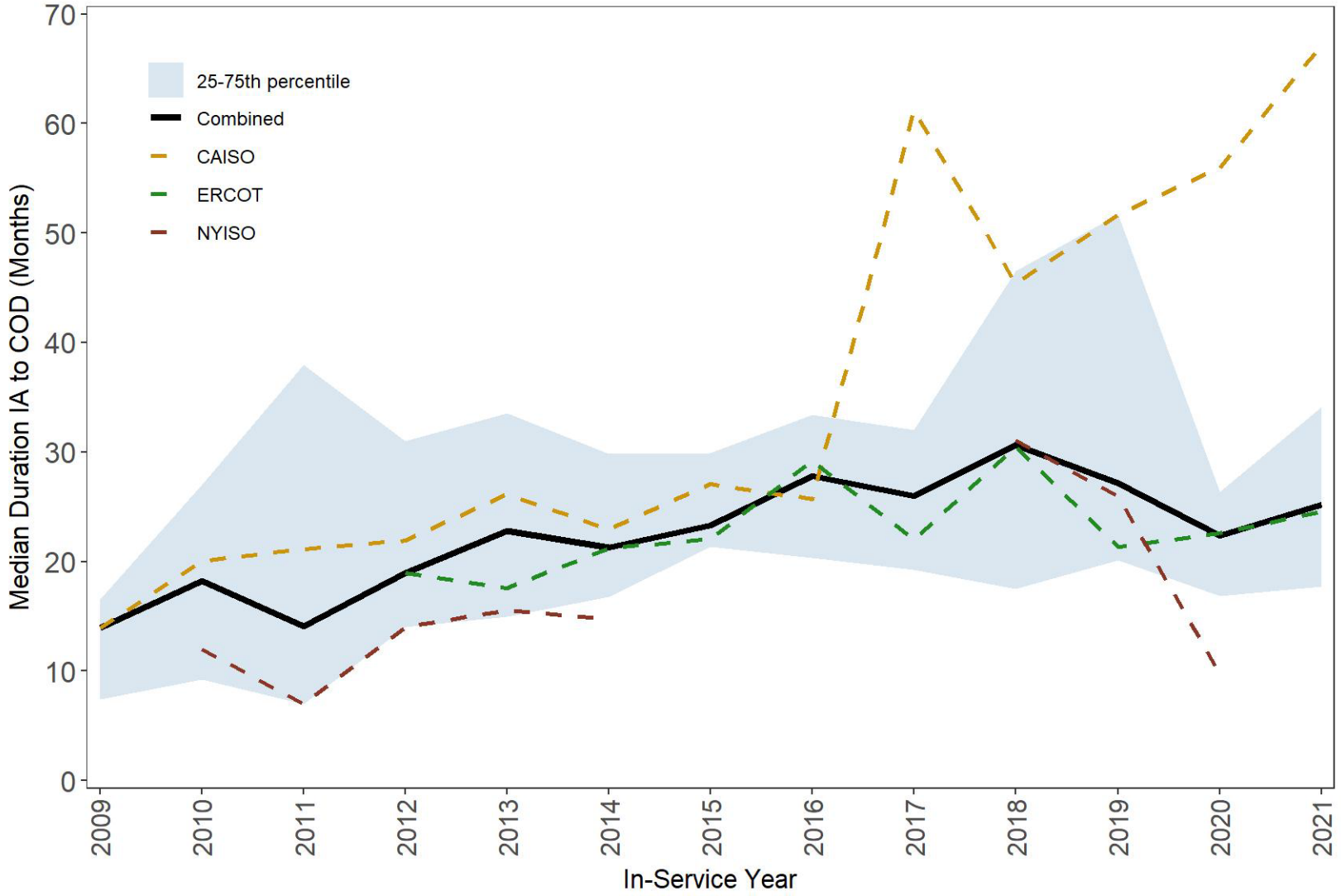
Sample Size (Number of Projects)

IA Year	CAISO	ERCOT	MISO	NYISO	SPP	West
2005		10	68		4	6
2006		24	65		7	5
2007	5	30	63		9	10
2008	9	15	83		6	26
2009	7	14	91		6	13
2010	17	5	109		10	20
2011	24	10	152	4	25	19
2012	16	19	162		14	10
2013	25	37	70	4	19	17
2014	27	30	41		14	29
2015	14	39	29		20	44
2016	11	24	37		18	24
2017	20	17	30	4	6	16
2018	27	66	37	5	20	27
2019	14	46	68	14	25	51
2020	22	76	55	23	25	31
2021	23	66	61	36	11	30

Notes: (1) Data are only shown where sample size is >2 for each region and year. (2) Not all data used in this analysis are publicly available.

