Title

Generator Interconnection Costs to the Transmission System - Summary Briefing

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Lawrence Berkeley National Laboratory

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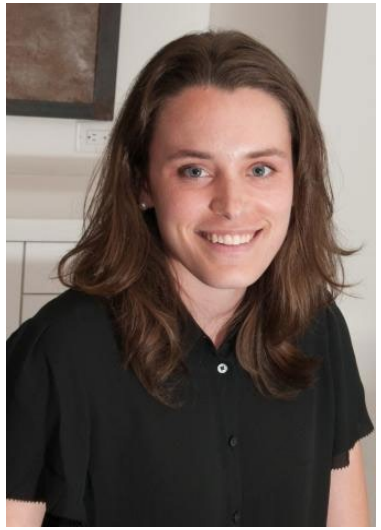
Photo source: National Renewable Energy Laboratory

LBNL Team Introduction

Joachim Seel



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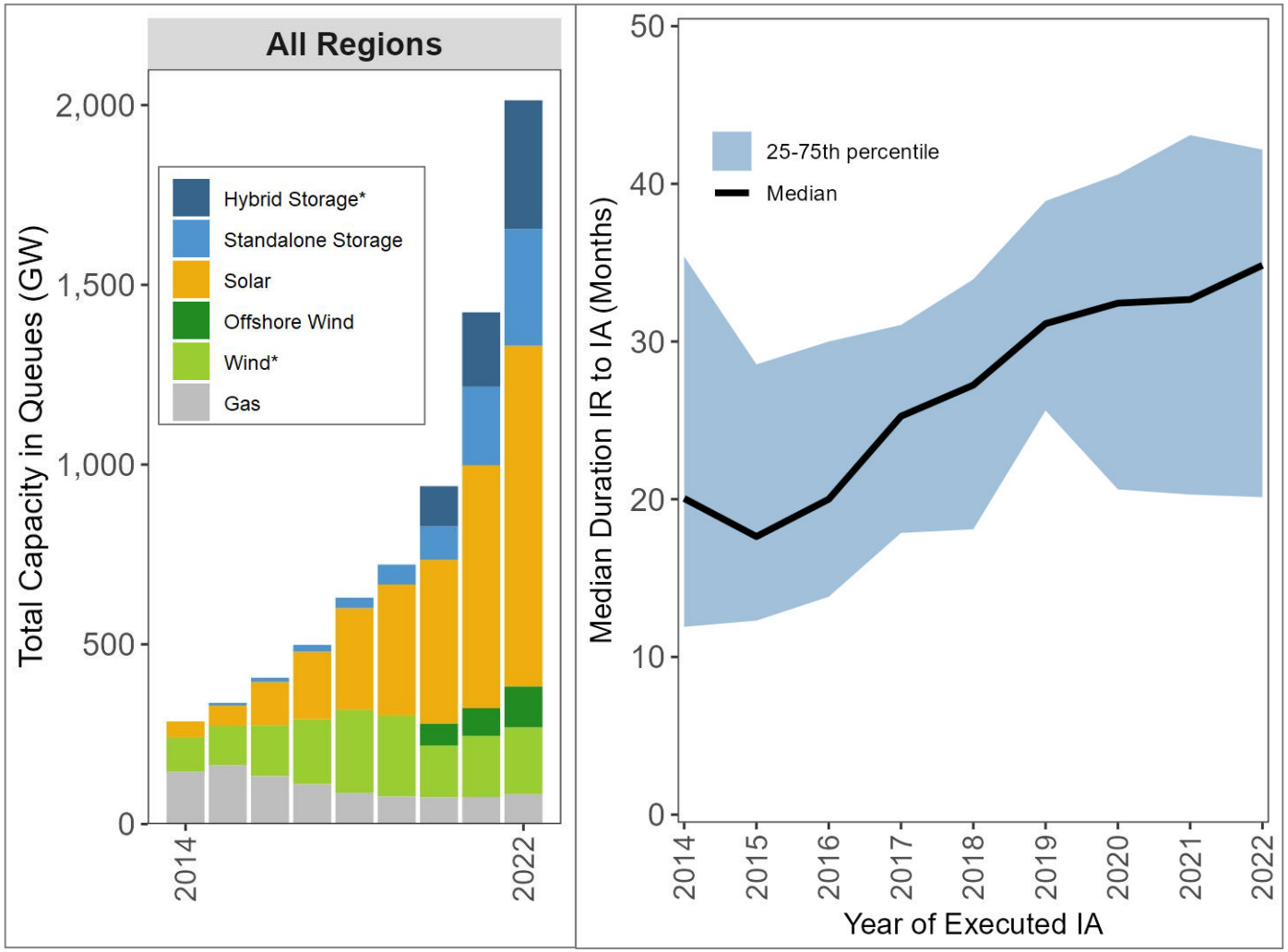
Active Interconnection Requests Have Surged, Increasing 6x in Capacity Since 2014; Study Duration (Wait Times) Are on the Rise; Completion Rates are Low

- Generator capacity actively seeking transmission connection is increasing rapidly in most balancing areas
- Queue requests are dominated by solar, storage, and wind capacity
- Typical (median) duration from interconnection request to interconnection agreement now exceeds 3 years in many regions
- Only 21% of projects (14% of capacity) requesting interconnection are ultimately built; even lower for solar
- See https://emp.lbl.gov/queues



*Do **interconnection costs** assigned to generators influence these trends in queue timelines and withdrawal rates?*

Renewed Federal Focus to Understand and Improve Interconnection Procedures

- **July 2021:** FERC ANOPR, "Building for the Future Through Electric Regional Transmission Planning and Cost Allocation and Generator Interconnection"
  - Commissioner Christie: "*The interconnection queues are, I think — to put it charitably — a mess*"
  - Focus on cost allocation and recovery for interconnection-related upgrade costs

- **June 2022:** FERC NOPR, "Improvements to Generator Interconnection Procedures and Agreements"
  - Proposes reforms to ensure that interconnection customers can access the grid in a reliable, efficient, transparent and timely manner
  - But, basically ignores interconnection upgrade cost allocation
  - Note: Multiple reforms also underway in ISOs (PJM, MISO, CAISO, etc.)

DOE's Interconnection Innovation e-Xchange (i2X)

Mission: To enable a **simpler**, **faster**, and **fairer** interconnection of clean energy resources while enhancing the **reliability**, **resiliency**, and **security** of our **distribution** and **bulk-power electric grids**

- **Stakeholder Engagement**
  - Nation-wide engagement platform and collaborative exchanges
  - Generate innovative solutions from discussion with utilities, grid operators, state/local governments, clean energy industry, non-profits
- **Data & Analytics**
  - Collect and analyze interconnection data to inform solutions development
  - Increase transparency of interconnection process
- **Strategic Roadmap**
  - Create roadmap to inform interconnection process improvements
  - Identify both near- and long-term opportunities and solutions
- **Technical Assistance**
  - Leverage DOE laboratory expertise to directly support stakeholders
  - Focus on requests targeting key problems identified in roadmap

https://www.energy.gov/eere/i2x/

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Key Outcomes from i2X e-Xchange Meetings

- Inform and formulate a **publicly available**, strategic roadmap for interconnection
  - Topical challenges and issues
  - Practical solutions to implement and scale
  - Knowledge and data gaps and new solutions to pilot
  - Success goals and measures of success
- Summary documentation for each meeting regarding ideas discussed and opportunities for targeted stakeholder action
- Provide platform for ongoing engagement before and after meetings
- **Longer term** vision: Solution e-Xchanges to continue building a national forum for all stakeholders as a community of practice, excellence, and innovation

Motivation for Interconnection Cost Trends Analysis

- A critical knowledge gap:
  - As interconnection requests balloon, have associated interconnection costs increased as well?
    - Are interconnection costs a serious entrance barrier for low-carbon generation?
  - Interconnection cost data are not easily accessible
    - Information barrier for developers and other stakeholders resulting in less efficient interconnection process
    - Reliable interconnection cost estimates can only be obtained by entering the queue, not as pre-request information
    - Interconnection cost estimates are rarely provided in an easily digestible format
    - i2X team initiated request for EIA to collect comprehensive data on ongoing basis
- Regulatory agencies like FERC and legislators don't have clear understanding of cost dynamics, impeding effective policies.

Generator Interconnection Costs to the Transmission System

ISO-specific briefings and underlying project cost data available at https://emp.lbl.gov/interconnection_costs

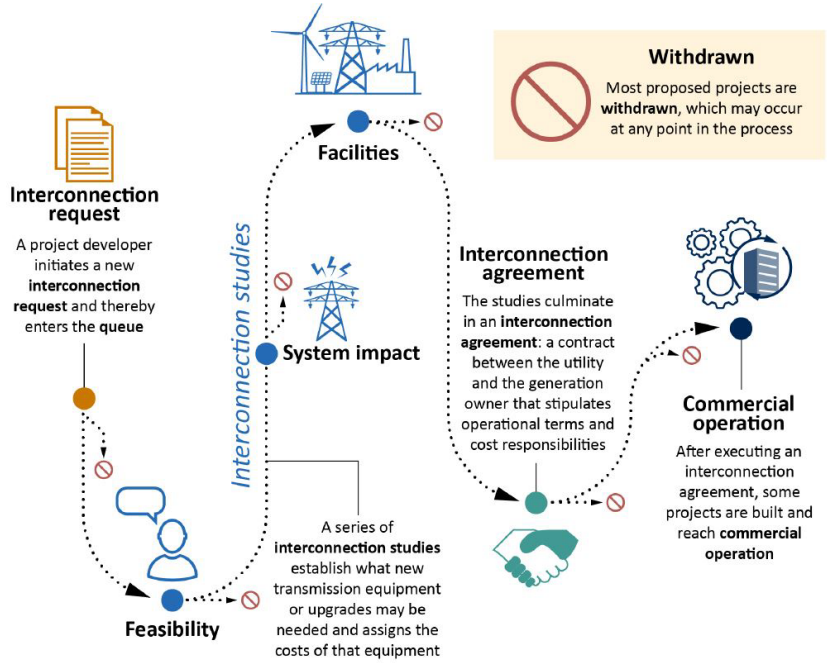
Berkeley Lab Provides Interconnection Cost Data + Analysis: Methods

- Collected robust sample of 2500+ project-level interconnection cost estimates in 2022/2023

- Regional coverage: SPP, MISO, PJM, NYISO, and ISONE
  - ERCOT has a "connect & manage" approach with lower interconnection costs
  - CAISO does not disclose project-level interconnection costs
  - Non-ISO regions rarely publish interconnection studies with cost estimates

- Cost data are only a subsample of all projects in the interconnection queues:
  - Interconnection studies are often not yet available for most recent queue entrants
  - RTOs often remove cost publications for older projects
  - Some projects may withdraw before cost estimates are released
  - Focus on new and unique generators (not uprates of existing projects)

- Interconnection cost data are often only available in interconnection studies
  - Require manual scraping: 400-500 person-hours per region



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- Temporal coverage: 2000-2023
  - Costs indexed by interconnection study year (not queue entry), real \$2022-terms/kW_{AC} (GDP deflator conversion)
  - Using most recent cost estimate available at time of data collection (mostly spring-summer 2022)

ISO-specific briefings and underlying cleaned cost data collections available at https://emp.lbl.gov/interconnection_costs

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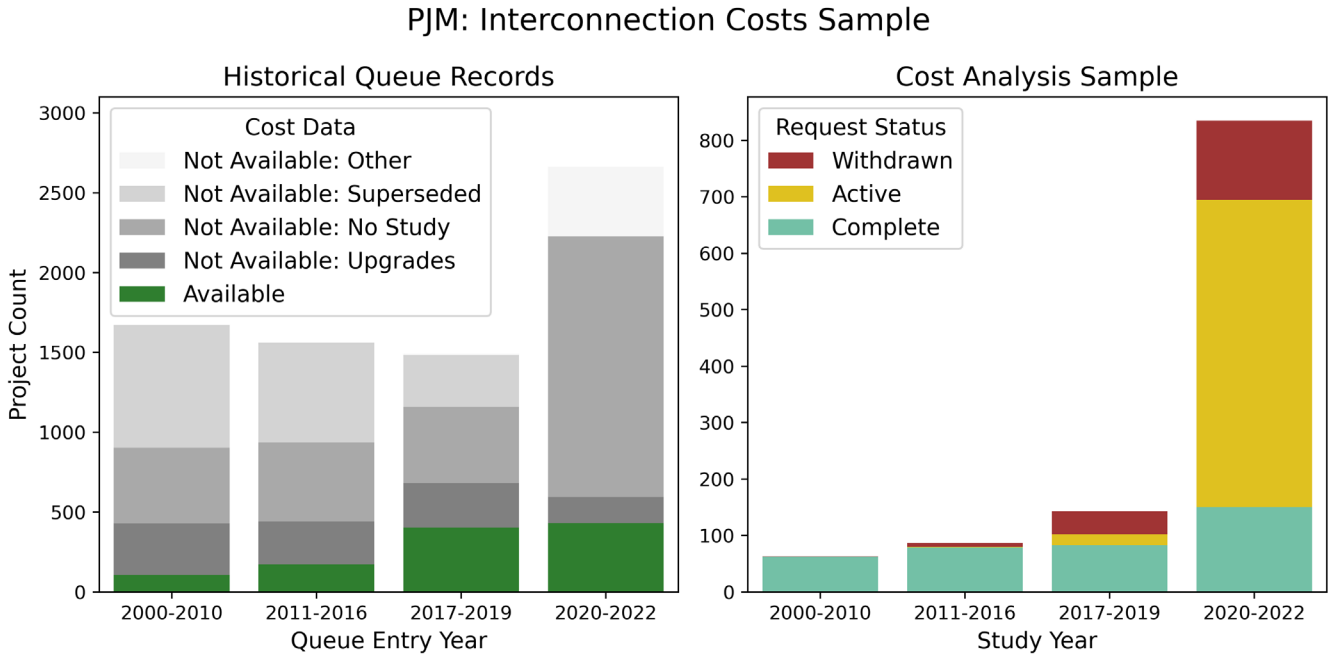
PJM example: Cost sample represents 86% of projects requesting interconnection since 2000

- Interconnection costs sample of 1127 projects
  - 86% sample coverage 2000-2022 after
  - Focus: 2017-2022 (robust data for all request status)

- Sources:
  - All cost data available online in the PJM system as of July 2022 (1073 projects).
  - Augmented with previously collected data of complete projects (55 projects)



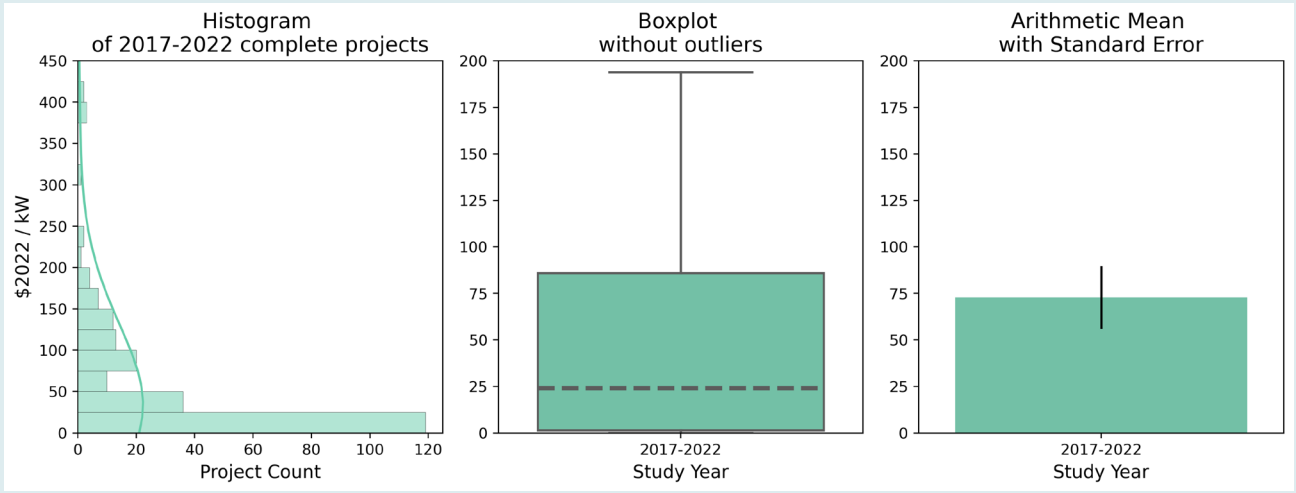
Interconnection Request Status Definitions

Complete: These projects have completed all of the interconnection studies, and have moved on to (or completed) the interconnection agreement phase. Includes plants that are now in service.

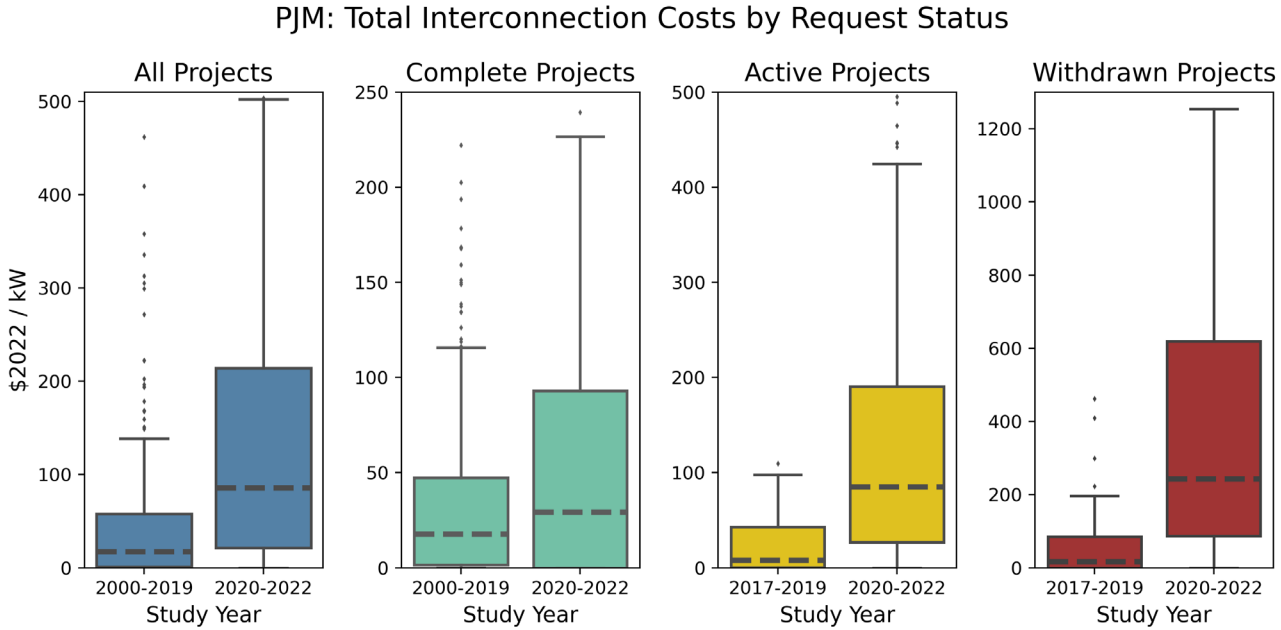
Active: These projects are actively working through the interconnection study process.

Withdrawn: These interconnection requests have been withdrawn (cancelled) from the queue.