Typical Duration from IA to Commercial Operations Date (COD) has Increased Modestly, Except in CAISO Where Recently Built Projects Took ~5 Years



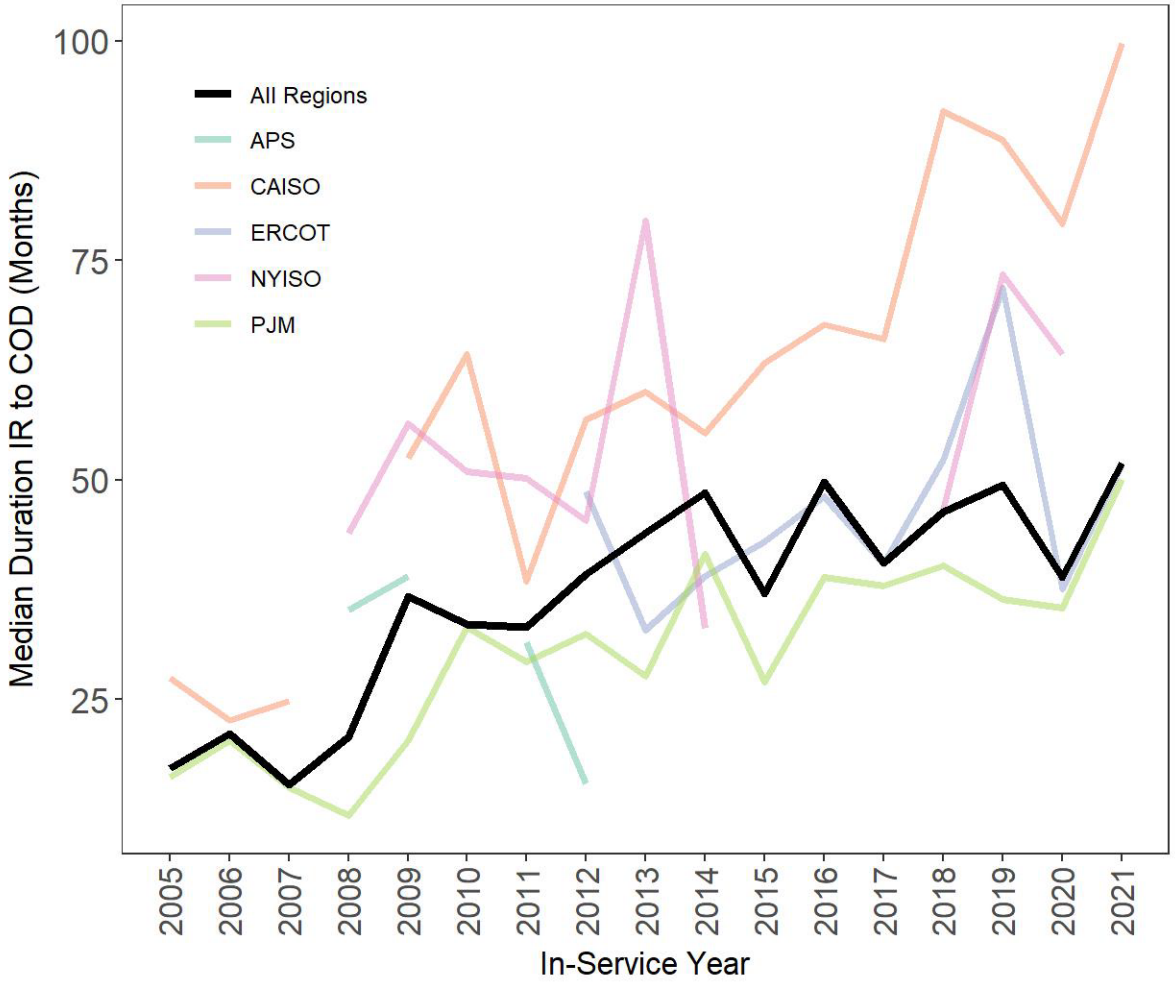


- Limited data were available to analyze typical durations from interconnection agreement to commercial operations
- Considering 366 projects across 3 ISO/RTOs, the typical IA to COD duration has increased only modestly since 2009.
  - From ~20 months for projects built from 2009-2014 to ~26 months for projects built from 2015-2021.
- But, that duration has increased dramatically for CAISO projects in the last 5 years.
  - For example: Solar projects built in CAISO in the last 5 years required 3.5 – 5.5 years to reach commercial operations *after securing an interconnection agreement.*