PJM example: Interconnection cost data can be quite skewed



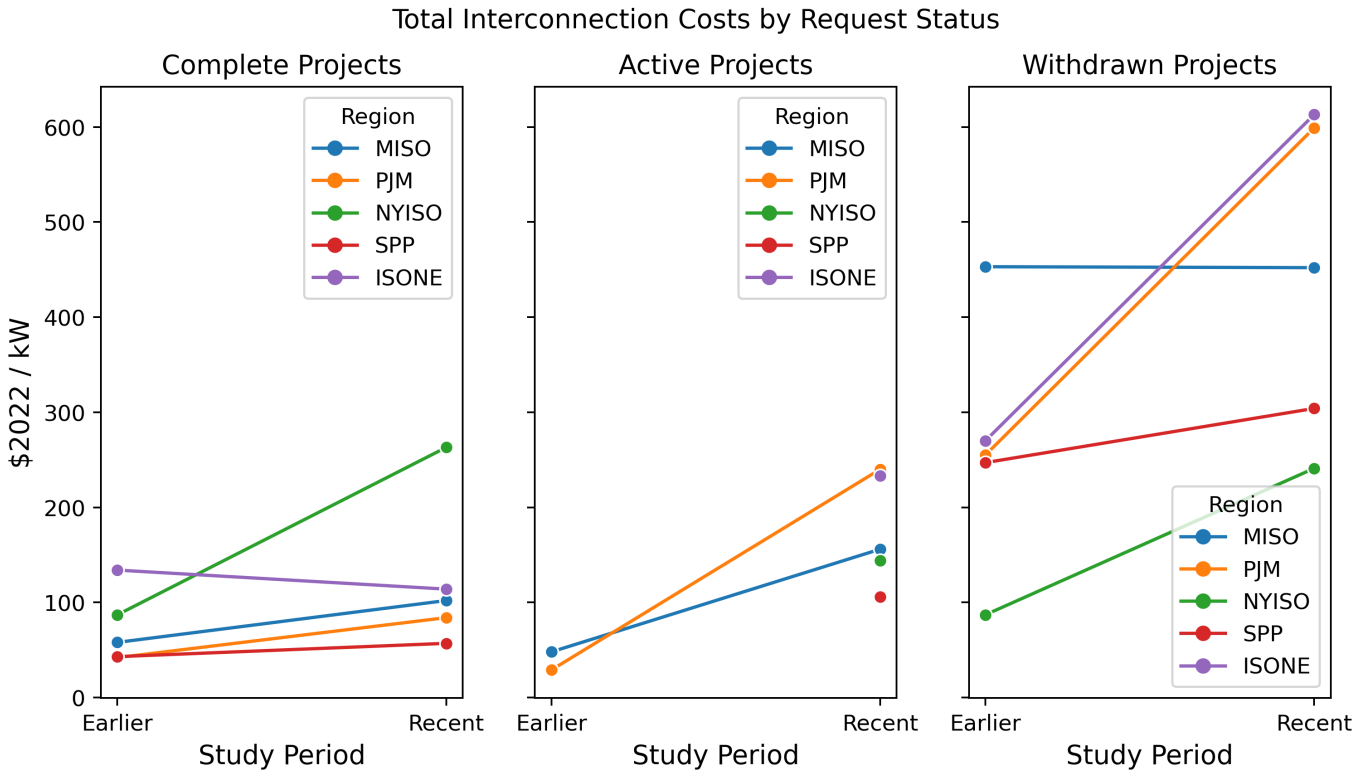
- Cost data often do not have normal distribution:
  - Many projects with very low interconnection costs
  - Some projects with very high interconnection costs that influence sample mean



- Most trends presented today also hold when looking at typical (median) projects:
  - For example, median total interconnection costs have also risen over time for each respective request status

Interconnection costs have grown over time in all studied regions

Average Interconnection Costs

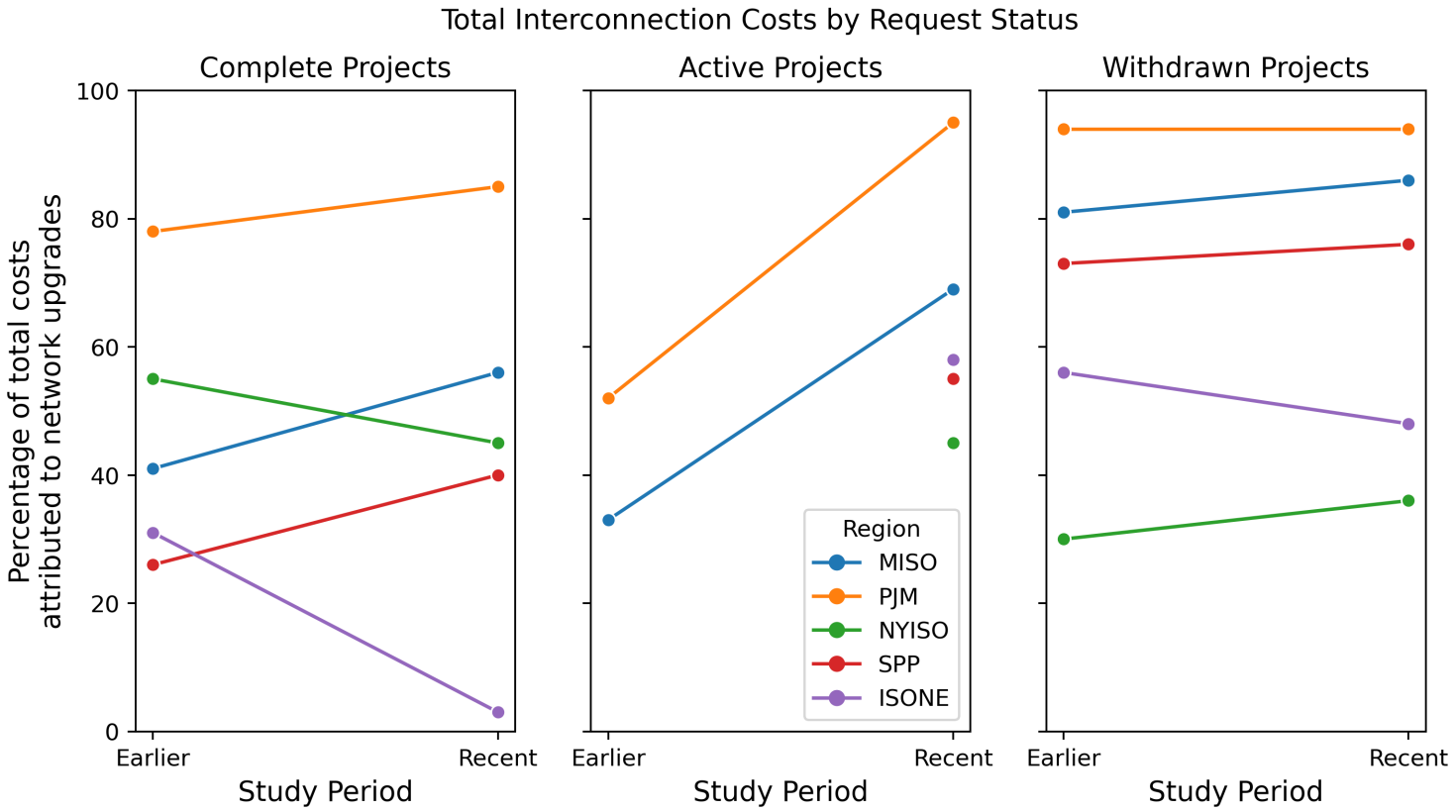


Region	"Earlier" period	"Recent" period
MISO	(2000-) 2018	2019-2021
SPP	2010-2019	2020-2022
PJM	2000/2017 - 2019	2020-2022
NYISO	2006-2016	2017-2021
ISO-NE	2010-2017	2018-2021

- Average interconnection costs have grown across regions and request types:
  - Often doubling for projects that have **completed** all studies
  - increasing even more for **active** projects currently moving through the queues.
  - Projects that **withdraw** have the highest interconnection costs

Broader network upgrades triggered by new interconnection requests mostly behind recent cost increases (not local interconnection costs)

Average Network Cost Share of Total Interconnection Costs



Interconnection Cost Components

Point of Interconnection (POI) or Interconnection / Attachment Facilities Costs:

- Interconnection station and transmission line extensions
- Often excludes other infrastructure (step-up transformer, spur lines…)

Network Costs:

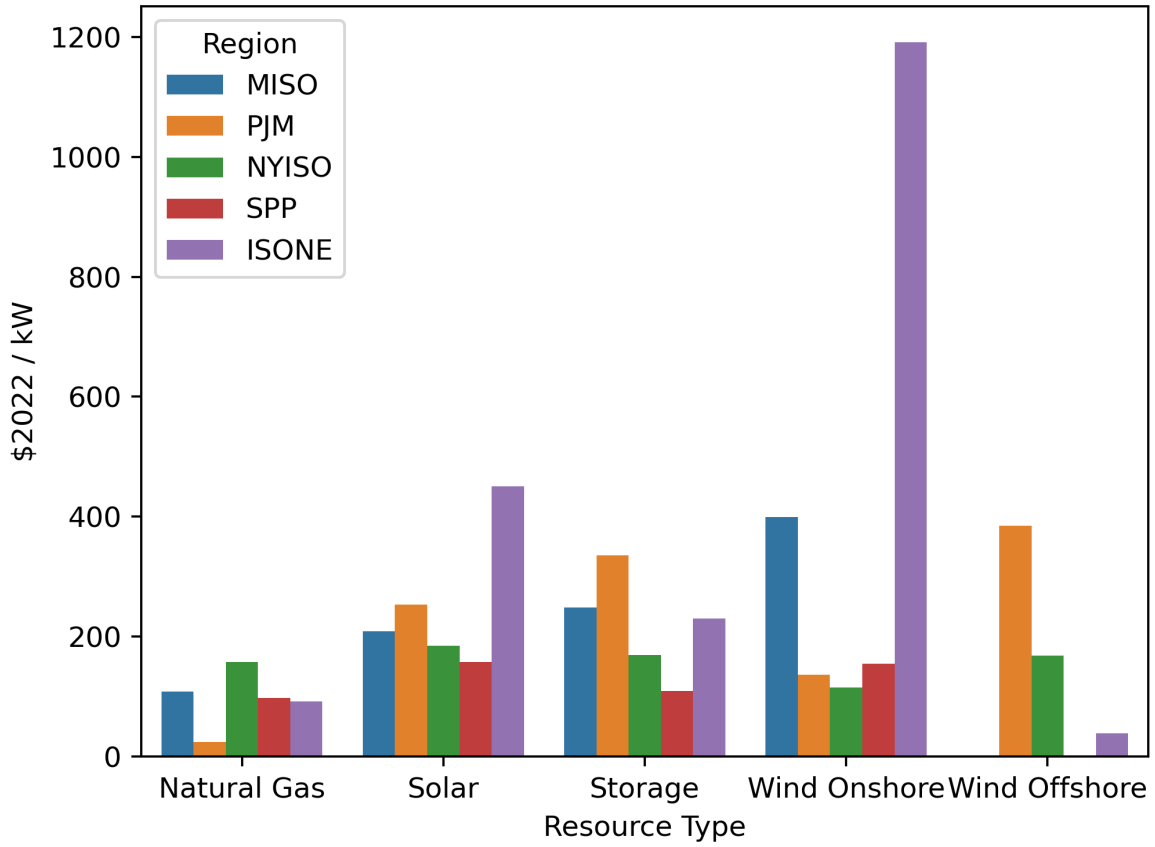
- Broader transmission network upgrades triggered by reliability or stability violations caused by a new generator.
- May require modest upgrades (breakers) or reconstruction of several high-voltage transmission lines.
- Costs may be shared by multiple generators that contribute to the upgrade and are usually paid for by project developers in the ISOs that we studied.

Region	"Earlier" period	"Recent" period
MISO	2018	2019-2021
SPP	2010-2019	2020-2022
PJM	2017-2019	2020-2022
NYISO	2006-2016	2017-2021
ISO-NE*	2010-2017	2018-2021

** ISO-NE: Cost components only available for ~50% of analyzed projects*

Renewables and storage often face higher interconnection costs than natural gas

Average Interconnection Costs in Recent Years (includes projects that withdraw application)



Offshore Wind costs exclude transmission investments offshore

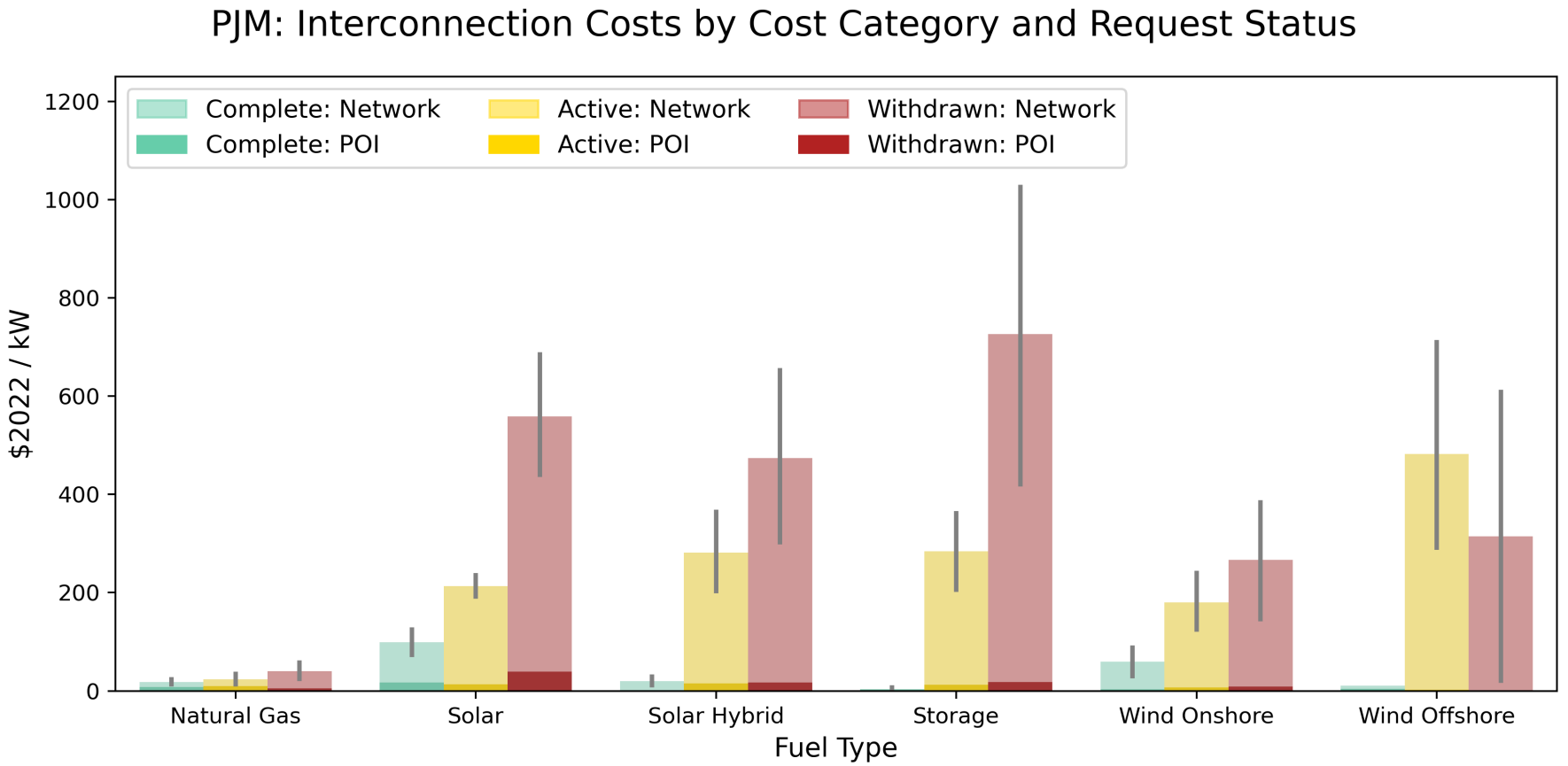
- Solar costs are fairly consistent across regions:
  - Completed: 5-10% of total project Capex
  - Withdrawn: 20-40%
- Wind costs have greater variation:
  - Completed: 3%-16% of total project Capex
  - Withdrawn: 10%-40%
- Storage expensive despite (or because of?) its locational flexibility

Hypothesis:
Renewables are often located in more rural areas where the existing transmission system is weaker, requiring costlier network upgrades.

	MISO	PJM	NYISO	SPP	ISO-NE
Years represented	2018-2021	2017-2022	2017-2021	2010-2022	2018-2021

PJM: Network upgrade costs drive interconnection expenses for renewables, especially for active and withdrawn projects

- POI costs don't vary much, but network costs increase dramatically for **active** and **withdrawn** projects.



- Interconnection costs are modest for complete projects, but are a development hurdle for those that withdraw:
  - **Wind:** 4% vs. 19% of total project capex
  - **Solar**: 7% vs 38% of total project capex

PJM: Most generators request capacity interconnection services at higher costs

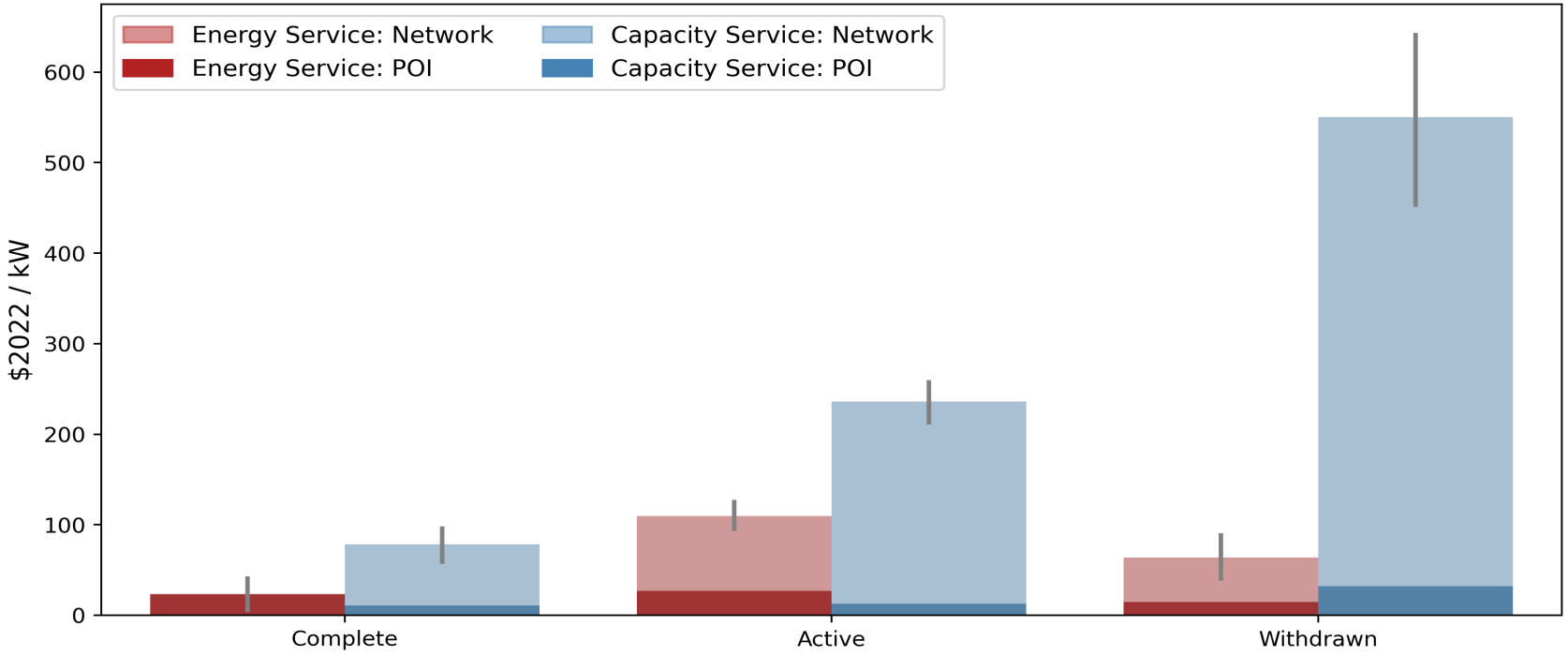
Interconnection Service Definitions

Capacity (Network resource interconnection service, **NRIS**): Transmission capacity reservation during high load hours, needed for bidding into resource adequacy markets. May need to pay for additional transmission upgrades.

Energy (Energy resource interconnection service, **ERIS**): May be curtailed before capacity resources during emergency events.

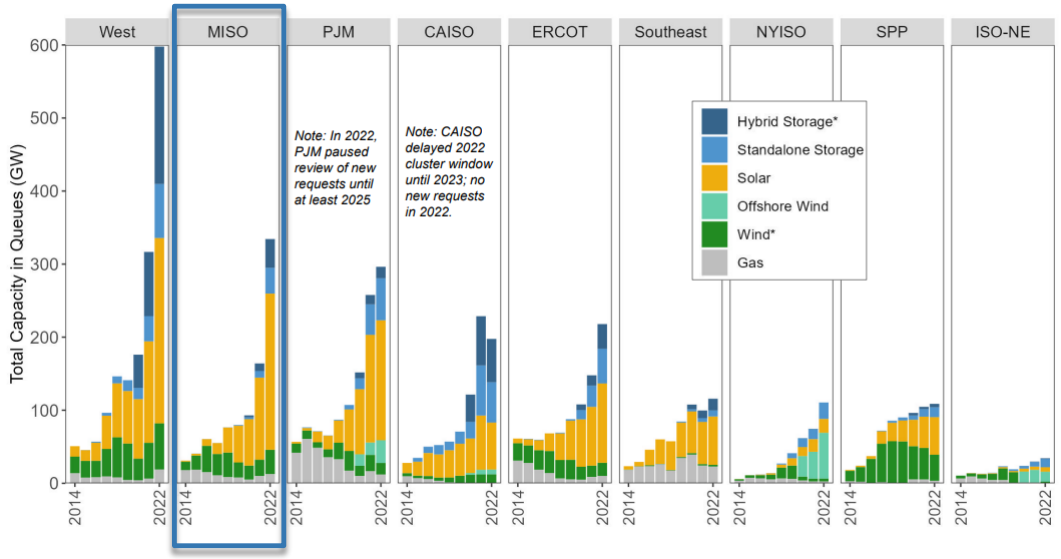
- Nearly all generators choose capacity service (2017-2022: 95% of all projects)
- Network costs for projects with capacity service have risen more than tenfold since 2017 (from $17/kW to $206/kW)

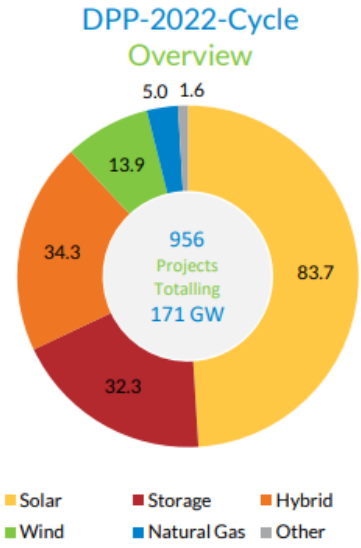
PJM: Interconnection Costs by Cost Category and Request Status since 2017



MISO: Interconnection queue doubled in capacity in last year

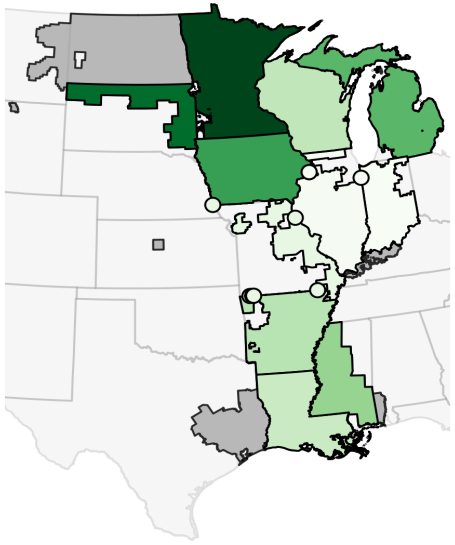
- MISO Queue at end of 2022:
  - Over 340 gigawatts (GW) of project capacity actively seeking grid interconnection
  - Dominated by solar (210 GW) and storage (75 GW) energy
  - Additional 373 GW of “withdrawn” projects and 66 GW of “in service” projects
- MISO’s 2022 Generator Interconnection Queue:
  - broke again all records, increasing by 220% over 2021 levels
  - 95% zero-carbon resources
- MISO has implemented numerous interconnection process reforms since 2008
  - shifted from a “first-come, first-served” serial approach to a “first-ready, first-served” cluster study approach
  - MISO introduced new milestones to demonstrate project readiness, requirements for project site control
  - Announced $10 billion new investments into bulk transmission system to integrate more renewables