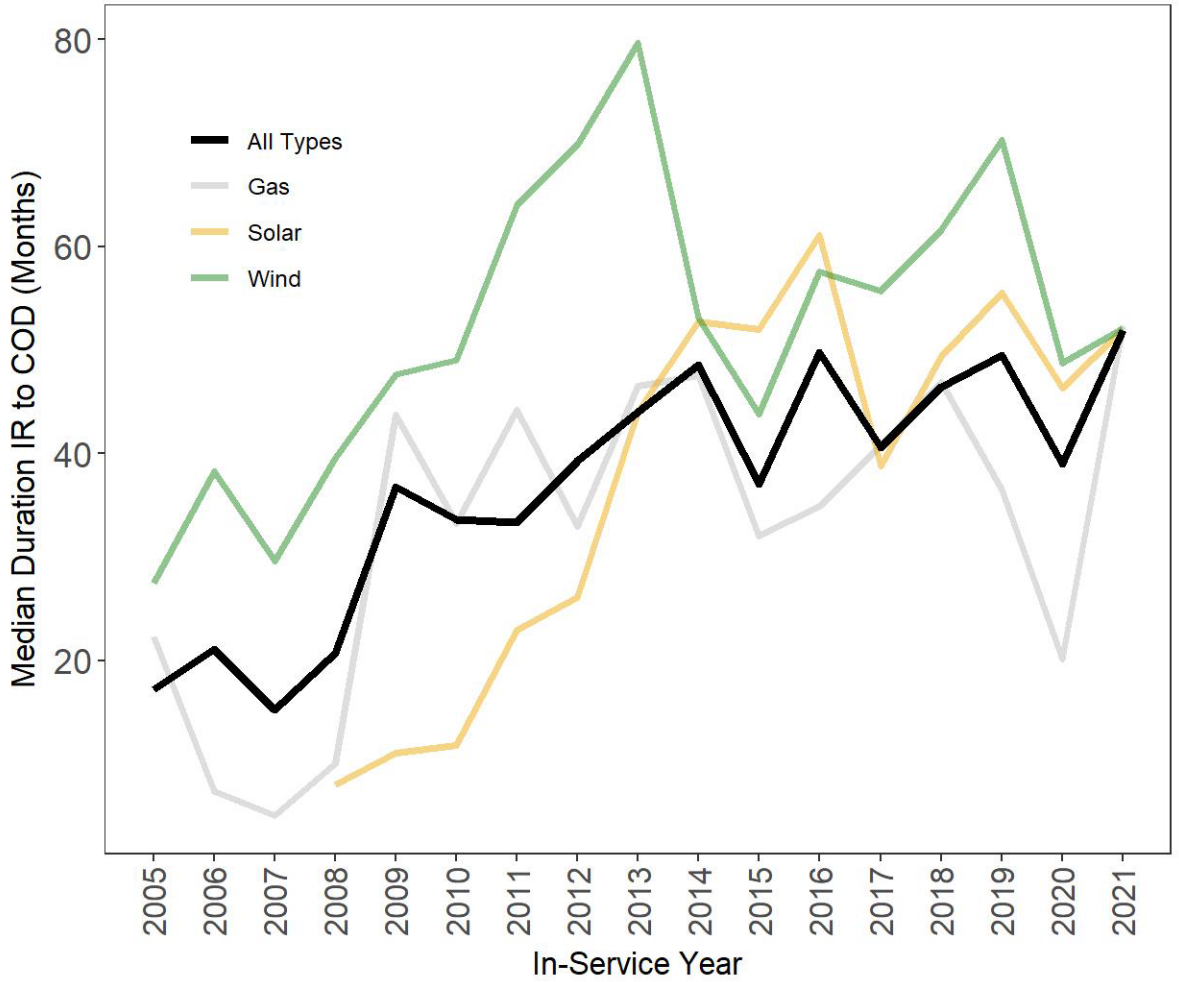
Notes: (1) Data were only available for 366 projects across the 3 ISO/RTOs shown. (2) Not all data used in this analysis are publicly available.

The typical time from interconnection request (IR) date to commercial operations date (COD) is increasing for some regions and generator types and now exceeds 4 years overall

Median Duration from Interconnection Request to Commercial Operations, by Region



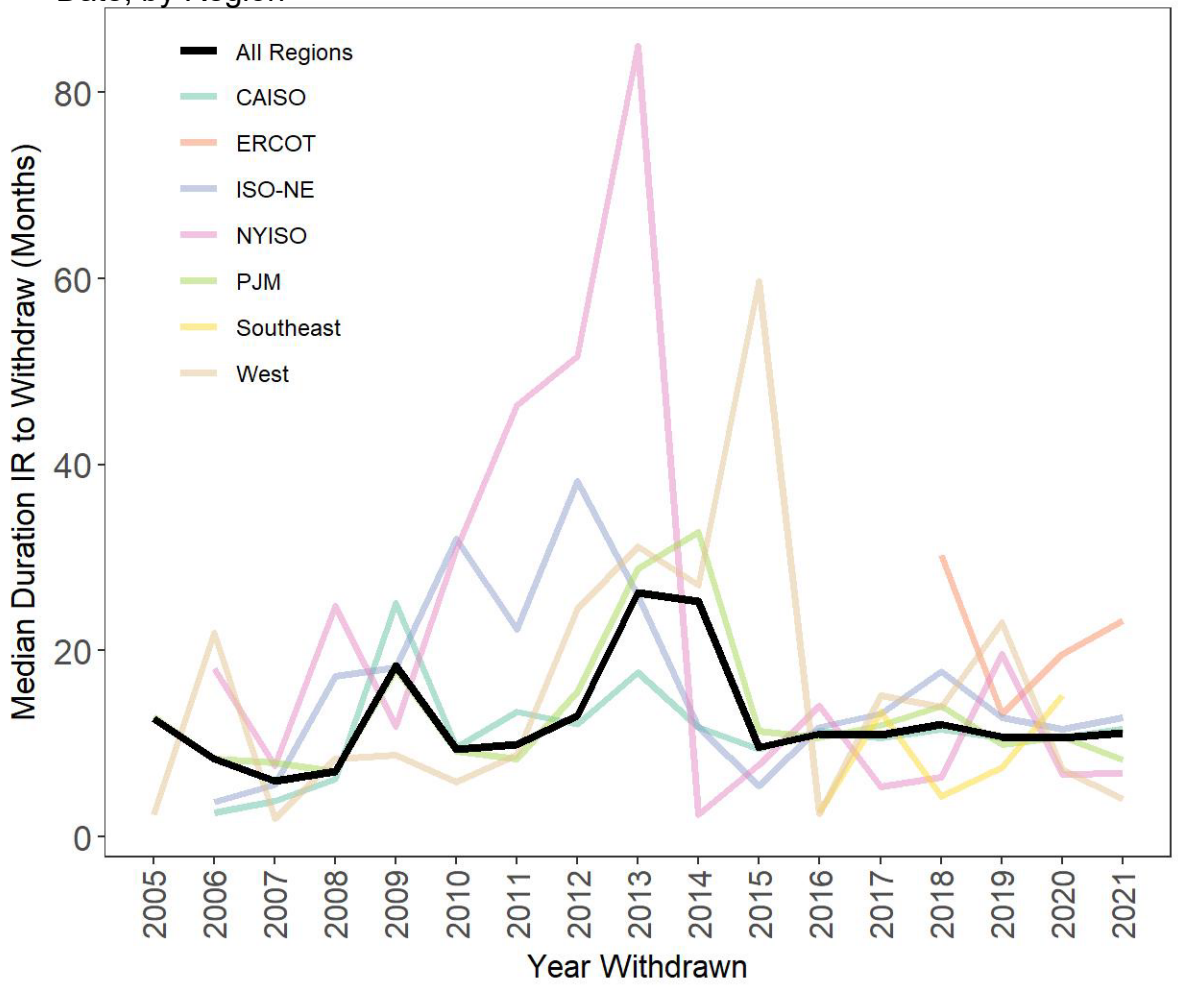
Median Duration from Interconnection Request to Commercial Operations, by Generator Type