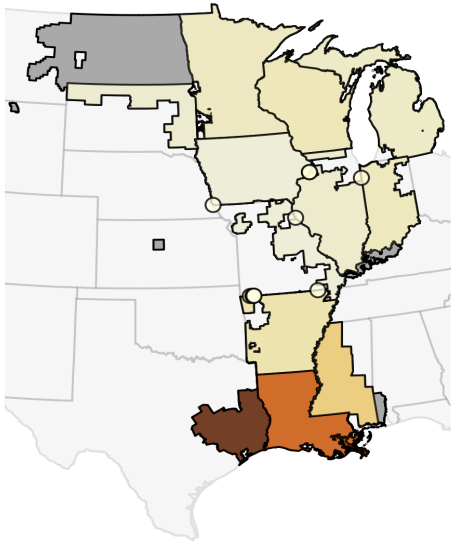


MISO: Interconnection costs rise in regions with limited transmission availability

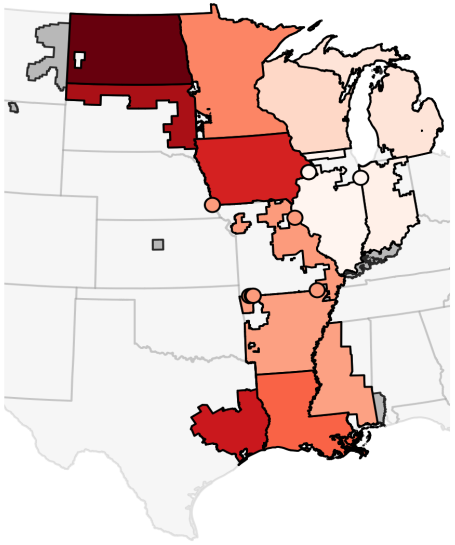
Complete Projects



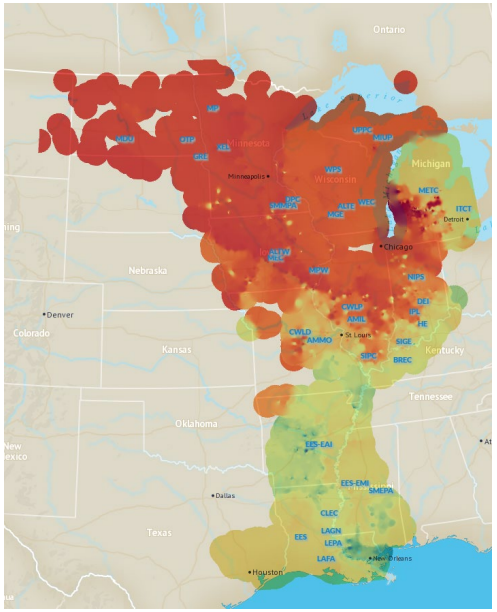
Active Projects



Withdrawn Projects



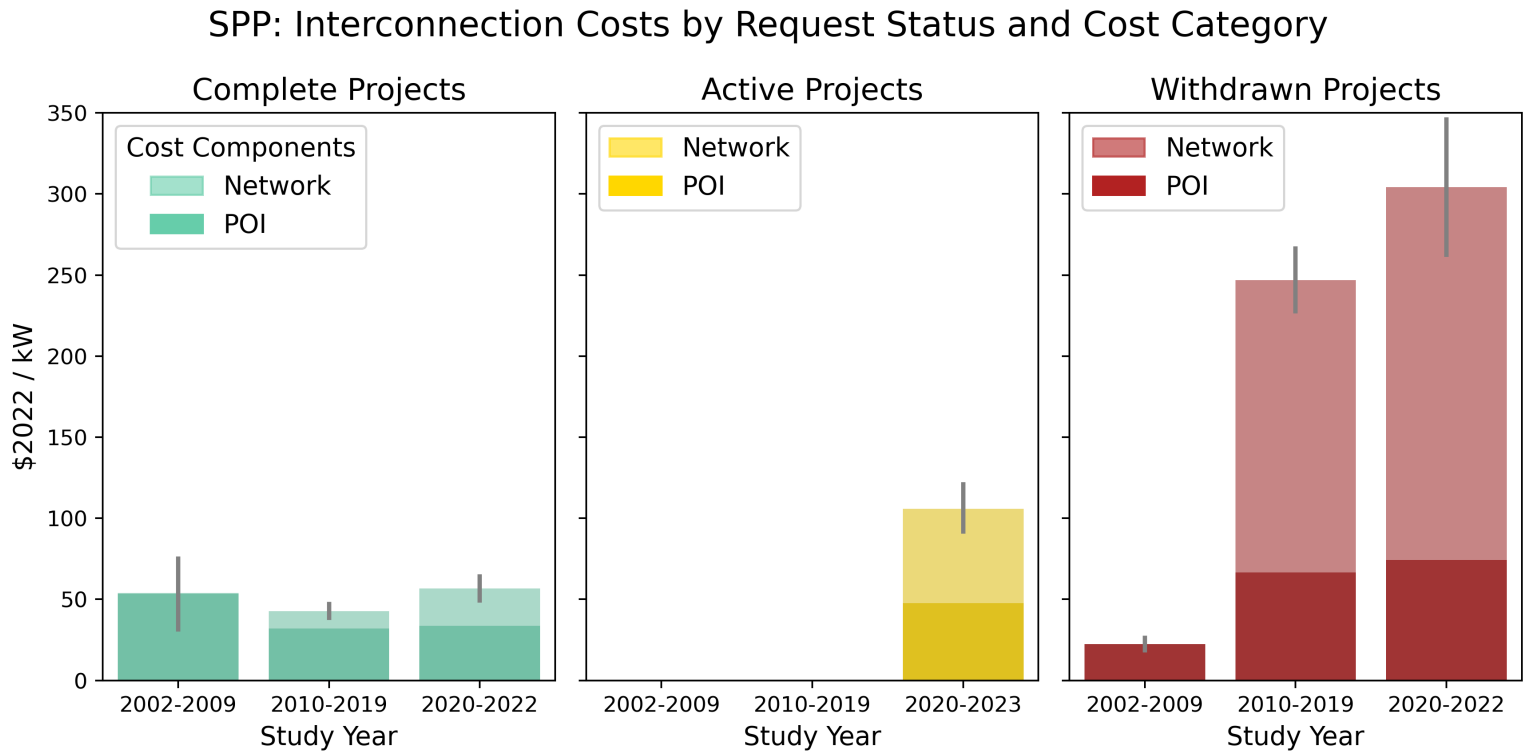
MISO Interactive Interconnection Capacity Availability Map (DPP-2020)



- Across all projects:
  - North and South Dakota and parts of Texas have high costs ($508-915/kW).
  - Indiana and Illinois report overall lower costs ($50-$69/kW).
  - States with limited availability of interconnection capacity are somewhat aligned with high-cost areas

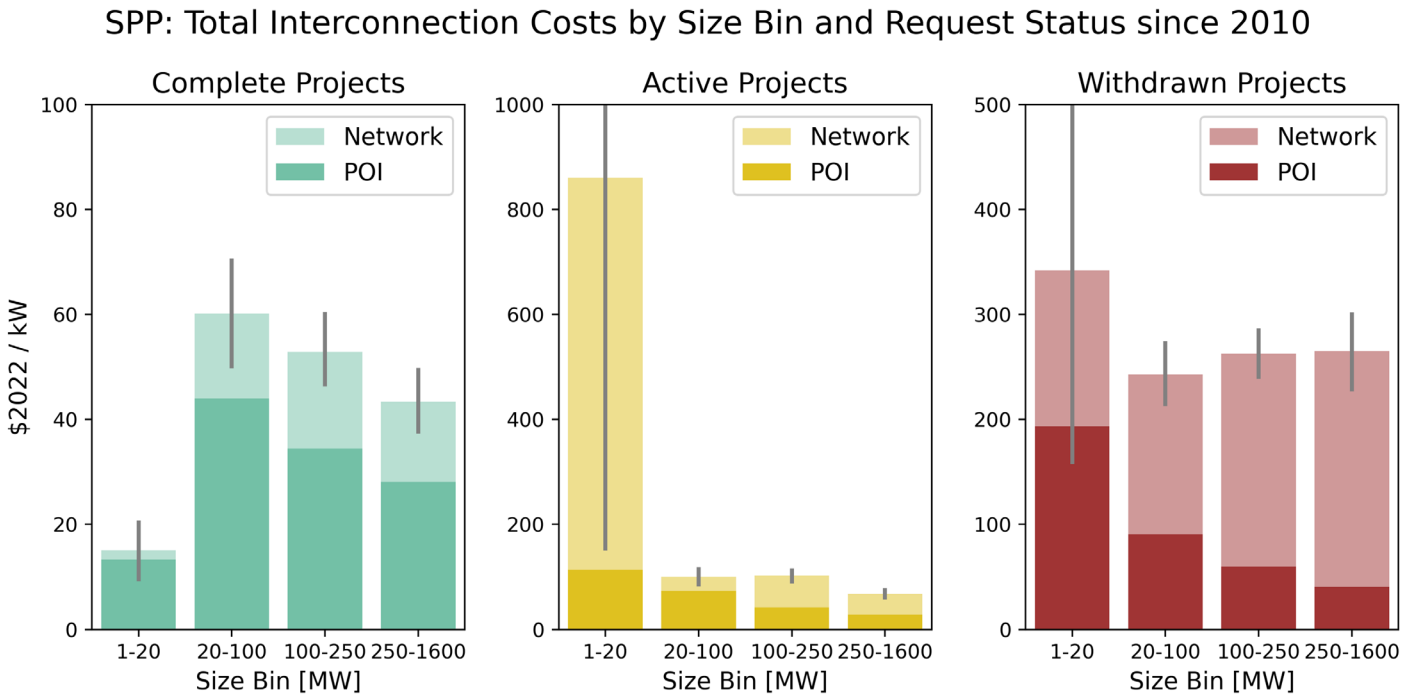
SPP: Historically, interconnection requests did not trigger network upgrade costs

- **Complete:**
  - POI expenses dominate
  - Network costs did not exist prior to 2010 and are still rare (but can add substantial costs)
- **Active:**
  - Network costs are slightly higher than POI costs among recent active projects
- **Withdrawn:**
  - Historically not higher costs than completed projects
  - Network upgrade costs grew strongly after 2009 (top 10% ranging between $859 and $1,219/kW)
  - They are much larger than for complete projects and have grown in recent years *(medians have fallen since 2010-2019).*
  - A facility study proposing upgrade costs of $147 million for a 152 MW wind project.



SPP: Larger complete generators have lower interconnection costs per kW, especially wind projects

Projects with larger nameplate capacity have greater interconnection costs in absolute terms, but these costs do not scale linearly on a per kW basis for complete projects, falling from $60/kW (medium), $53/kW (large), and $43/kW (very large project size).

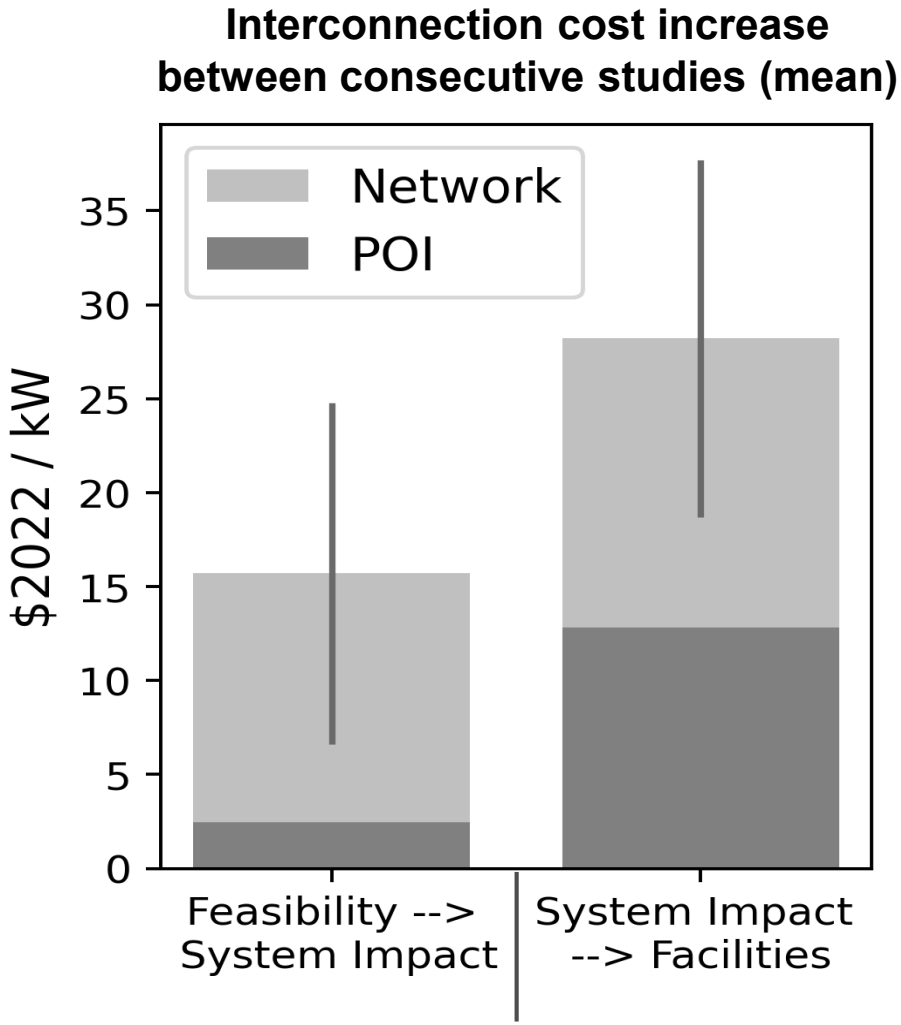


- Economies of scale are only present for complete projects but not withdrawn projects, driven by declining POI costs (network costs are stable or increase for withdrawn projects).
- No consistent economies of scale across all fuels. Only among complete projects do we see some evidence for wind and solar, but not for natural gas:

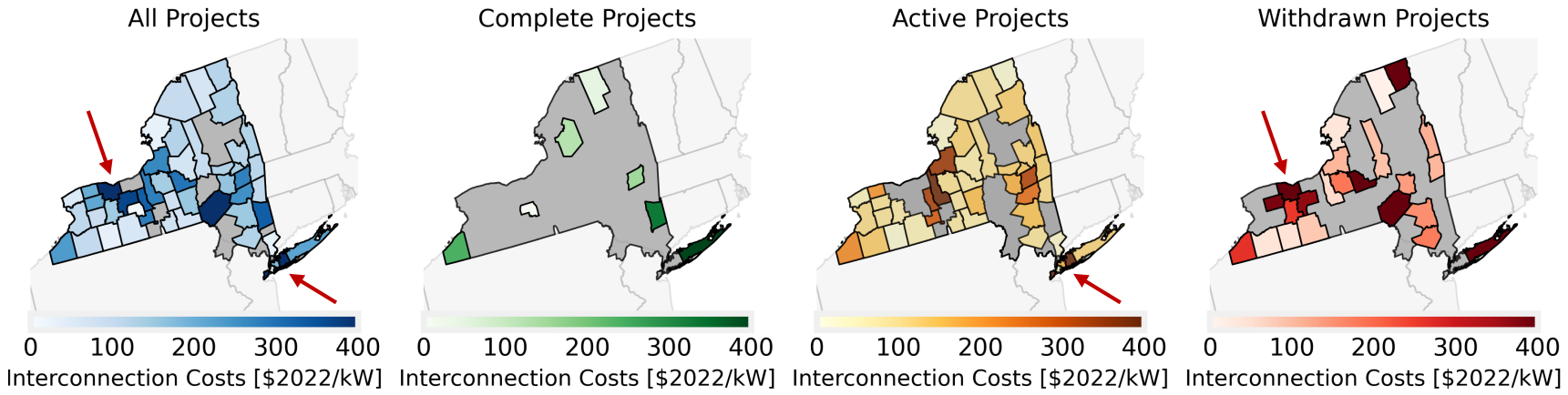
Fuel	1-20 MW	20-100 MW	100-250 MW	250-675 MW
Natural Gas	$20/kW	$6/kW	$52/kW	$26/kW
Solar		$90/kW	$85/kW	
Onshore Wind	$8/kW	$61/kW	$47/kW	$44/kW

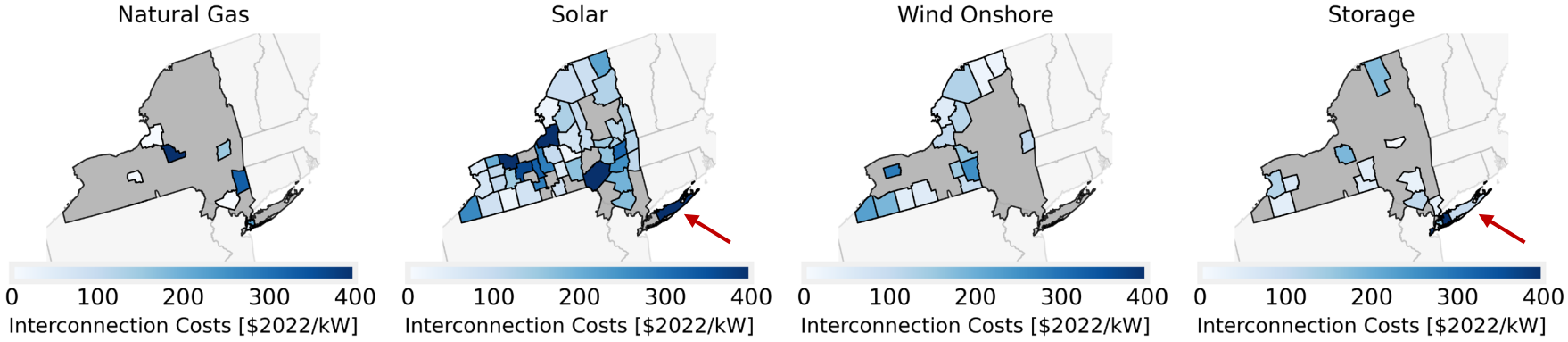
NYISO: Costs tend to increase as projects complete more studies

- From Feasibility to System Impact studies:
  - $16/kW average increase
  - Increase between 25% and -5% for majority of projects
  - Mostly network costs
- From System Impact to Facilities studies:
  - $28/kW average increase
  - ≥100% cost increase for more than 25% of projects
  - ≥50% cost change (up or down) for around 50% of projects
  - Increases at POI and in broader network
- **Costs for active projects will likely increase as they progress**



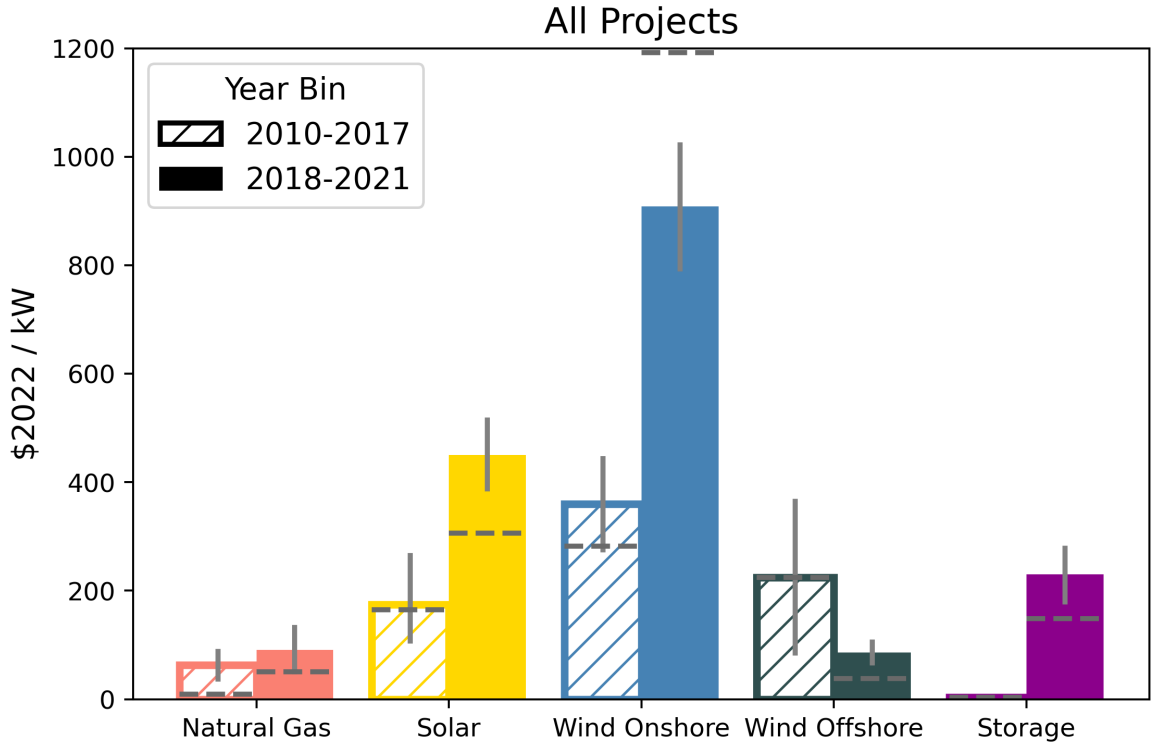
NYISO: Interconnection costs rise in regions with limited transmission availability



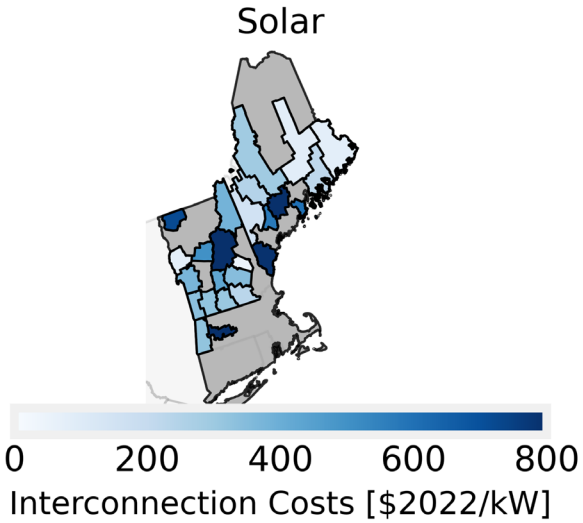


- Highest-cost counties with 2+ projects:
  - Nassau County on Long Island
  - Monroe County which contains Rochester
- Transmission constraints to Long Island result in high capacity prices in Zone K:
  - Suffolk Co.: Expensive for solar but cheap for storage
  - Nassau Co.: Expensive for storage
  - ➡ Challenge to estimate costs in advance

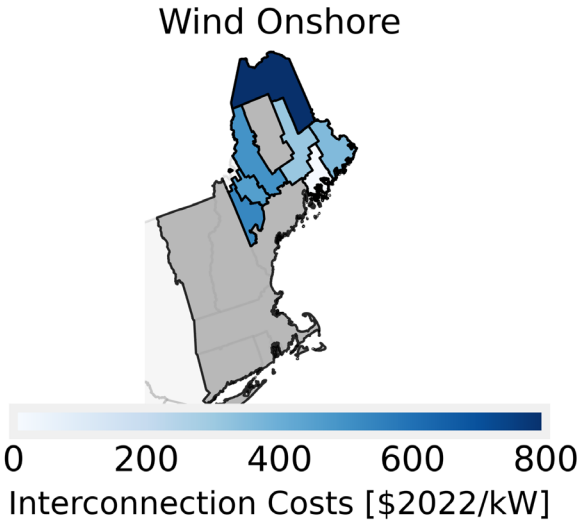
ISO-NE: Onshore wind and solar interconnection costs have surged since 2018



- Costs to interconnect onshore wind and solar have more than doubled
  - ➡ Of all regions, ISO-NE has the highest costs for these resources
- Nearly all (81%) of the onshore wind projects studied since 2018 have withdrawn



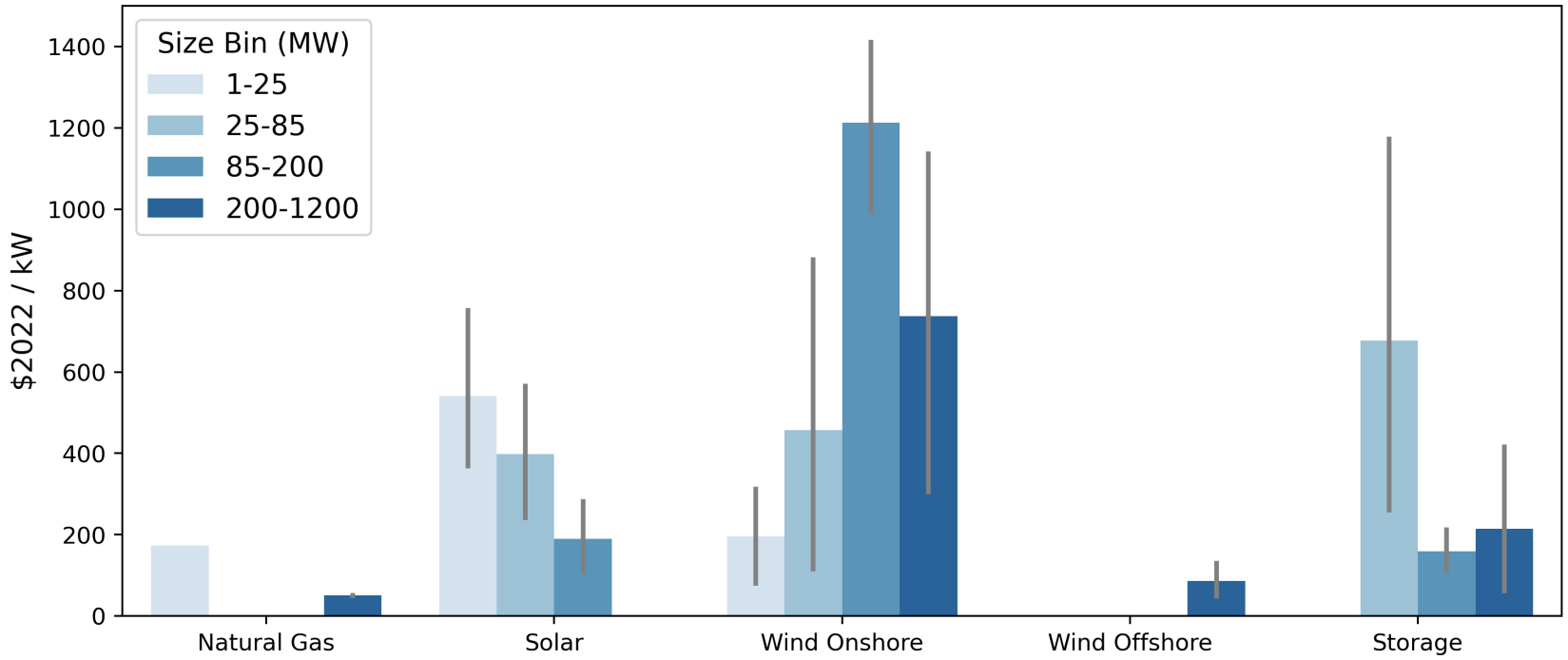
- **Solar:** Projects with high interconnection costs can be found throughout the region



- **Onshore wind:** Maine is the site of most projects and long new transmission lines are often needed just to reach existing network

ISO-NE: Larger generators have greater interconnection costs in absolute terms, but economies of scale exist on a per kW basis for solar projects.

Interconnection Costs by Size Bin and Resource Type (2018-2021)



- Solar interconnection costs fall from an average of $541/kW for small projects (1-25 MW) to $190/kW for the largest projects (85-200 MW)
- Storage shows some signs of interconnection economies of scale, but inconclusive
- Other resource types do not exhibit economies of scale on a per-kW basis

Next steps for Berkeley Lab Research

- Deeper comparative analysis of interconnection costs between ISOs
- i2X Solution eXchange meetings bringing together stakeholders to discuss challenges
- i2X Roadmap outlining opportunities to improve the interconnection process
- Potential expansion of interconnection costs into additional regions, pending data availability

Conclusion

- Interconnection queues have exploded over the past years, resulting in lengthy study processes with high applicant withdrawal rates
- Interconnection costs are not available as pre-request information
- Interconnection costs of completed studies are challenging to collect
- Interconnection costs have grown over time in all studied regions
- Upgrade requirements of the broader transmission system are the primary cost driver
- Many projects facing high interconnection costs withdraw from the queue
- Renewables and storage projects have higher interconnection costs than natural gas power plants

- Engage in the i2X program to help inform potential solutions:
  - https://www.energy.gov/eere/i2x/i2x-solution-e-xchanges
  - 07/06/2023, 2-4 p.m. ET: DER+ BPS post-interconnection data for metrics and tracking
  - 07/12/2023, 2-4 p.m. ET: Improving interconnection study methodologies in the bulk power system
  - 07/19/2023, 2-4 p.m. ET: Collecting and considering feedback in public policy for equity

Project Team:

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Fritz Kahrl (fkahrl@lbl.gov) – Interconnection Cost Allocation

Dev Millstein (dmillstein@lbl.gov) – Transmission Valuation

More Information: Visit https://emp.lbl.gov/queues and https://emp.lbl.gov/interconnection-costs

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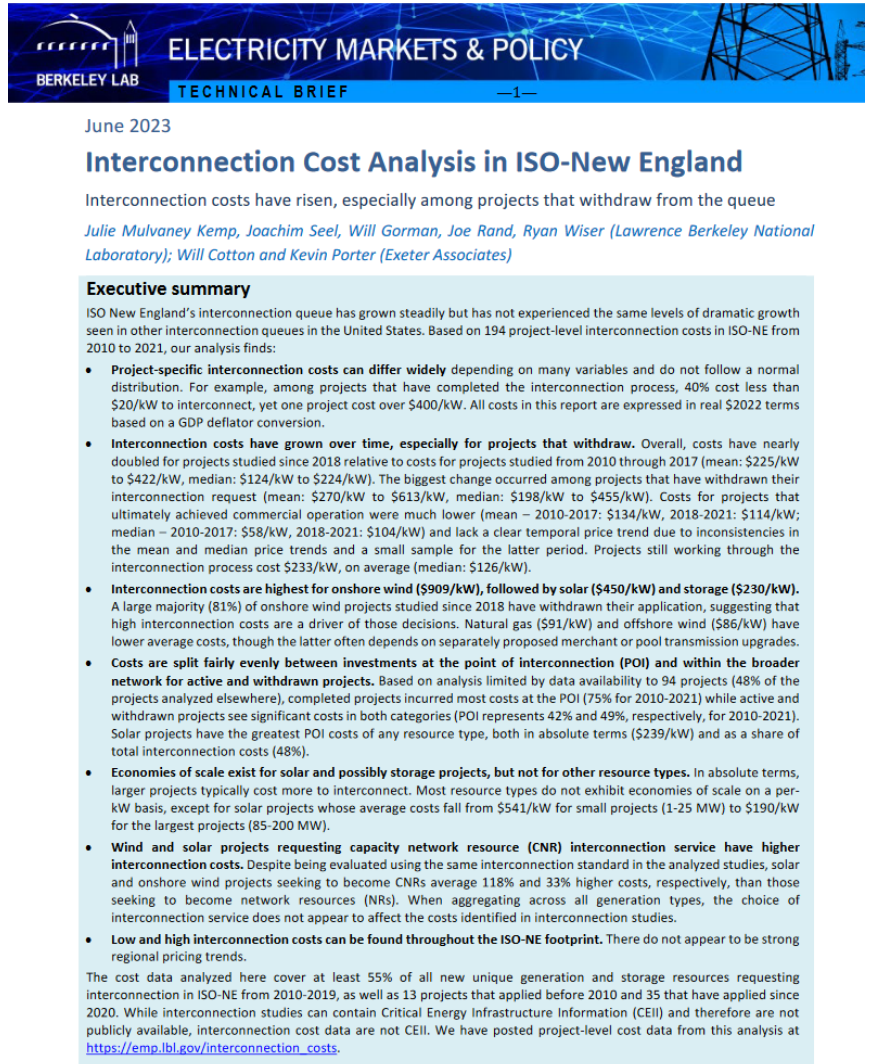
Appendix

ISO-specific briefings and underlying project cost data available at https://emp.lbl.gov/interconnection_costs

ISO-NE

See Briefing and Data at:
https://emp.lbl.gov/publications/interconnection-cost-analysis-iso-new



BERKELEY LAB ELECTRICITY MARKETS & POLICY
TECHNICAL BRIEF —1—

June 2023

Interconnection Cost Analysis in ISO-New England

Interconnection costs have risen, especially among projects that withdraw from the queue

Julie Mulvaney Kemp, Joachim Seel, Will Gorman, Joe Rand, Ryan Wiser (Lawrence Berkeley National Laboratory); Will Cotton and Kevin Porter (Exeter Associates)

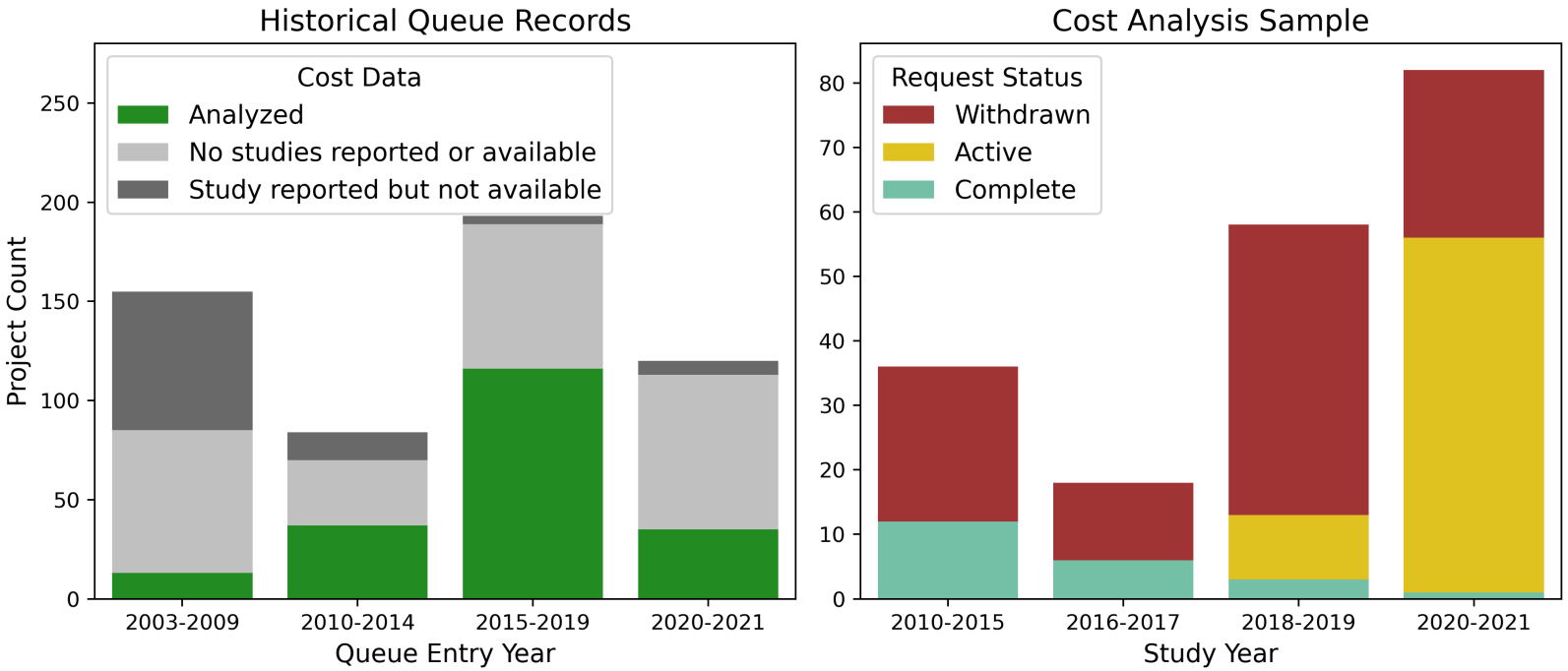
Executive summary

ISO New England's interconnection queue has grown steadily but has not experienced the same levels of dramatic growth seen in other interconnection queues in the United States. Based on 194 project-level interconnection costs in ISO-NE from 2010 to 2021, our analysis finds:

- **Project-specific interconnection costs can differ widely** depending on many variables and do not follow a normal distribution. For example, among projects that have completed the interconnection process, 40% cost less than $20/kW to interconnect, yet one project cost over $400/kW. All costs in this report are expressed in real $2022 terms based on a GDP deflator conversion.
- **Interconnection costs have grown over time, especially for projects that withdraw.** Overall, costs have nearly doubled for projects studied since 2018 relative to costs for projects studied from 2010 through 2017 (mean: $225/kW to $422/kW, median: $124/kW to $224/kW). The biggest change occurred among projects that have withdrawn their interconnection request (mean: $270/kW to $613/kW, median: $198/kW to $455/kW). Costs for projects that ultimately achieved commercial operation were much lower (mean – 2010-2017: $134/kW, 2018-2021: $114/kW; median – 2010-2017: $58/kW, 2018-2021: $104/kW) and lack a clear temporal price trend due to inconsistencies in the mean and median price trends and a small sample for the latter period. Projects still working through the interconnection process cost $233/kW, on average (median: $126/kW).
- **Interconnection costs are highest for onshore wind ($909/kW), followed by solar ($450/kW) and storage ($230/kW).** A large majority (81%) of onshore wind projects studied since 2018 have withdrawn their application, suggesting that high interconnection costs are a driver of those decisions. Natural gas ($91/kW) and offshore wind ($86/kW) have lower average costs, though the latter often depends on separately proposed merchant or pool transmission upgrades.
- **Costs are split fairly evenly between investments at the point of interconnection (POI) and within the broader network for active and withdrawn projects.** Based on analysis limited by data availability to 94 projects (48% of the projects analyzed elsewhere), completed projects incurred most costs at the POI (75% for 2010-2021) while active and withdrawn projects see significant costs in both categories (POI represents 42% and 49%, respectively, for 2010-2021). Solar projects have the greatest POI costs of any resource type, both in absolute terms ($239/kW) and as a share of total interconnection costs (48%).
- **Economies of scale exist for solar and possibly storage projects, but not for other resource types.** In absolute terms, larger projects typically cost more to interconnect. Most resource types do not exhibit economies of scale on a per-kW basis, except for solar projects whose average costs fall from $541/kW for small projects (1-25 MW) to $190/kW for the largest projects (85-200 MW).
- **Wind and solar projects requesting capacity network resource (CNR) interconnection service have higher interconnection costs.** Despite being evaluated using the same interconnection standard in the analyzed studies, solar and onshore wind projects seeking to become CNRs average 118% and 33% higher costs, respectively, than those seeking to become network resources (NRs). When aggregating across all generation types, the choice of interconnection service does not appear to affect the costs identified in interconnection studies.
- **Low and high interconnection costs can be found throughout the ISO-NE footprint.** There do not appear to be strong regional pricing trends.

The cost data analyzed here cover at least 55% of all new unique generation and storage resources requesting interconnection in ISO-NE from 2010-2019, as well as 13 projects that applied before 2010 and 35 that have applied since 2020. While interconnection studies can contain Critical Energy Infrastructure Information (CEII) and therefore are not publicly available, interconnection cost data are not CEII. We have posted project-level cost data from this analysis at https://emp.lbl.gov/interconnection_costs.

Costs were obtained for at least 47% of generation and storage projects requesting interconnection since 2010



Interconnection Request Status Definitions

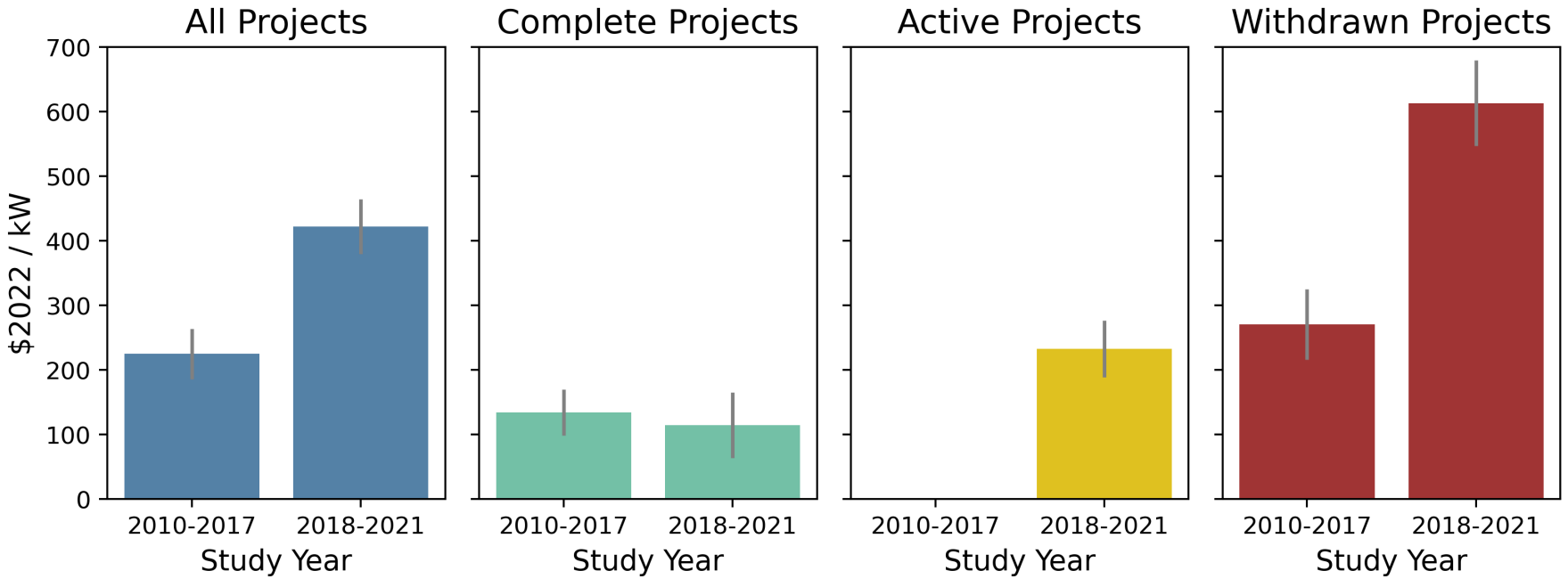
Complete: These projects are commercially operational.

Active: These projects are working through the interconnection process and are actively under study or are developing an interconnection agreement.

Withdrawn: These interconnection requests have been withdrawn from the queue (cancelled).