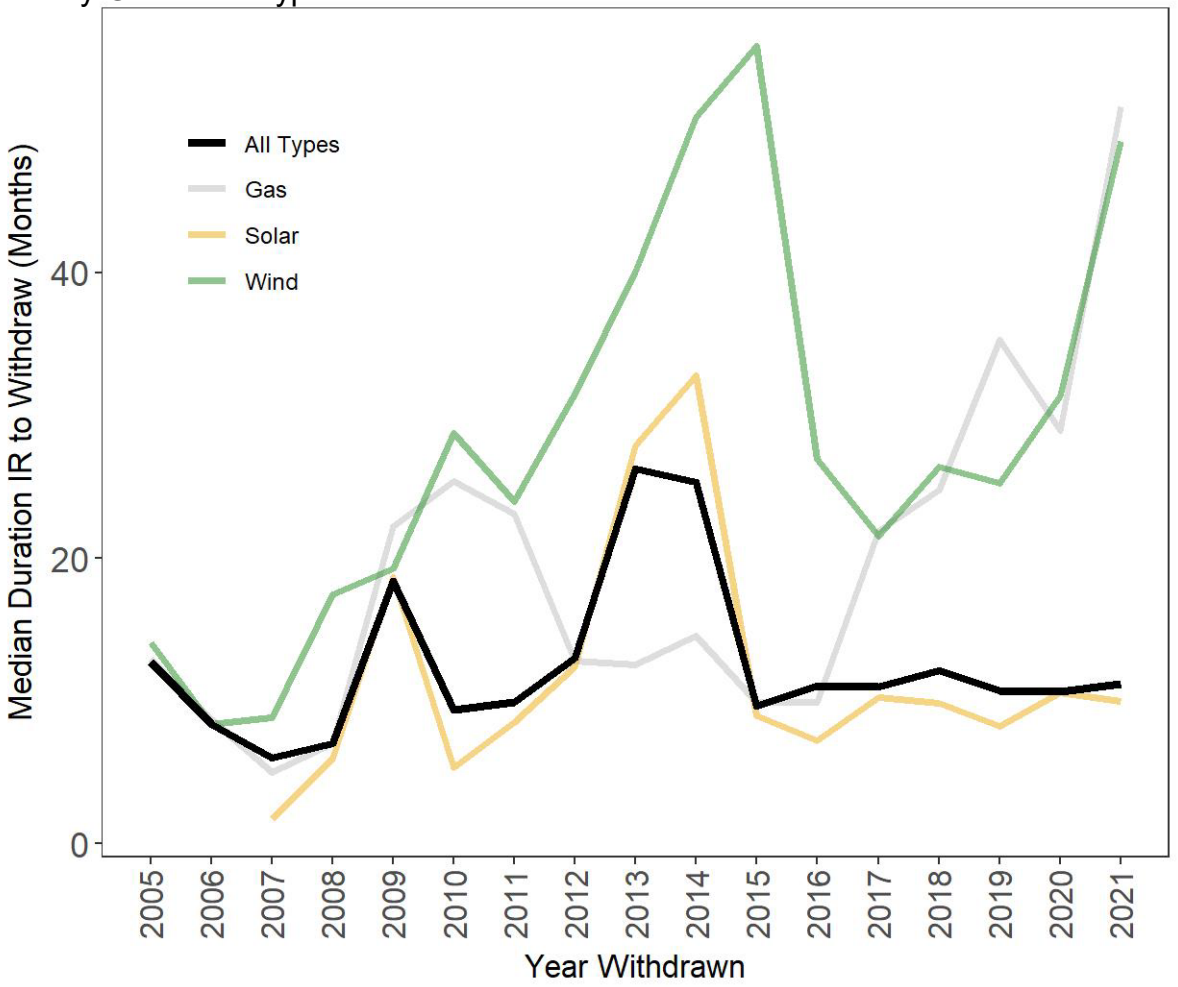
Notes: (1) In-service date was only available for 1,570 operational projects from 4 ISOs and one utility. (2) Duration is calculated as the number of months from the queue entry date to the in-service date.