- Interconnection cost dataset of 194 projects
- Source: All interconnection studies available online in the ISO-NE system as of May 2022
  - Studies were available less often for older projects because of document retention policies, in part
- Methods:
  - Critical Energy Infrastructure Information (CEII) access was obtained to review interconnection studies
  - Cost data were collected manually from interconnection study reports
  - Interconnection costs reported in real $2022-terms based on a GDP deflator conversion (assuming nominal dollars as of the time of the interconnection study, unless otherwise stated)

Interconnection costs have grown over time, especially for withdrawn projects

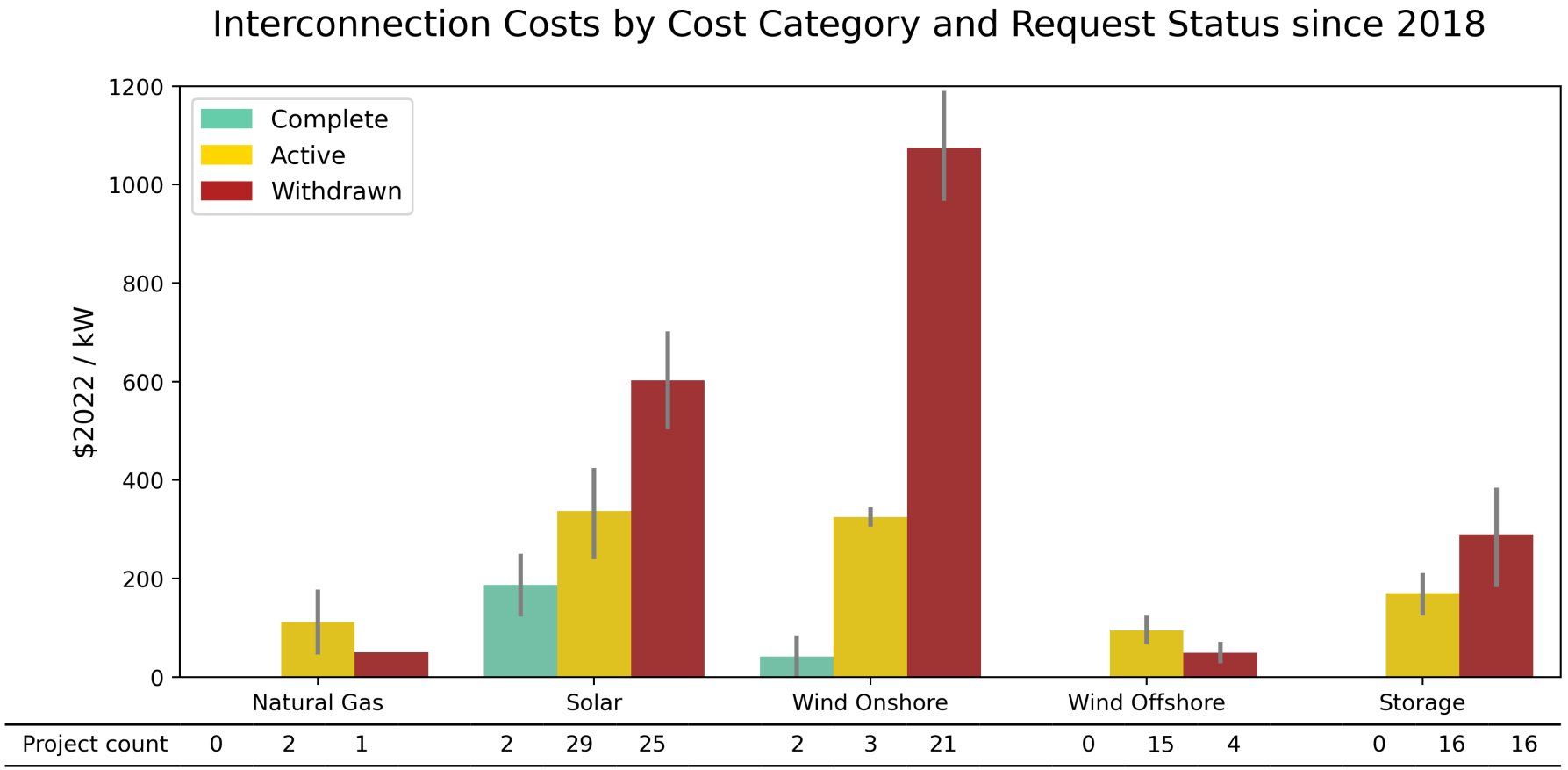


Mean cost ($/kW)	**225**	**422**	**134**	**114**	**-**	**233**	**270**	**613**

Projects currently moving through the interconnection process have **similar** costs to the 2010-17 average

Withdrawn project costs more than **doubled**

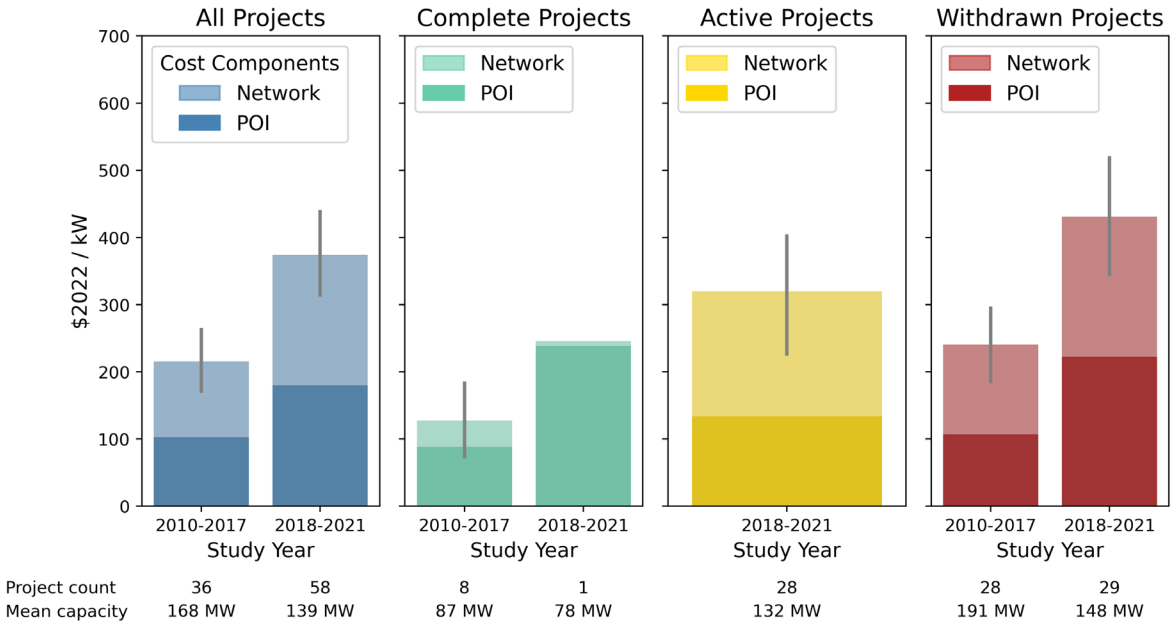
The trend of higher costs for withdrawn than active projects is found among solar, onshore wind, and storage projects



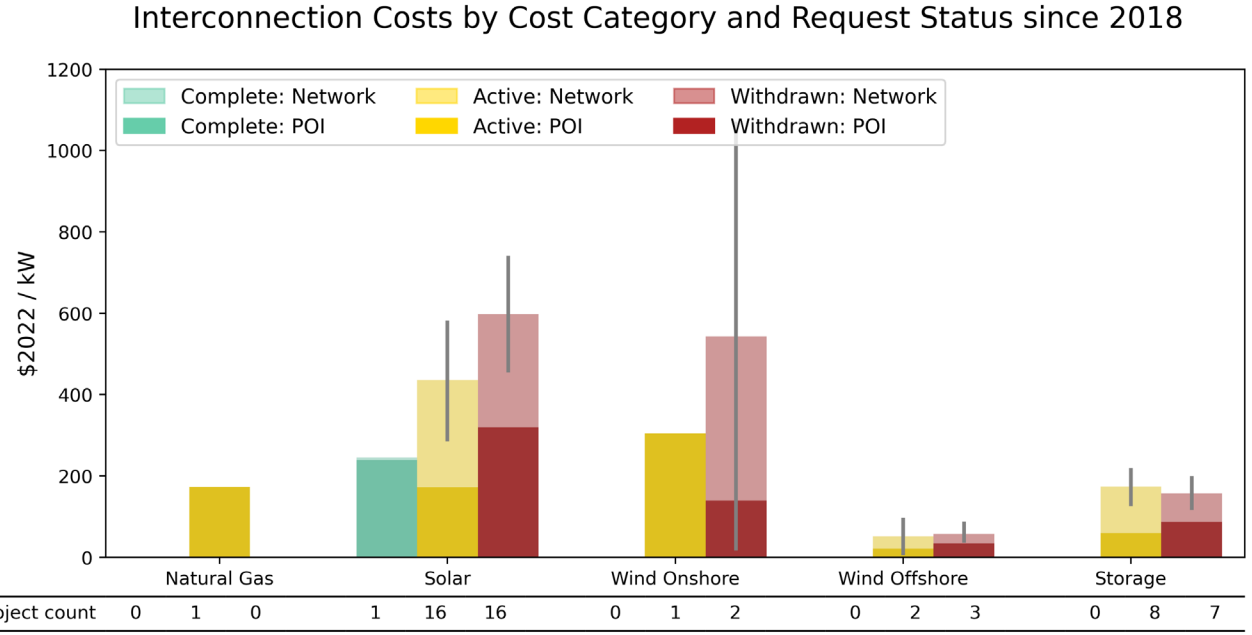
- High interconnection costs appear to be a driver of withdrawal decisions for many resource types
- For offshore wind, interconnection costs do not appear to drive withdrawals. Instead, factors outside of interconnection may play a larger role, such as failure to be selected in states' competitive capacity procurement processes

Interconnection regularly requires significant upgrades at multiple places in the network

Costs are split fairly evenly between investments at the point of interconnection (POI) and within the broader network



Solar projects have the greatest POI costs of any resource type – both as the share of total costs and in absolute $/kW terms

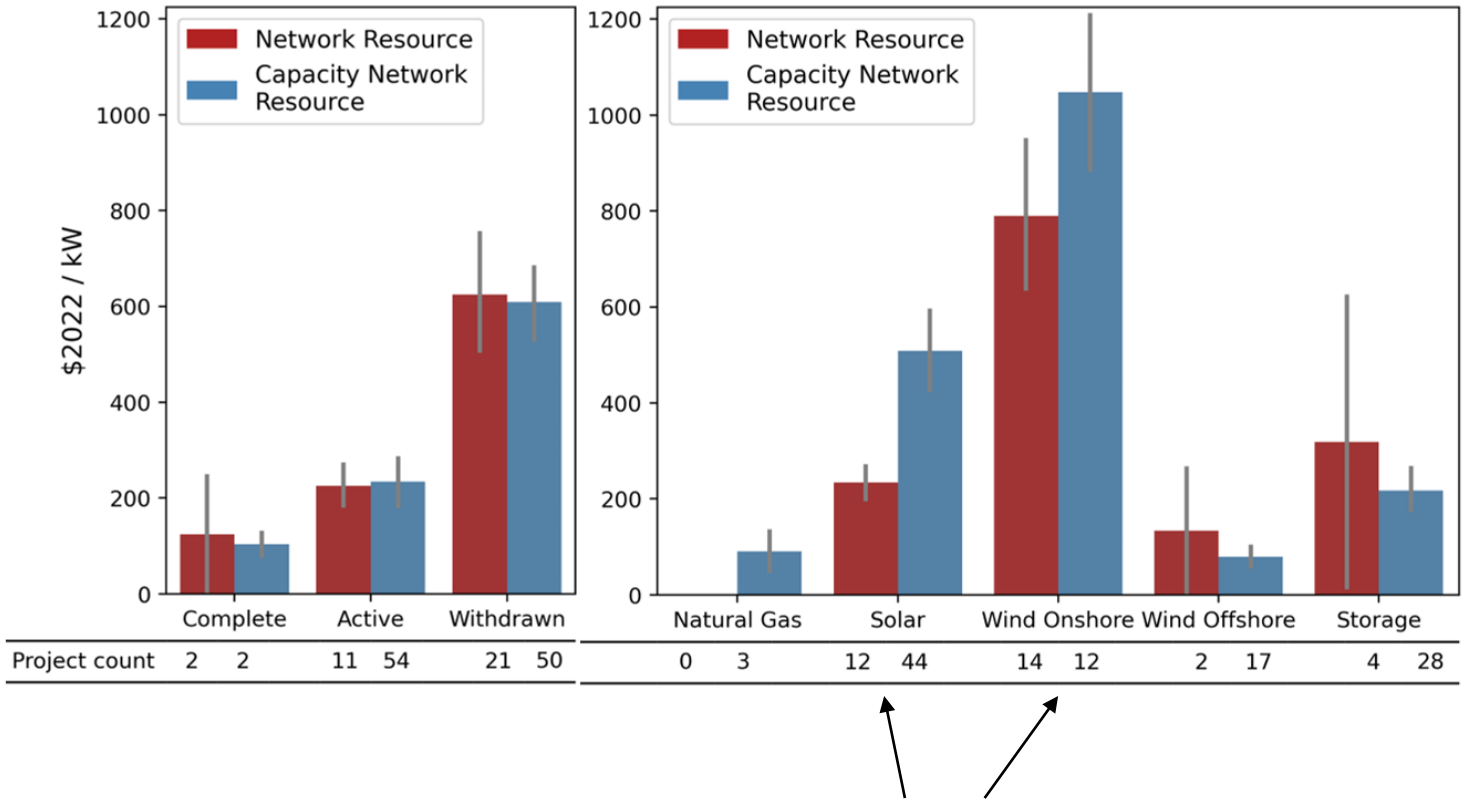


- Proportion of projects requiring at least some upgrade at the POI increased from 64% to 93% from 2010-2017 to 2018-2021
- Complete project costs are concentrated at the POI

Cost categorization only available for 48% of the projects analyzed elsewhere.
These results are based on those 94 projects.

Solar and onshore wind projects requesting CNR interconnection service have higher interconnection costs, despite being evaluated using the same interconnection standard

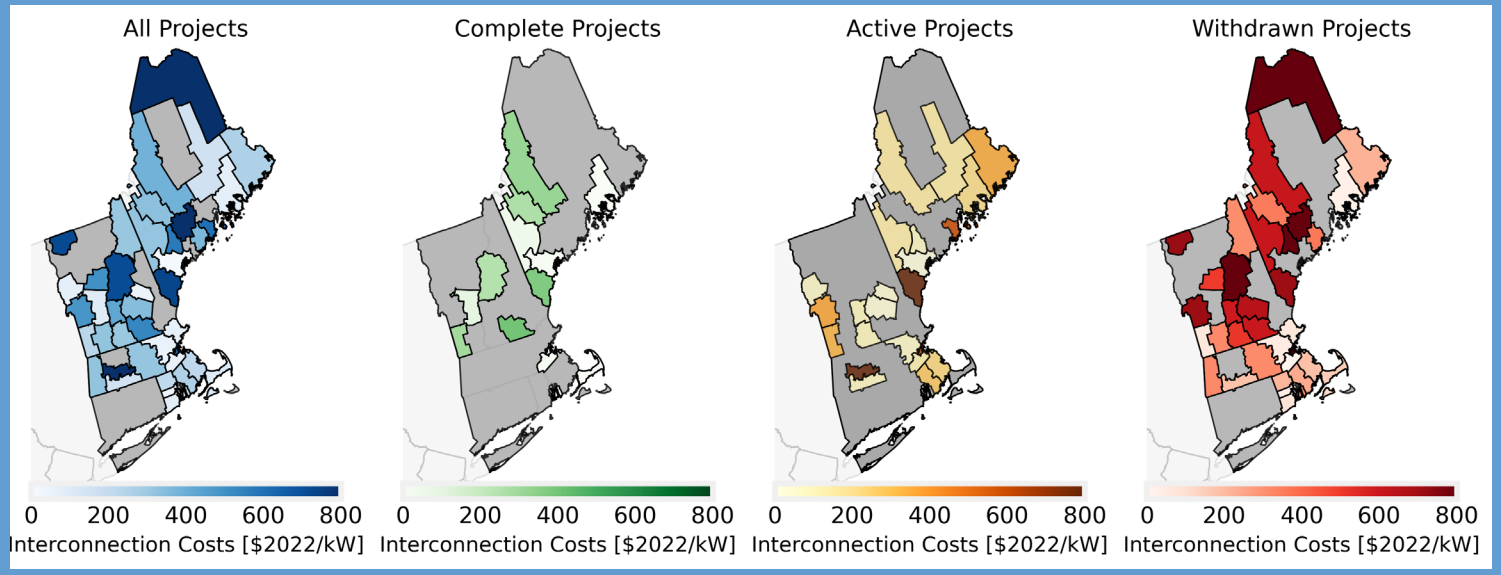
- Applicants seeking interconnection choose either capacity network resource (CNR) interconnection service or network resource (NR) interconnection service
- All interconnection studies analyzed here are conducted according to the Network Capability Interconnection Standard, regardless of their CNR or NR choice
- CNR projects seeking capacity qualification may be responsible for additional qualification transmission upgrades not captured here



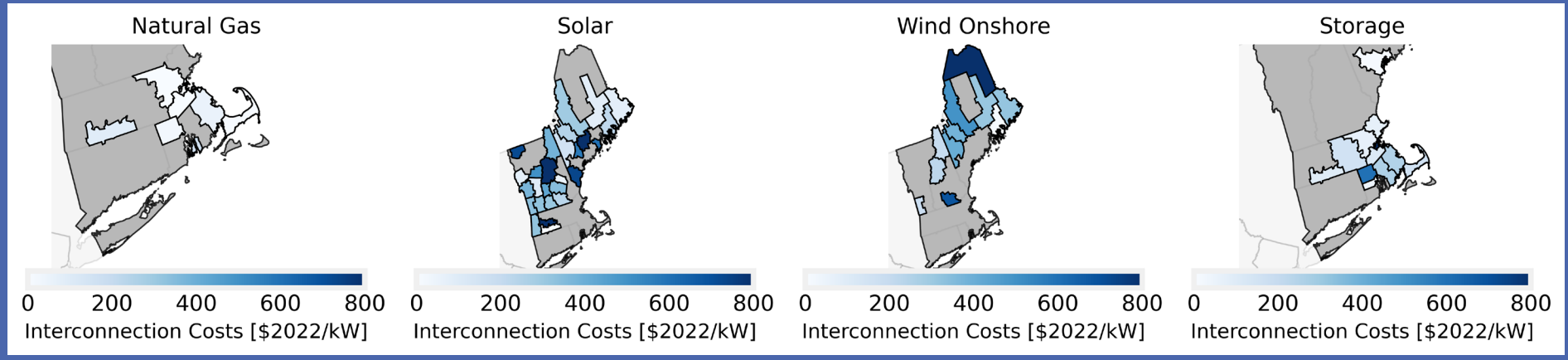
Unexpected cost difference by service type (evaluation standard is the same).
Suggests a correlation between the selection of CNR interconnection service and other drivers of high costs, such as location, for solar and onshore wind.

Low and high interconnection costs can be found throughout the ISO-NE footprint

Costs by county and request status (2010-2021)

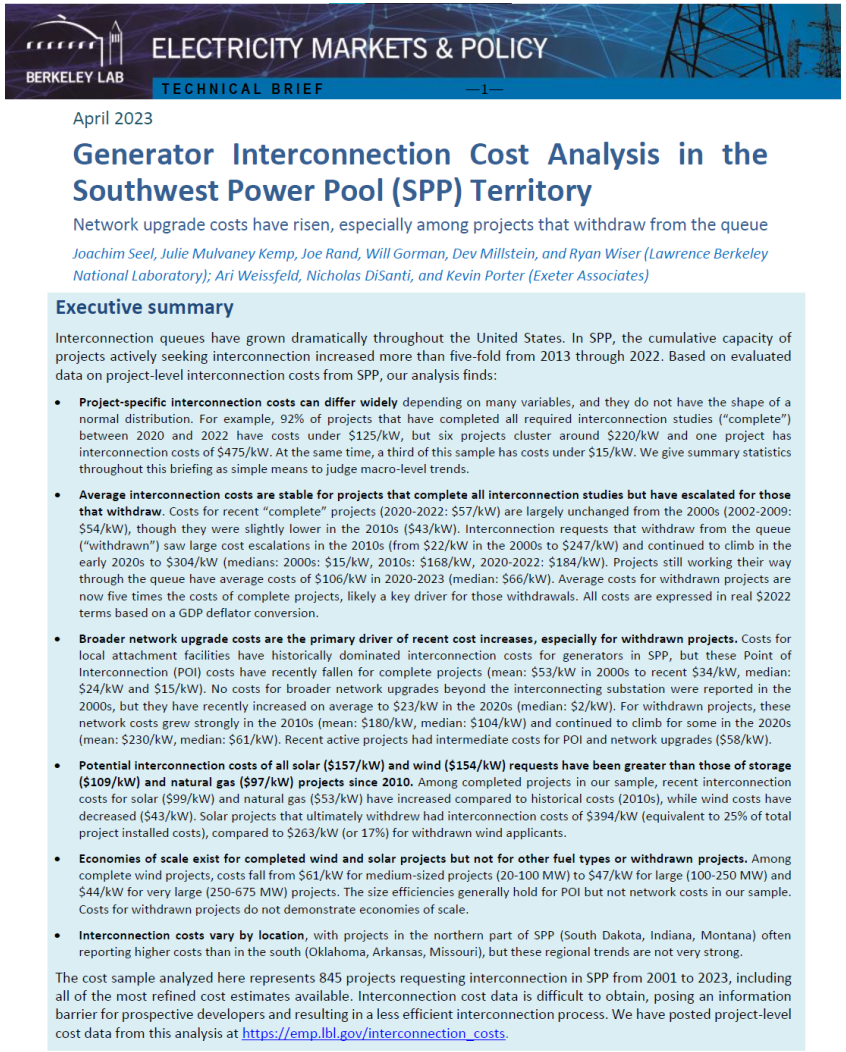


Costs by county and resource type (2010-2021)



SPP

See Briefing and Data at:
https://emp.lbl.gov/publications/generator-interconnection-cost-0



BERKELEY LAB ELECTRICITY MARKETS & POLICY
TECHNICAL BRIEF —1—

April 2023

Generator Interconnection Cost Analysis in the Southwest Power Pool (SPP) Territory

Network upgrade costs have risen, especially among projects that withdraw from the queue

Joachim Seel, Julie Mulvaney Kemp, Joe Rand, Will Gorman, Dev Millstein, and Ryan Wiser (Lawrence Berkeley National Laboratory); Ari Weissfeld, Nicholas DiSanti, and Kevin Porter (Exeter Associates)

Executive summary

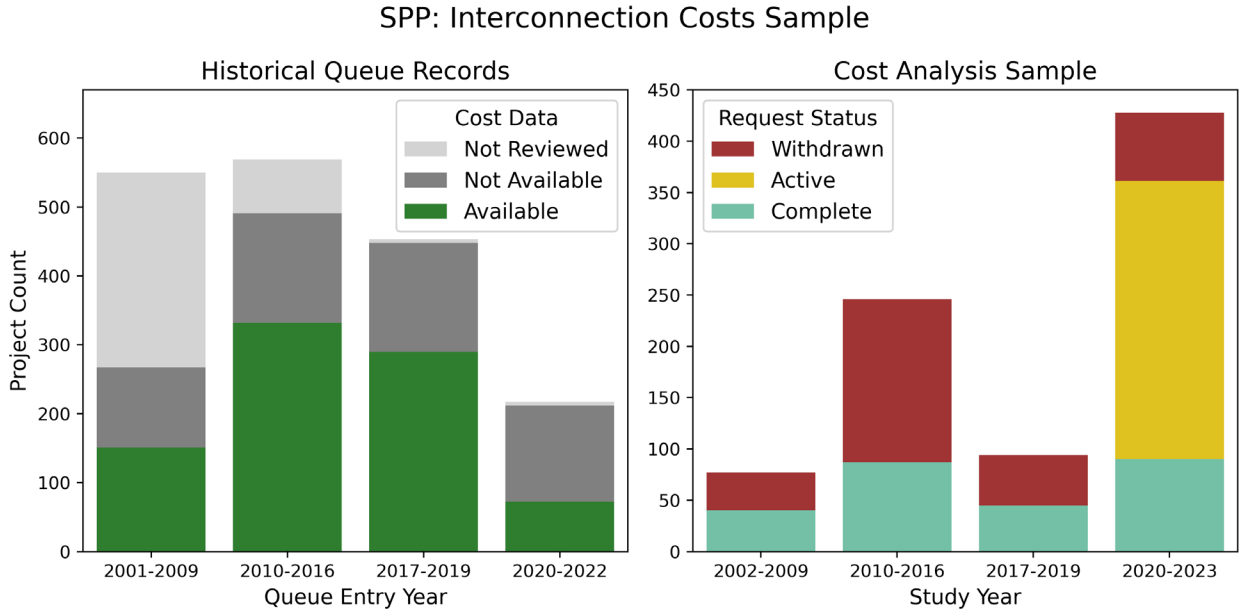
Interconnection queues have grown dramatically throughout the United States. In SPP, the cumulative capacity of projects actively seeking interconnection increased more than five-fold from 2013 through 2022. Based on evaluated data on project-level interconnection costs from SPP, our analysis finds:

- **Project-specific interconnection costs can differ widely** depending on many variables, and they do not have the shape of a normal distribution. For example, 92% of projects that have completed all required interconnection studies ("complete") between 2020 and 2022 have costs under $125/kW, but six projects cluster around $220/kW and one project has interconnection costs of $475/kW. At the same time, a third of this sample has costs under $15/kW. We give summary statistics throughout this briefing as simple means to judge macro-level trends.
- **Average interconnection costs are stable for projects that complete all interconnection studies but have escalated for those that withdraw**. Costs for recent "complete" projects (2020-2022: $57/kW) are largely unchanged from the 2000s (2002-2009: $54/kW), though they were slightly lower in the 2010s ($43/kW). Interconnection requests that withdraw from the queue ("withdrawn") saw large cost escalations in the 2010s (from $22/kW in the 2000s to $247/kW) and continued to climb in the early 2020s to $304/kW (medians: 2000s: $15/kW, 2010s: $168/kW, 2020-2022: $184/kW). Projects still working their way through the queue have average costs of $106/kW in 2020-2023 (median: $66/kW). Average costs for withdrawn projects are now five times the costs of complete projects, likely a key driver for those withdrawals. All costs are expressed in real $2022 terms based on a GDP deflator conversion.
- **Broader network upgrade costs are the primary driver of recent cost increases, especially for withdrawn projects.** Costs for local attachment facilities have historically dominated interconnection costs for generators in SPP, but these Point of Interconnection (POI) costs have recently fallen for complete projects (mean: $53/kW in 2000s to recent $34/kW, median: $24/kW and $15/kW). No costs for broader network upgrades beyond the interconnecting substation were reported in the 2000s, but they have recently increased on average to $23/kW in the 2020s (median: $2/kW). For withdrawn projects, these network costs grew strongly in the 2010s (mean: $180/kW, median: $104/kW) and continued to climb for some in the 2020s (mean: $230/kW, median: $61/kW). Recent active projects had intermediate costs for POI and network upgrades ($58/kW).
- **Potential interconnection costs of all solar ($157/kW) and wind ($154/kW) requests have been greater than those of storage ($109/kW) and natural gas ($97/kW) projects since 2010.** Among completed projects in our sample, recent interconnection costs for solar ($99/kW) and natural gas ($53/kW) have increased compared to historical costs (2010s), while wind costs have decreased ($43/kW). Solar projects that ultimately withdrew had interconnection costs of $394/kW (equivalent to 25% of total project installed costs), compared to $263/kW (or 17%) for withdrawn wind applicants.
- **Economies of scale exist for completed wind and solar projects but not for other fuel types or withdrawn projects.** Among complete wind projects, costs fall from $61/kW for medium-sized projects (20-100 MW) to $47/kW for large (100-250 MW) and $44/kW for very large (250-675 MW) projects. The size efficiencies generally hold for POI but not network costs in our sample. Costs for withdrawn projects do not demonstrate economies of scale.
- **Interconnection costs vary by location**, with projects in the northern part of SPP (South Dakota, Indiana, Montana) often reporting higher costs than in the south (Oklahoma, Arkansas, Missouri), but these regional trends are not very strong.

The cost sample analyzed here represents 845 projects requesting interconnection in SPP from 2001 to 2023, including all of the most refined cost estimates available. Interconnection cost data is difficult to obtain, posing an information barrier for prospective developers and resulting in a less efficient interconnection process. We have posted project-level cost data from this analysis at https://emp.lbl.gov/interconnection_costs.

Cost sample represents all of the most refined cost estimates available

- Interconnection costs sample of 845 projects
  - 47% sample coverage 2001-2022:
    - Excluded projects without cost estimates
    - Excluded superseded projects
  - Reviewed 31 out of 204 feasibility cluster studies
    - (146 out of 472 interconnection requests). Most of the examined projects withdrew their requests, resulting in 86 final cost estimates.
  - Reviewed all recent system impact studies and half of the historical studies
    - DISIS cluster studies are available in excel format for queue entrants since 2016, allowing for easier processing
    - Resulting in 308 final cost estimate.
  - Reviewed all of the available 572 facility studies
    - Best available cost estimates (GIA not publicly posted), resulting in 453 final cost estimates.
  - Focusing on studies performed between 2010-2023
- Methods:
  - Cost data were collected manually from public interconnection study reports.
  - Interconnection costs in real $2022-terms based on a GDP deflator conversion (assuming nominal dollars as of the time of the interconnection study)
  - Presenting simple means



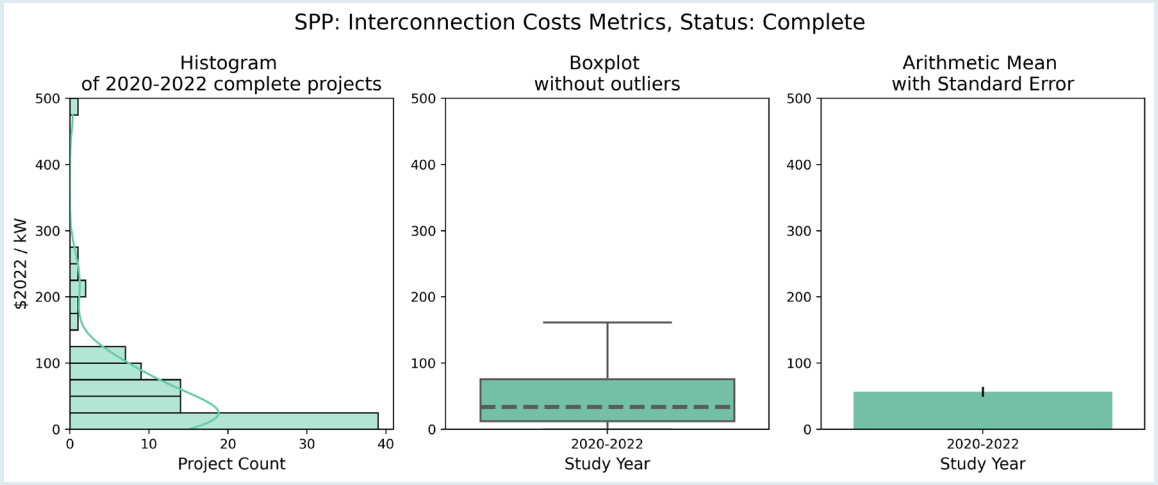
Interconnection Request Status Definitions

Complete: These projects have completed all of the interconnection studies, and have moved on to (or completed) the interconnection agreement phase. Includes plants that are now in service.

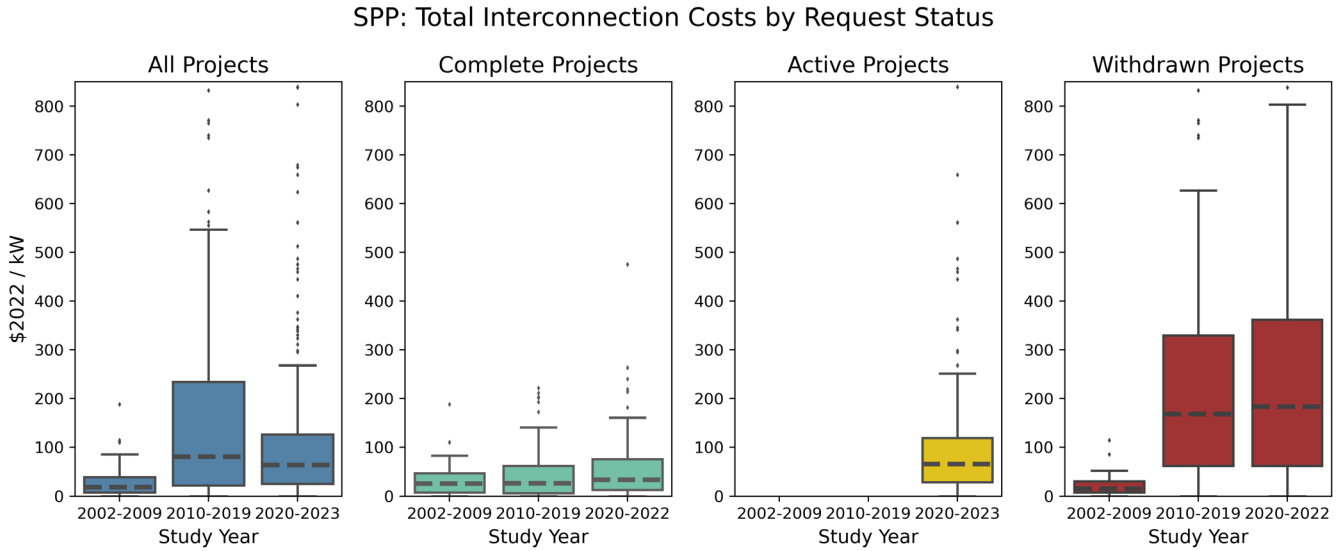
Active: These projects are actively working through the interconnection study process.

Withdrawn: These interconnection requests have been withdrawn (cancelled) from the queue.

Trend of increasing cost holds when looking at overall project distribution



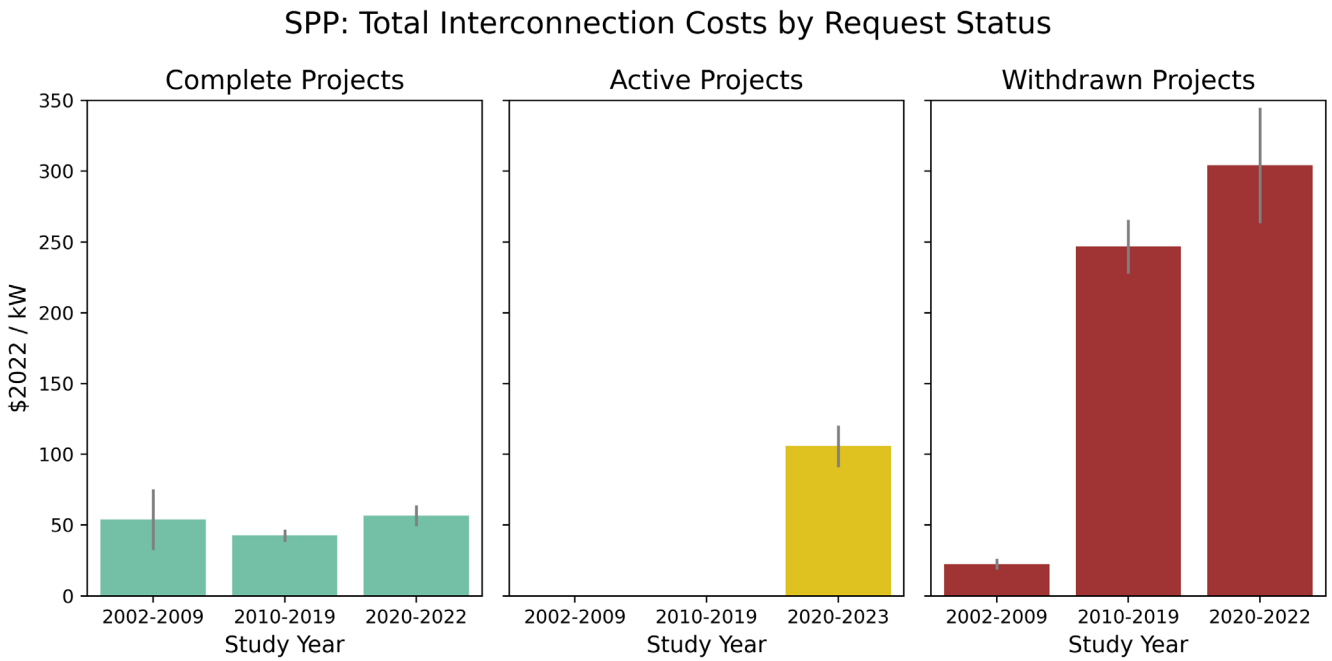
- Cost data do not have normal distribution:
  - Many projects with very low interconnection costs
  - Some projects with very high interconnection costs that influence sample mean



- Many trends presented today also hold when looking at typical (median) projects. When deviations occur we note them in the coming slides.

Average Interconnection costs have grown over time

Interconnection costs increase in our sample for complete (after 2019) and especially for withdrawn projects (after 2009).



By Interconnection Request Status

- **Complete:**
  - Costs fell from $54/kW (2002-2009) to $43/kW (2010-2019),but rose again to $57/kW between 2020 and 2022.
- **Active:**
  - Projects still actively moving through the queue have costs of $106/kW, more than complete, but less than withdrawn projects
- **Withdrawn:**
  - Strong cost increase from $22/kW (2002-2009) to $247/kW (2010-2019), average costs climbing further to $304/kW between 2020 and 2022.
  - Five times the costs of “complete” projects over the past three years.

Broader network upgrade costs are the primary driver of recent cost increases and dominate among withdrawn projects

By Interconnection Request Status

- **Complete:**
  - Local upgrades at POI dominate interconnection costs in SPP. Costs fell from $53/kW (2002-2009) to $32/kW (2010-2019),but rose again to $34/kW between 2020 and 2022.
  - Network upgrades are only triggered by a few projects but can add substantial costs. They did not exist prior to 2010 and have been primary driver of average cost increases since then, doubling from $11/kW (2010-2019) to $23 (2020-2022). *(medians: $0 and $1/kW)*
- **Active:**
  - Network costs at $56/kW are slightly higher than POI costs ($46/kW) among recent active projects.
- **Withdrawn:**
  - POI cost have quadrupled over time (2002-2009: $22/kW, 2010-2019: $67/kW, 2020-2022: $74/kW) and are now more than twice as high compared to complete projects.
  - Again, network upgrade costs only appeared after 2010. They are much larger than for complete projects and have grown in recent years (from $180 to $230/kW). *(Medians have fallen from $104/kW to $61/kW).*
  - The top 10% of recent network upgrade costs range between $859 and $1,219/kW (a facility study proposing upgrade costs of $147 million for a 152 MW wind project: https://opsportal.spp.org/documents/studies/files/2016_Generation_Studies/GEN-2016-110-IFS-2016-002-16_IFS-Summary_R0-FINAL.pdf).

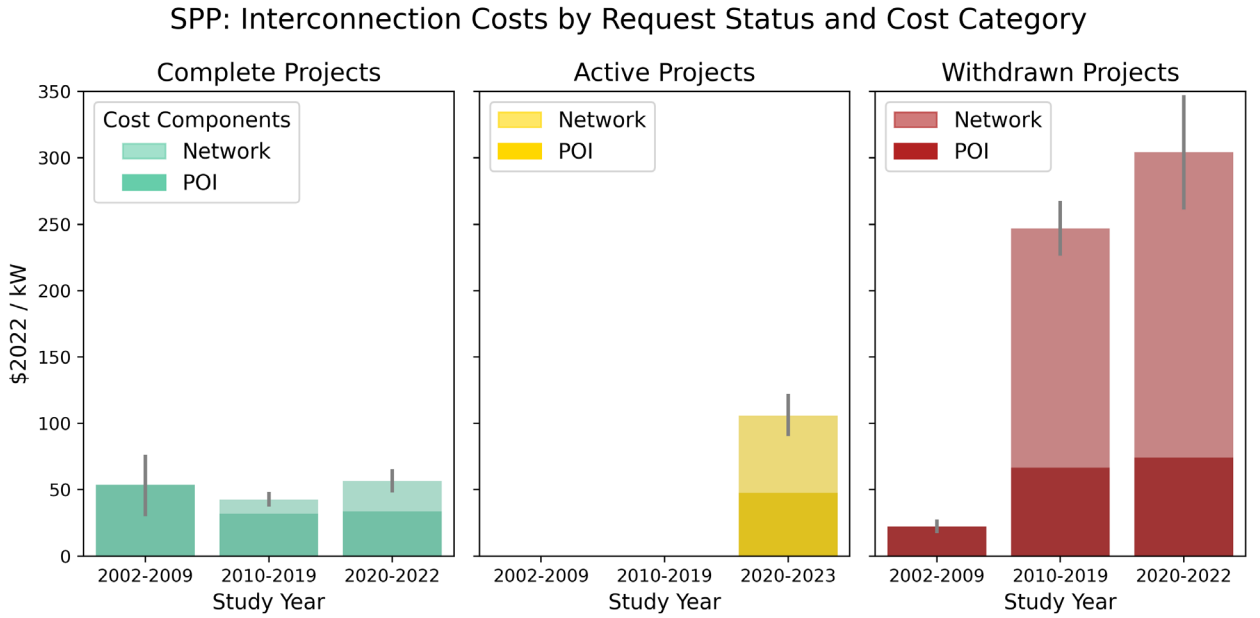
Interconnection Cost Components

Point of Interconnection (POI) or Interconnection Facilities Costs:

- Interconnection station and transmission line extensions. In SPP, this is the sum of *Transmission Owner Interconnection Facilities (TOIF)* and *Stand Alone Network Upgrades* (also referred to as *Non-Shared Network Upgrade Costs*)
- Excludes interconnection customer interconnection facilities (equipment located between the generating facility and the point of change of ownership like step-up transformer, spur lines…)

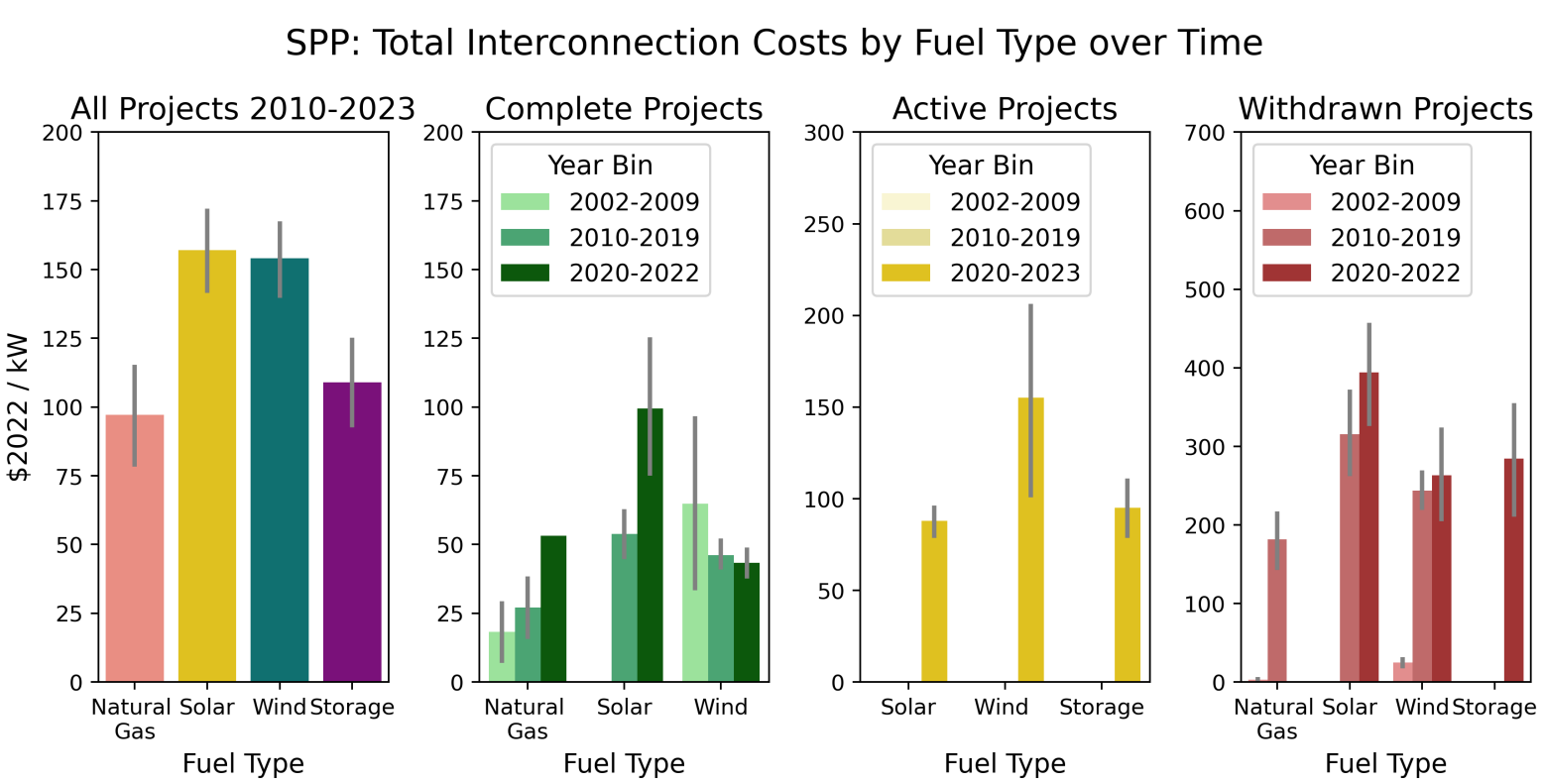
Network Costs:

- Sum of *Shared Network Upgrades* and *Affected System Upgrades* (Facility Studies) or sum of *ERIS* and *NRIS Network Upgrades* (Feasibility Studies)
- Excludes *Contingent Network Upgrades*, *Previous Network Upgrades* or *Other Network Upgrades*.



Interconnection costs for solar and wind are larger than for natural gas

Solar ($157/kW), and **onshore wind** ($154/kW) costs are greater than **storage** ($109/kW) and **natural gas** interconnection costs ($97/kW) among recent applicants, irrespective of request status.



Recent cost trends:

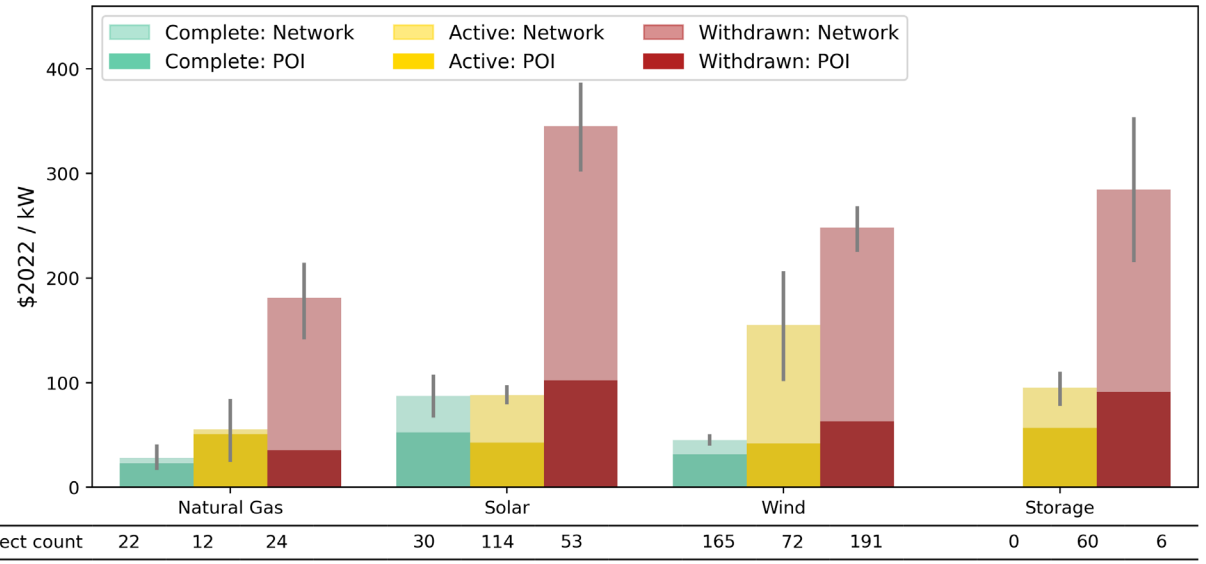
- **Complete**:
  - Natural gas costs increase ($18, $27, $53/kW) **2020-2022 n=1*
  - Solar average cost grow ($54 to $99/kW) **medians stable at $60/kW*
  - Wind have recently fallen ($65, $46, $43/kW)
- **Active**:
  - Wind ($155/kW) has higher costs than storage ($95/kW) and solar ($88/kW)
- **Withdrawn**:
  - Natural gas remains least cost ($181/kW) **no 2020-2022 data*
  - Solar cost grow ($316 to $394/kW)
  - Wind average costs increase from early years ($25, $244 to $263/kW) **medians: $17, $168, $85/kW*
  - Storage has high costs at $285/kW

Network costs cause increase in interconnection expenses for renewables, especially for withdrawn projects

- POI costs tend to be higher for withdrawn projects
  - Natural Gas: $23/kW vs. $35/kW
  - Solar: $52/kW vs. $102/kW
  - Onshore wind: $31/kW vs. $63/kW
  - Storage: $57/kW (active) vs. $91/kW

- Network costs increase dramatically for **withdrawn** projects.
  - Natural Gas: $6/kW vs. $146/kW
  - Solar: $35/kW vs. $243/kW
  - Onshore wind: $14/kW vs. $185/kW
  - Storage: $38/kW (active) vs. $193/kW

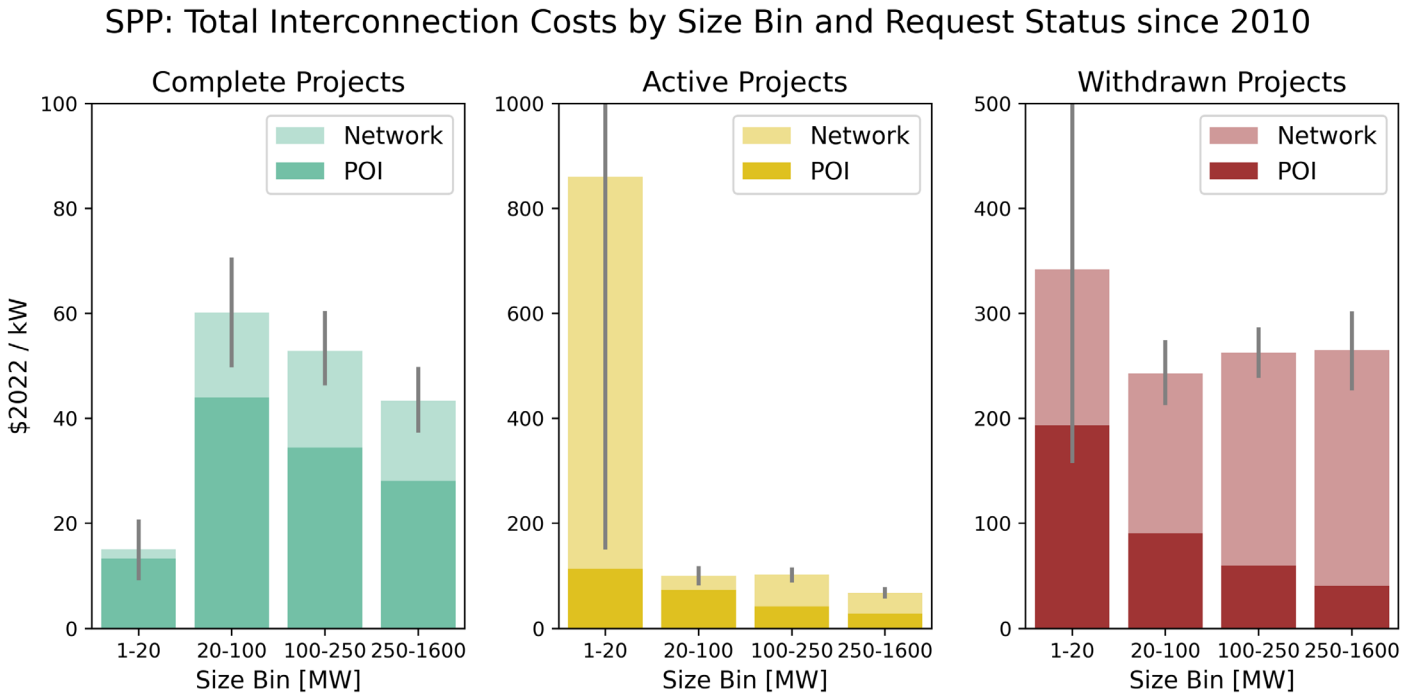
SPP: Interconnection Costs by Cost Category and Request Status since 2010



- SPP interconnection costs represent modest share of overall project costs for those that have completed all studies, but are a development hurdle for those that withdraw:
  - **Onshore Wind:** Complete projects: 3% of total project capex, withdrawn projects: 17%.
  - **Solar**: Complete projects: 6% of total project capex, withdrawn projects: 25%

Larger complete generators have lower interconnection costs per kW, especially wind projects

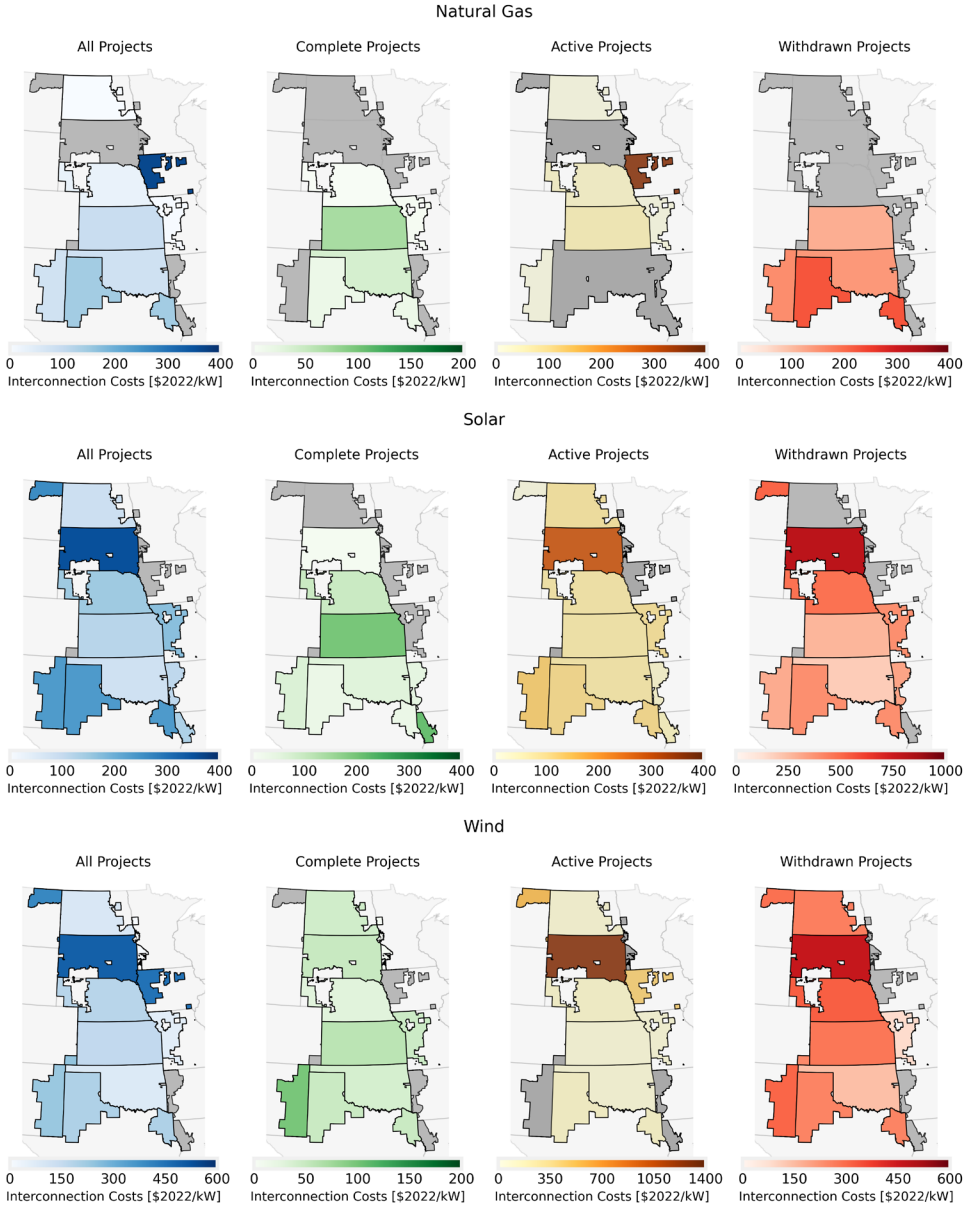
Projects with larger nameplate capacity have greater interconnection costs in absolute terms, but these costs do not scale linearly on a per kW basis for complete projects, falling from $60/kW (medium), $53/kW (large), and $43/kW (very large project size).



- Economies of scale are only present for complete projects but not withdrawn projects, driven by declining POI costs (network costs are stable or increase for withdrawn projects).
- No consistent economies of scale across all fuels. Only among complete projects do we see some evidence for wind and solar, but not for natural gas:

Fuel	1-20 MW	20-100 MW	100-250 MW	250-675 MW
Natural Gas	$20/kW	$6/kW	$52/kW	$26/kW
Solar		$90/kW	$85/kW	
Onshore Wind	$8/kW	$61/kW	$47/kW	$44/kW

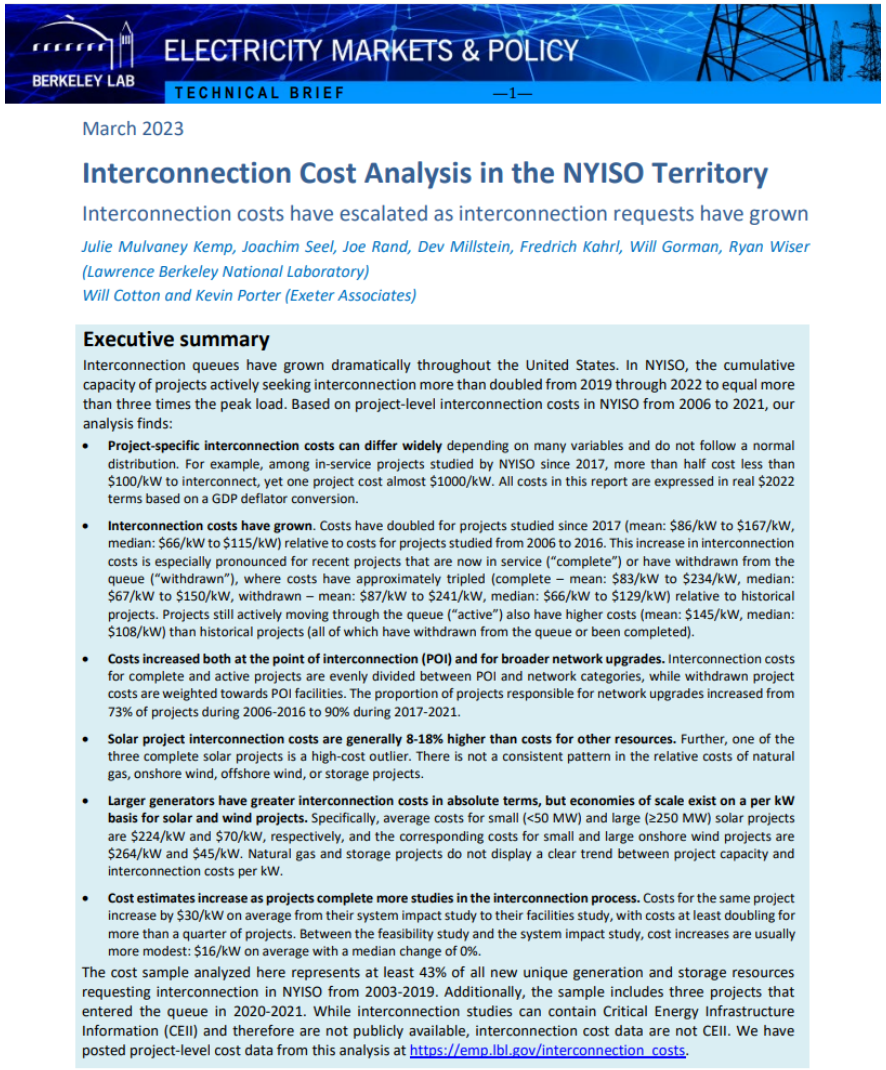
Interconnection costs vary by location, but regional trends are not very strong



- Across all projects 2010-2022:
  - Northern projects in South Dakota ($440/kW), Indiana ($419/kW) and Montana ($358/kW) reporting overall higher costs than southern applicants in Oklahoma, Arkansas, and Missouri ($84-95/kW).
- By fuel type:
  - Natural gas projects report higher costs in Indiana and Texas than in North Dakota, Missouri, and Nebraska.
  - No strong regional trends for wind and solar.
  - Storage has rather uniform costs across all active projects, though withdrawn storage costs are particularly high in Texas.

NYISO

See Briefing and Data at:
https://emp.lbl.gov/publications/interconnection-cost-analysis-nyiso



BERKELEY LAB ELECTRICITY MARKETS & POLICY
TECHNICAL BRIEF —1—

March 2023

Interconnection Cost Analysis in the NYISO Territory

Interconnection costs have escalated as interconnection requests have grown

Julie Mulvaney Kemp, Joachim Seel, Joe Rand, Dev Millstein, Fredrich Kahrl, Will Gorman, Ryan Wiser (Lawrence Berkeley National Laboratory)
Will Cotton and Kevin Porter (Exeter Associates)

Executive summary

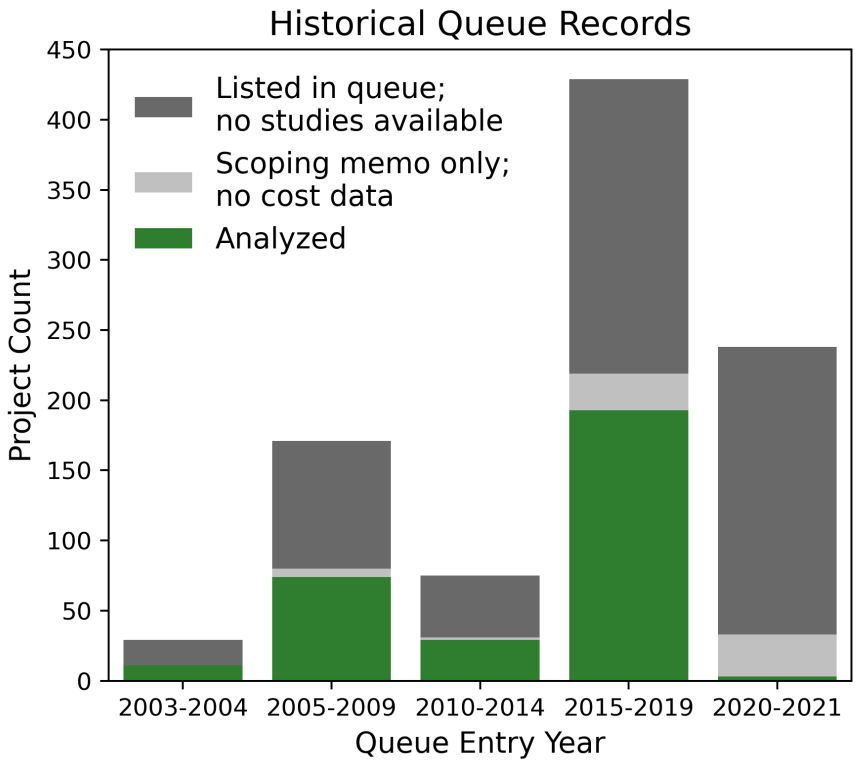
Interconnection queues have grown dramatically throughout the United States. In NYISO, the cumulative capacity of projects actively seeking interconnection more than doubled from 2019 through 2022 to equal more than three times the peak load. Based on project-level interconnection costs in NYISO from 2006 to 2021, our analysis finds:

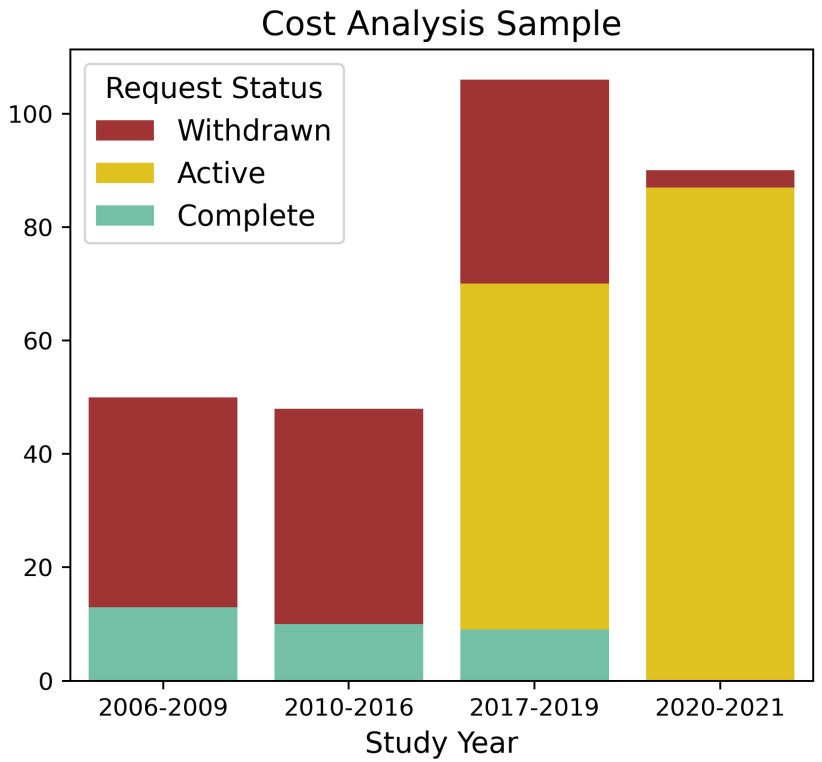
- **Project-specific interconnection costs can differ widely** depending on many variables and do not follow a normal distribution. For example, among in-service projects studied by NYISO since 2017, more than half cost less than $100/kW to interconnect, yet one project cost almost $1000/kW. All costs in this report are expressed in real $2022 terms based on a GDP deflator conversion.
- **Interconnection costs have grown**. Costs have doubled for projects studied since 2017 (mean: $86/kW to $167/kW, median: $66/kW to $115/kW) relative to costs for projects studied from 2006 to 2016. This increase in interconnection costs is especially pronounced for recent projects that are now in service ("complete") or have withdrawn from the queue ("withdrawn"), where costs have approximately tripled (complete – mean: $83/kW to $234/kW, median: $67/kW to $150/kW, withdrawn – mean: $87/kW to $241/kW, median: $66/kW to $129/kW) relative to historical projects. Projects still actively moving through the queue ("active") also have higher costs (mean: $145/kW, median: $108/kW) than historical projects (all of which have withdrawn from the queue or been completed).
- **Costs increased both at the point of interconnection (POI) and for broader network upgrades.** Interconnection costs for complete and active projects are evenly divided between POI and network categories, while withdrawn project costs are weighted towards POI facilities. The proportion of projects responsible for network upgrades increased from 73% of projects during 2006-2016 to 90% during 2017-2021.
- **Solar project interconnection costs are generally 8-18% higher than costs for other resources.** Further, one of the three complete solar projects is a high-cost outlier. There is not a consistent pattern in the relative costs of natural gas, onshore wind, offshore wind, or storage projects.
- **Larger generators have greater interconnection costs in absolute terms, but economies of scale exist on a per kW basis for solar and wind projects.** Specifically, average costs for small (<50 MW) and large (≥250 MW) solar projects are $224/kW and $70/kW, respectively, and the corresponding costs for small and large onshore wind projects are $264/kW and $45/kW. Natural gas and storage projects do not display a clear trend between project capacity and interconnection costs per kW.
- **Cost estimates increase as projects complete more studies in the interconnection process.** Costs for the same project increase by $30/kW on average from their system impact study to their facilities study, with costs at least doubling for more than a quarter of projects. Between the feasibility study and the system impact study, cost increases are usually more modest: $16/kW on average with a median change of 0%.