A series of queue reforms in 2012-2013[1] may have cleared out some older projects; since 2016, the typical withdrawn solar project spends just 7 months in queues

Median Duration from Interconnection Request to Withdrawn Date, by Region



Median Duration from Interconnection Request to Withdrawn Date, by Generator Type



1. Americans for a Clean Energy Grid. *Disconnected: The Need for a New Generator Interconnection Policy.* January, 2021.

Notes: (1) Withdrawn date was available for 6,323 projects from 5 ISOs and 6 utilities. (2) Duration is calculated as the number of months from the queue entry date to the date the project was withdrawn from queues.

BERKELEY LAB

Conclusions

As of the end of 2021, there were over 8,100 projects seeking grid interconnection across the U.S., representing over 1,000 GW of generation and an estimated 427 GW of storage.

- Solar (676 GW) accounts for >65% of all active generator capacity in the queues, though substantial wind (247 GW) and gas (75 GW) capacity is also in development. Over 77 GW of offshore wind is currently active in the queues.
- Considerable standalone (213 GW) and hybrid (~208 GW[1]) battery capacity is in development, along with 7 GW of other storage.
- Growth in proposed solar and storage capacity is consistent across regions. Proposed wind has contracted in some regions, but continues to grow in those with proposed offshore development. Gas is most common in the Southeast.
- Hybrids now comprise a large – and increasing – share of proposed projects, particularly in CAISO and non-ISO West. 286 GW of solar hybrids (primarily solar+battery) and 19 GW of wind hybrids are in the queues.
- The vast majority (73%) of capacity in the queues requested to come online before 2025, and some (13%) already has an executed interconnection agreement (IA).
- The time projects spend in queues before reaching COD may be increasing. For the regions with available data[2], the typical duration from IR to COD went from ~2.1 years for projects built in 2000-2010 up to ~3.7 years for those built in 2010-2021.
  - The typical full interconnection study duration (from IR to IA) has also increased sharply since 2015, exceeding 3 years in 2021.
- More than 84% (930 GW) of the estimated 1,100 GW of wind and solar capacity needed to approach a zero-carbon electricity target is already in development[3]; additional queues not included in this report (e.g., from Hawaii) would add even more.
- Ultimately, much of this proposed capacity will not be built. Historically only ~23% of projects in the queues reached commercial operations, and less for wind (20%) and solar (16%).

BERKELEY LAB

Notes: (1) Hybrid battery capacity is estimated using storage:generator ratios from projects that provide separate capacity data. (2) Data for this analysis were available for four ISO/RTOs and one utility. (3) See https://gridlab.org/2035-report/

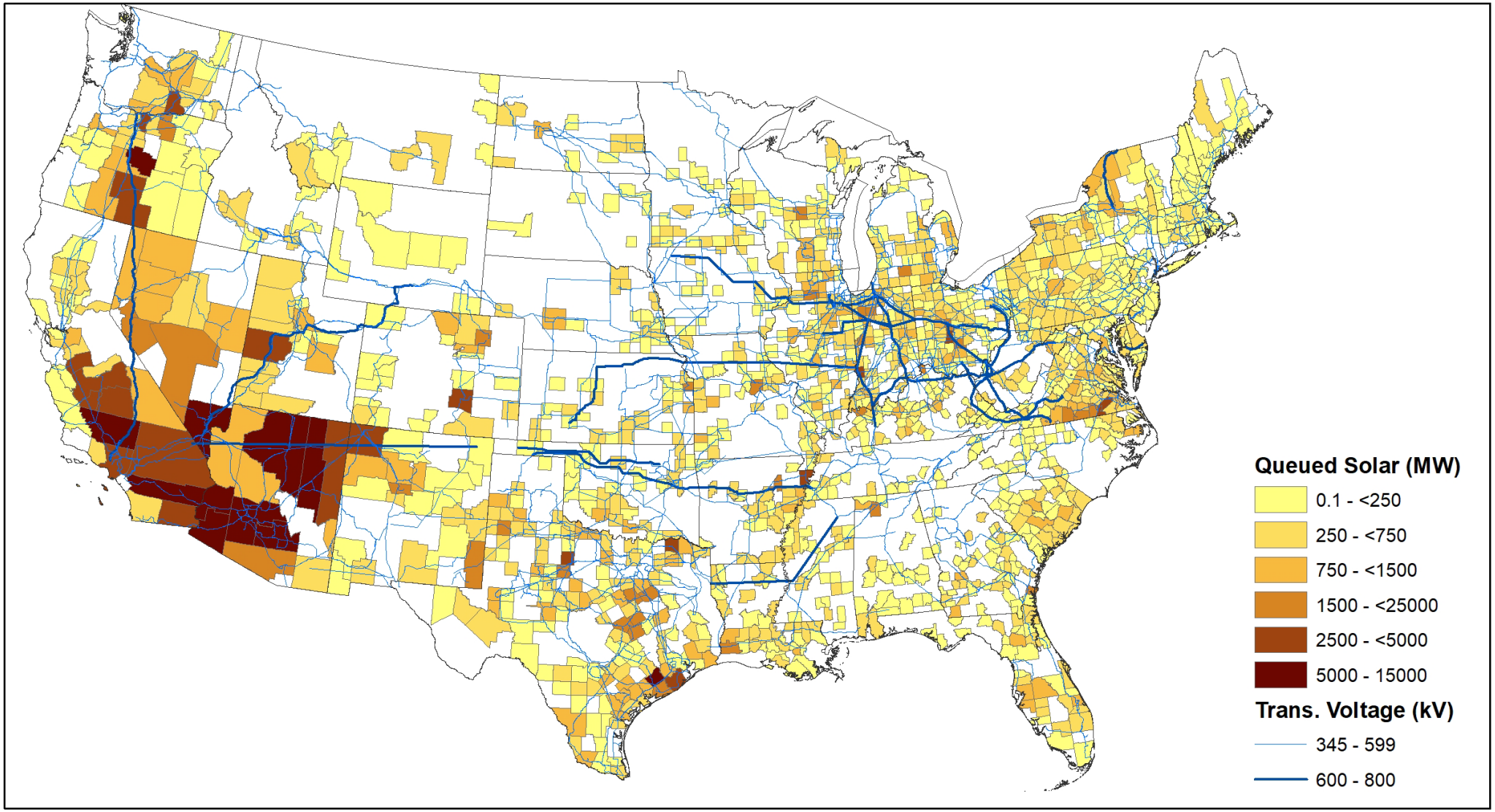
Contact:
Joseph Rand (jrand@lbl.gov)

More Information:
Visit https://emp.lbl.gov/queues to download the data used for this analysis and to access an interactive data visualization tool

Acknowledgements:
This work was funded by the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy, in particular the Solar Energy Technologies Office (Award Number 38444) and the Wind Energy Technologies Office. We thank Ammar Qusaibaty, Juan Botero, Patrick Gilman, and Gage Reber for supporting this project.

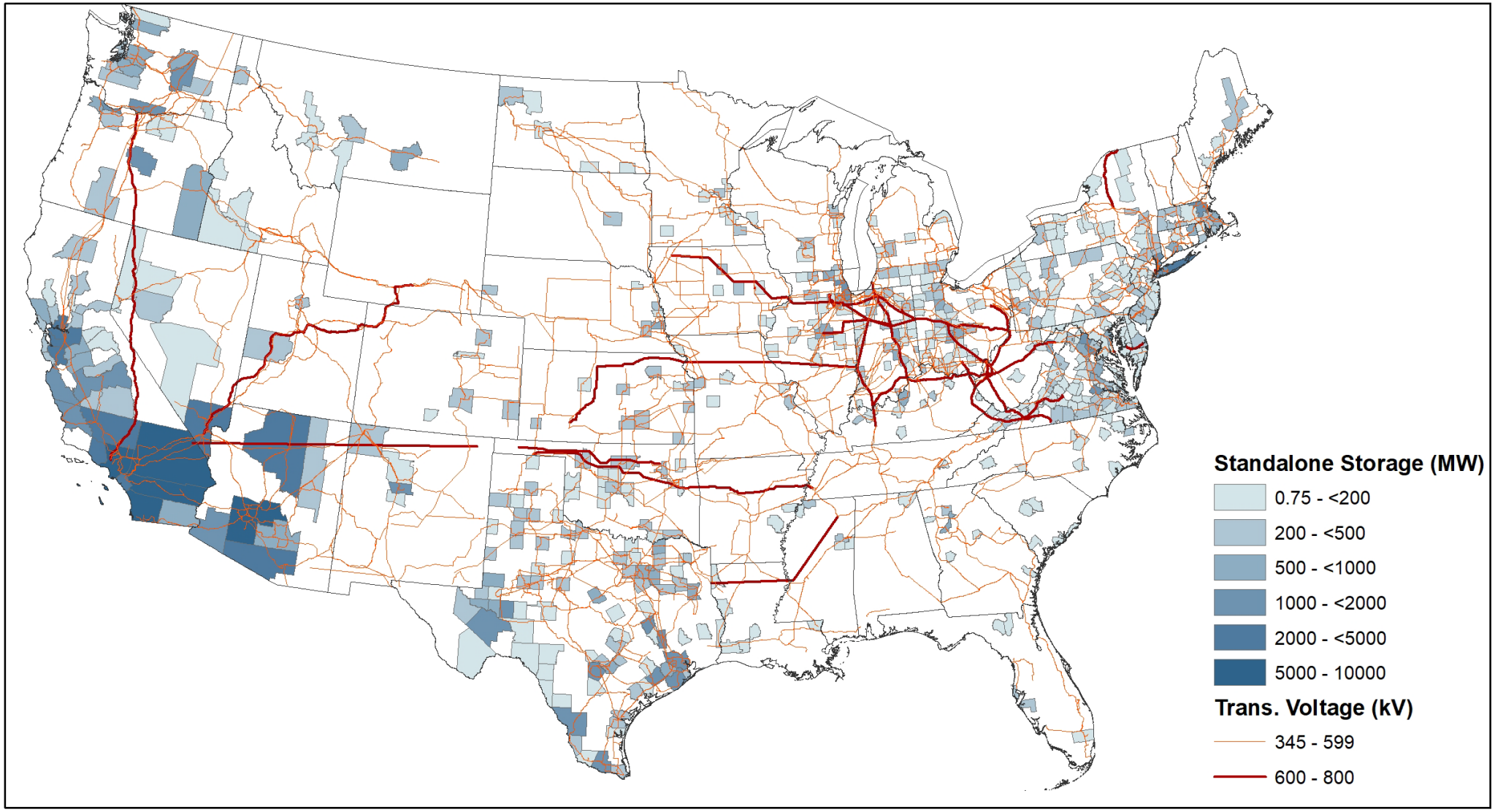
Appendix

Solar capacity in queues: by county



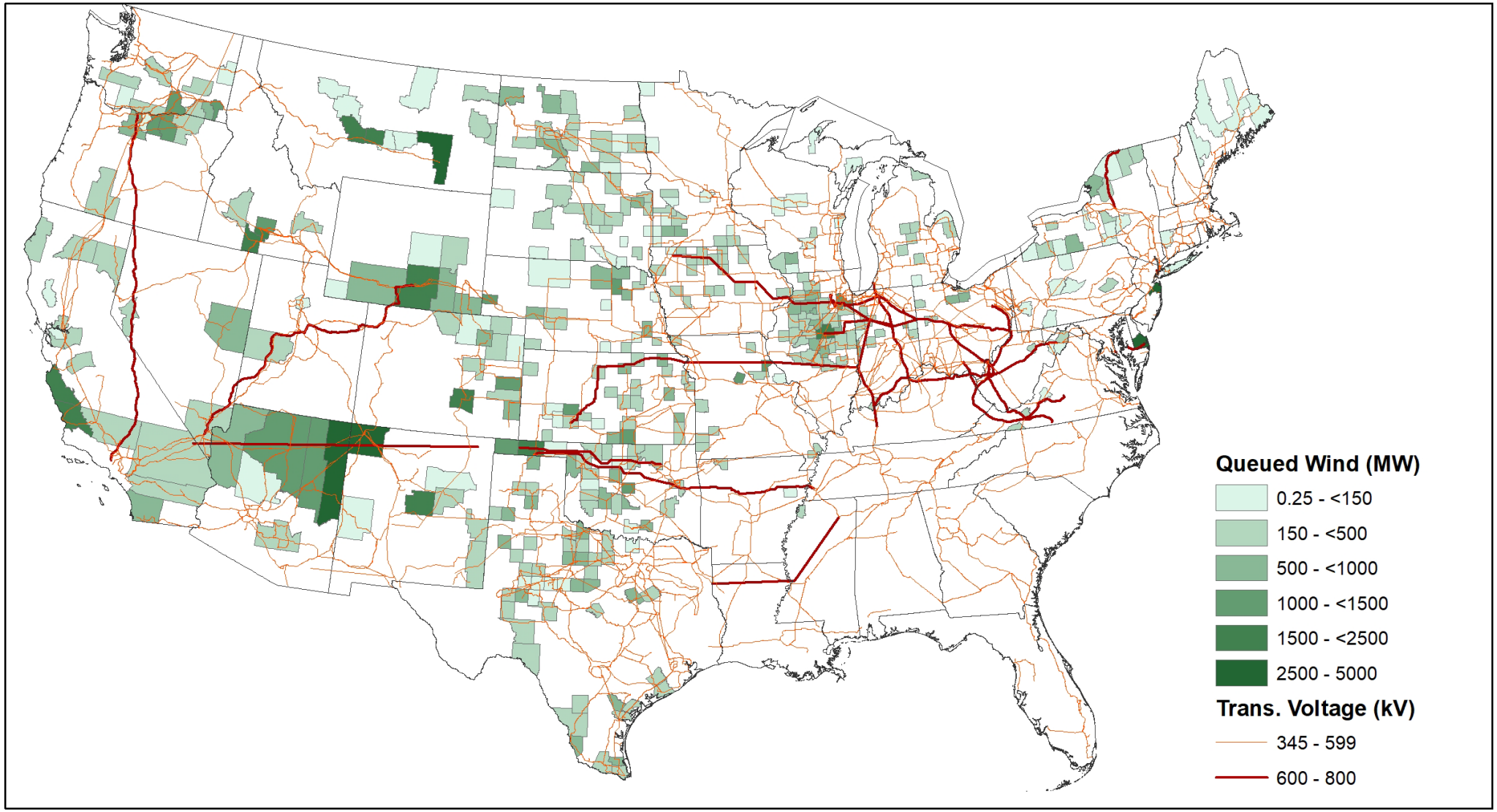
Note: Includes "active" capacity only

Standalone storage capacity in queues: by county



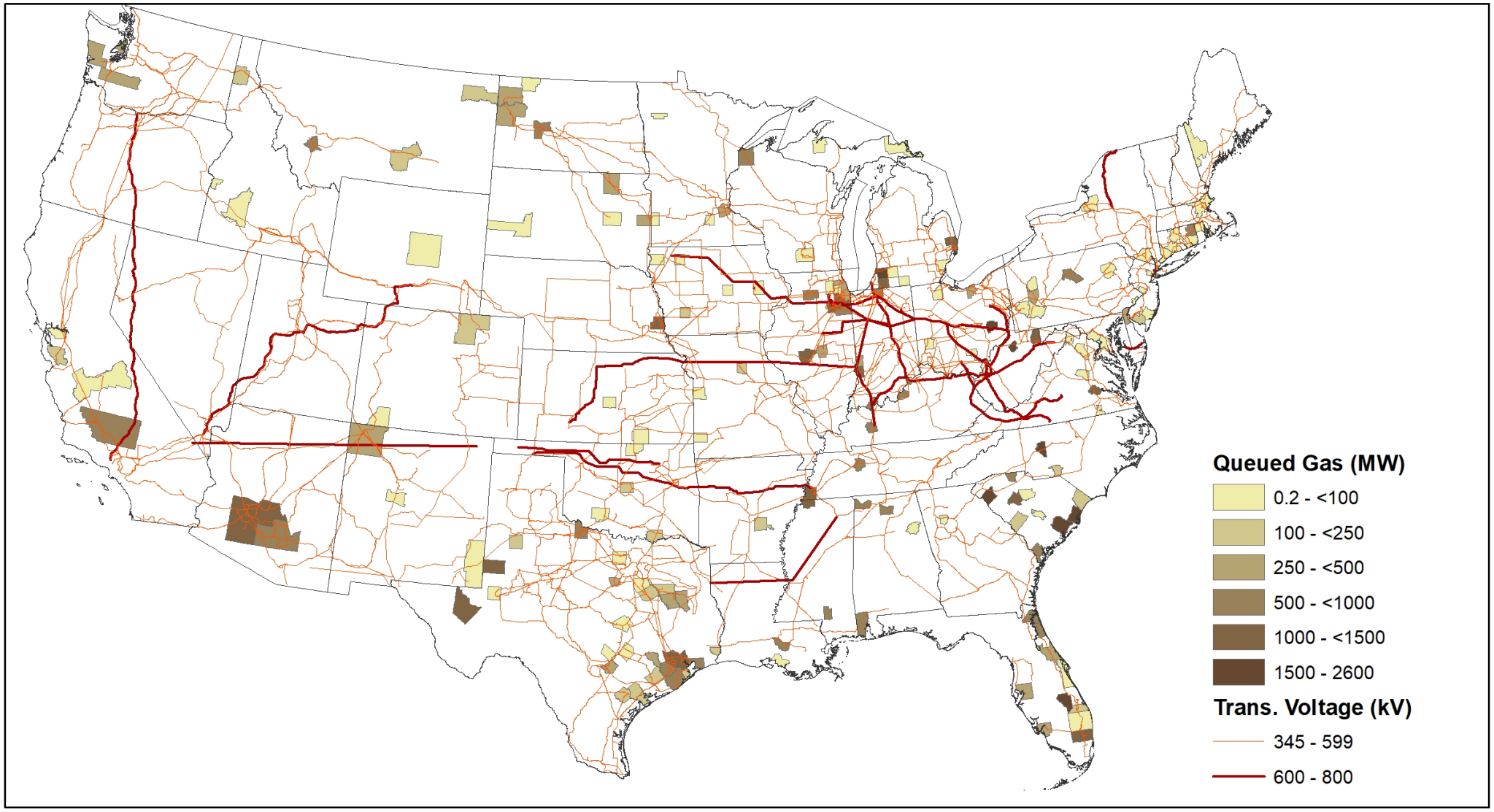
Notes: Excludes hybrid storage capacity, which could not be estimated at the county-level. Includes "active" capacity only

Wind capacity in queues: by county



Note: Includes "active" capacity only

Gas capacity in queues: by county



Note: Includes "active" capacity only

Balancing Areas Included In Data:

ISO/RTOs	Other (non-ISO) Transmission Operators				
PJM	Southern Company	Associated Electric Coop.	LG&E & KU Energy	Portland General Electric	Public Service Co. of NM
MISO	Tennessee Valley Authority	PSCO	Salt River Projects	Idaho Power	Avista
ERCOT	Duke/Progress	Santee Cooper	NV Energy	Florida Municipal Power Pool	El Paso Electric
SPP	WAPA	Georgia Transmission Corp.	Navajo-Crystal	Tri-State G&T	Imperial Irrigation District
NYISO	Florida Power & Light	Arizona Public Service	Dominion	Jacksonville Electric Authority	Platte River Power Authority
CAISO	Bonneville Power Admin.	LADWP	Puget Sound Energy	Tucson Electric Power	Black Hills Colorado
ISO-NE	PacifiCorp	Seminole Electric Coop.	Tampa Electric Co.	NorthWestern	Cheyenne Light Fuel & Power