The cost sample analyzed here represents at least 43% of all new unique generation and storage resources requesting interconnection in NYISO from 2003-2019. Additionally, the sample includes three projects that entered the queue in 2020-2021. While interconnection studies can contain Critical Energy Infrastructure Information (CEII) and therefore are not publicly available, interconnection cost data are not CEII. We have posted project-level cost data from this analysis at https://emp.lbl.gov/interconnection_costs.

Projects analyzed represent ≥44% of all new unique generation and storage requesting interconnection in NYISO from 2003-2019

- 310 projects analyzed
- Reviewed all studies posted on ISO-NE website
- Required Critical Energy Infrastructure Information (CEII) access
- 430 hours of work to extract cost information from study PDFs
- 2020-21: Projects entering the queue in 2020 or later rarely had completed a study by May 2022





Interconnection Request Status Definitions

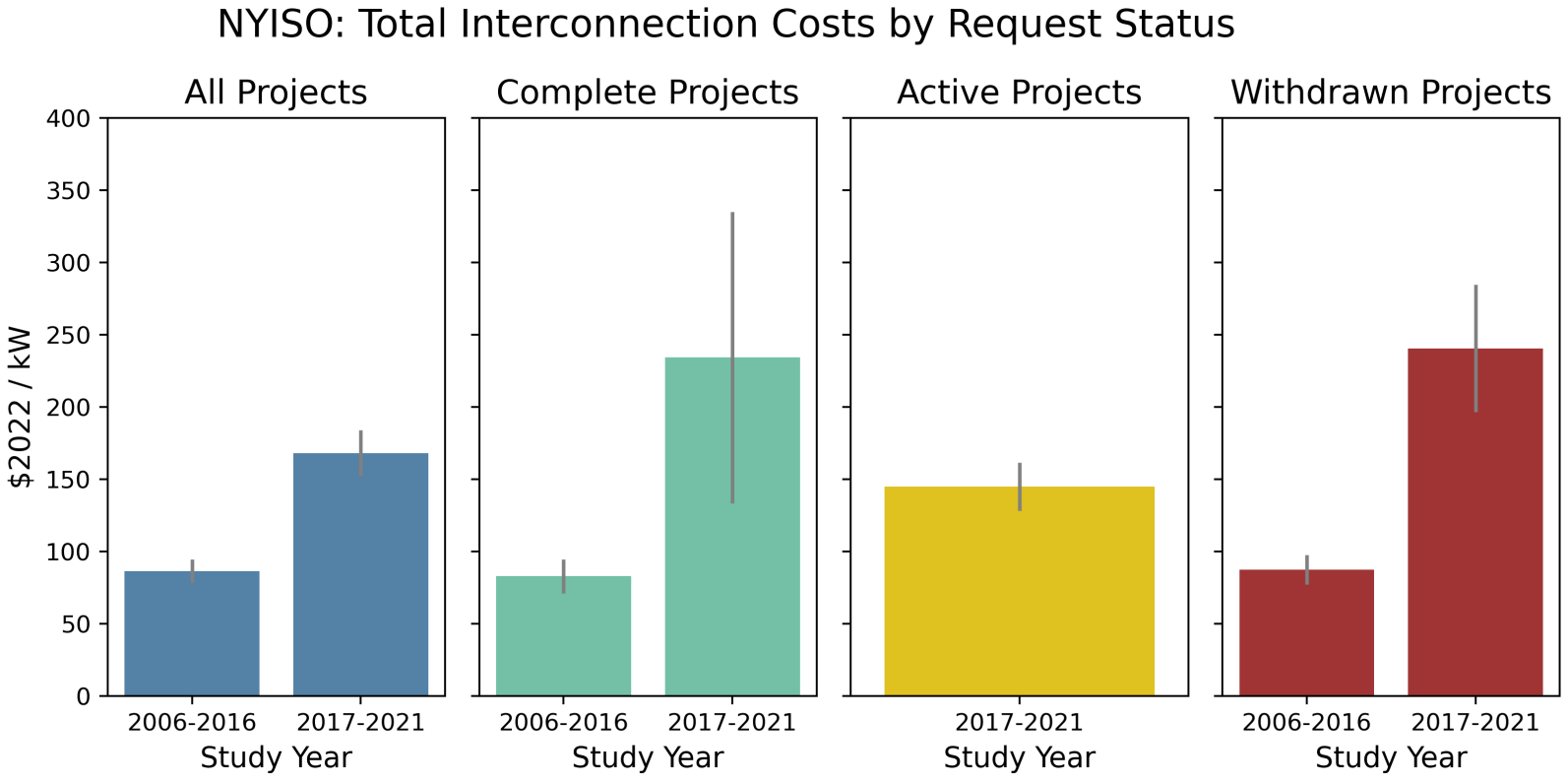
Complete: These projects are in service.

Active: These projects are actively working through the interconnection study process.

Withdrawn: These interconnection requests have been withdrawn (cancelled) from the queue.

Average interconnection costs have grown, but show some signs of slowing

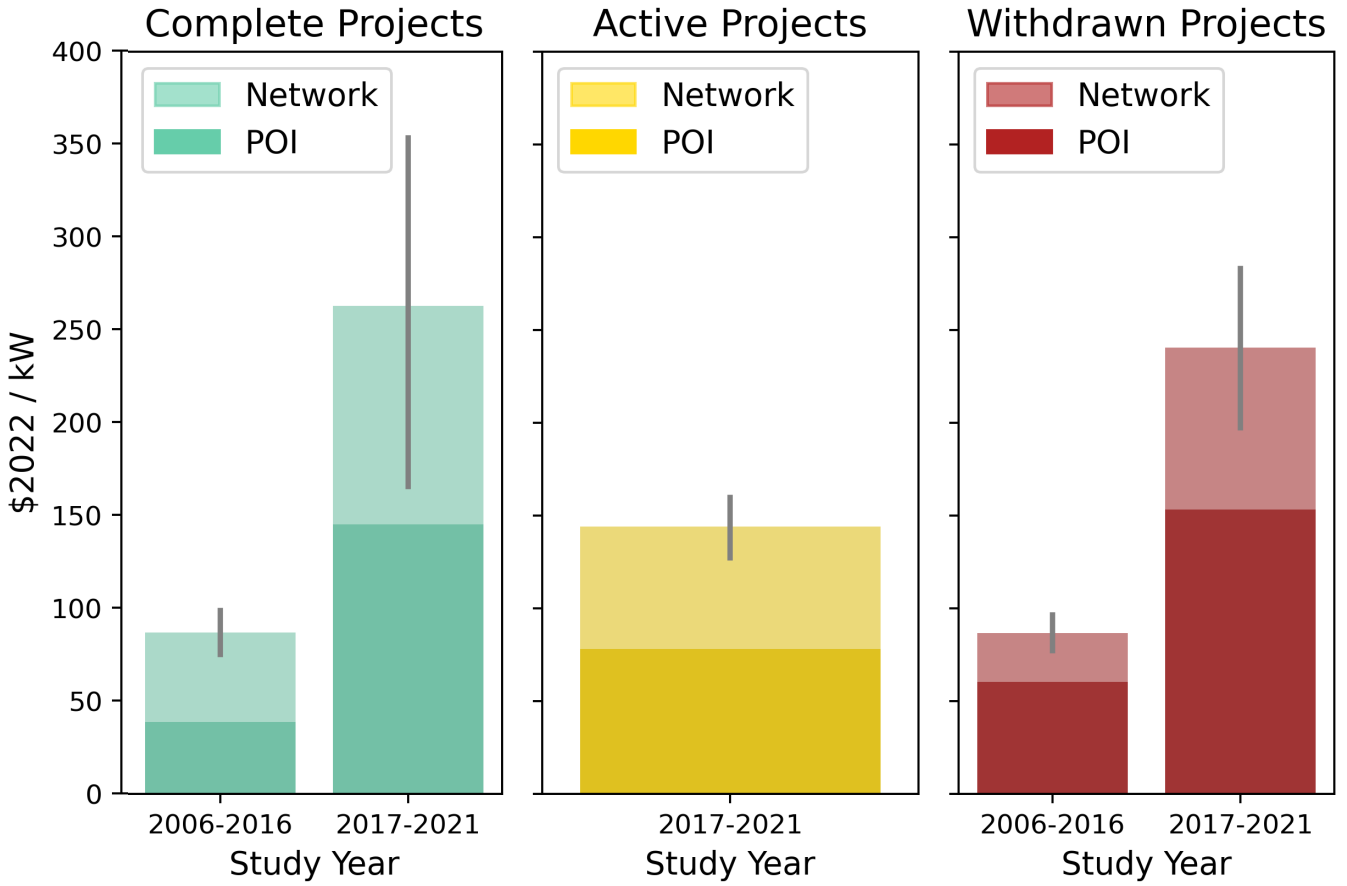
- Average costs have nearly doubled (to $167/kW) for projects studied in recent years relative to costs from projects last studied between 2006 and 2016 ($86/kW)
- Cost increase closer to 3x for complete and withdrawn projects
- Active projects have higher costs than historical projects, but lower costs than complete or withdrawn projects in the same time period
- Median costs also up and more high-cost outliers



	All Projects		Complete Projects		Active Projects	Withdrawn Projects	
Mean capacity	175 MW	144 MW	140 MW	181 MW	154 MW	186 MW	97 MW
Facilities Study	29%	21%	74%	100%	19%	15%	10%
Project count	98	196	23	9	148	75	39
Solar	2	106	1	2	80	1	24
Wind Onshore	70	31	15	3	20	55	8
Wind Offshore	2	8	0	0	8	2	0
Natural Gas	15	13	3	4	5	12	4
Storage	0	36	0	0	33	0	3
Other	9	2	4	0	2	5	0

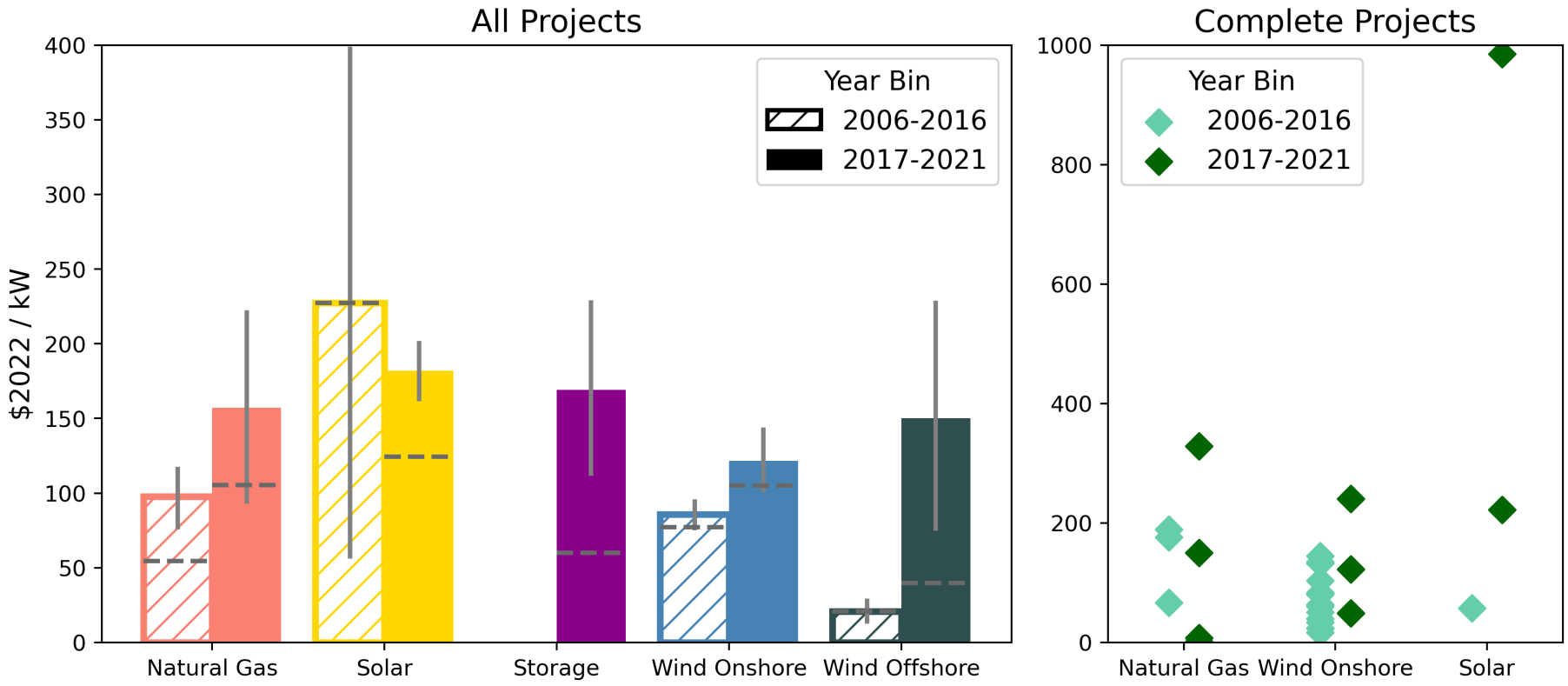
Broader network upgrades and point of interconnection investments both contribute to recent cost increases

- Divide total into 2 categories:
  1. Local interconnection facility costs describing investments at the point of interconnection (POI) with the broader transmission system
  2. Broader network upgrade costs
- **Complete** projects:
  - POI share of total grew from 40% to 48%
- **Active** projects:
  - 53% of costs are POI upgrades
- **Withdrawn** projects:
  - Weighted toward POI costs
  - But, network costs grew at a faster rate than POI costs, decreasing POI's share of the total from 69% to 62%



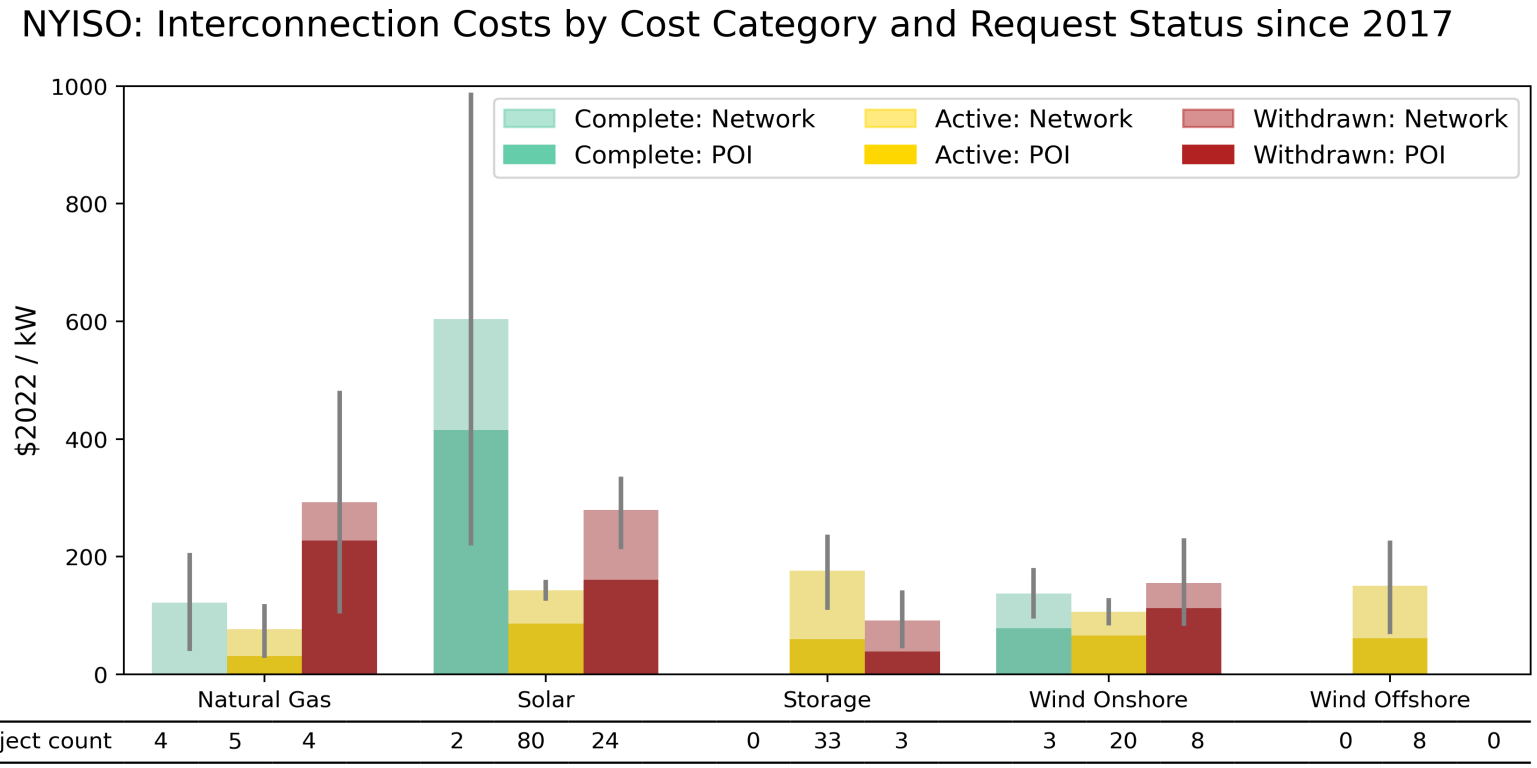
Solar project interconnection costs are generally at least 8-18% higher than costs for other resources

- Solar
  - Highest cost when considering means or medians
  - 1 of 3 complete solar projects is a high-cost outlier
- Other resource types – not consistently high or low cost



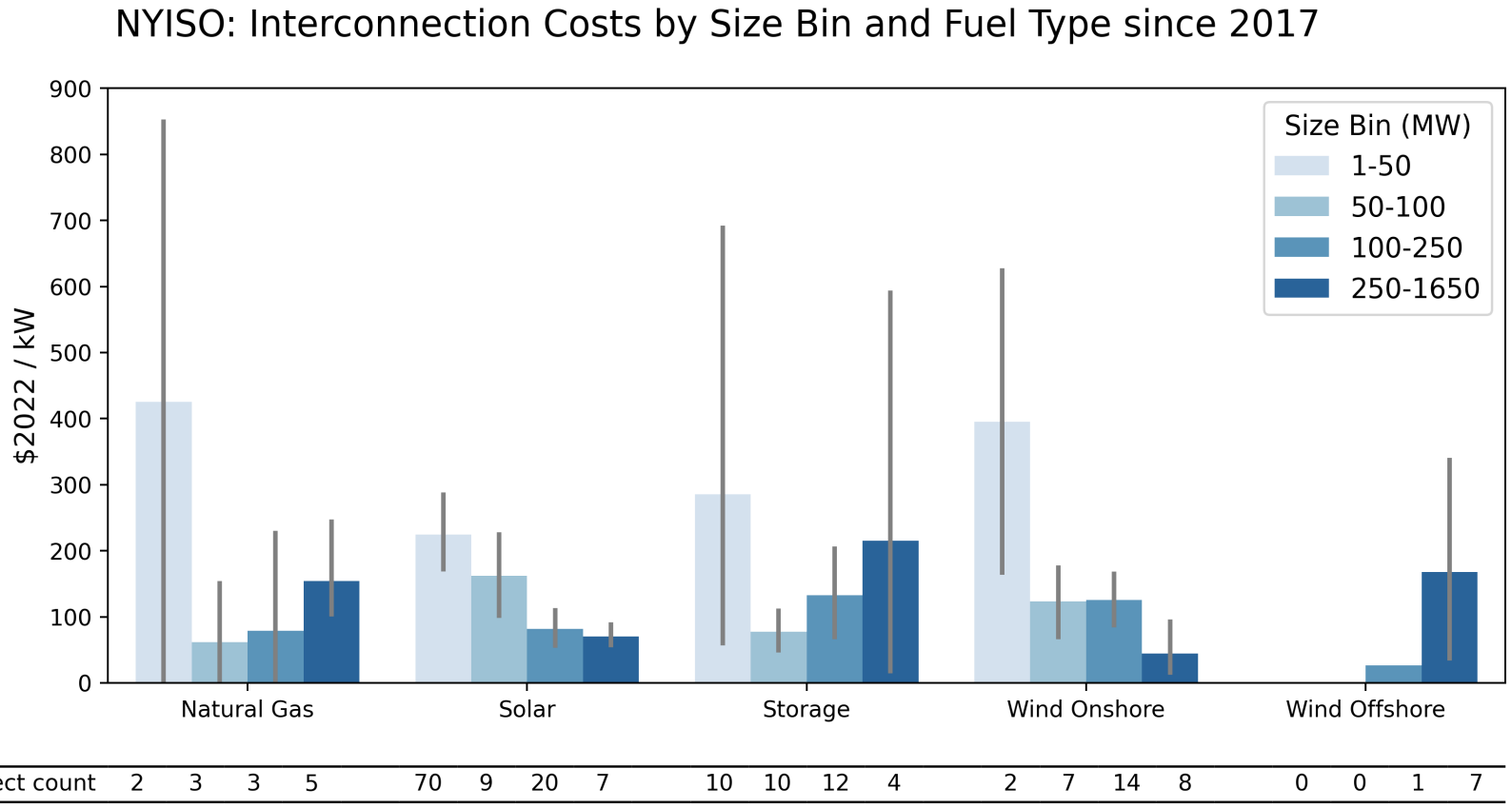
High interconnection costs likely play a role in withdrawal decisions for natural gas and solar projects

- **Natural gas** projects that withdraw see higher interconnection costs than those that are complete or still active
- **Solar** projects that withdrew cost more to interconnect than those that are still active
  - 2 complete projects have wide range
- **Storage** projects experience the highest average network costs among active projects, despite most being located near load centers
- **Onshore wind** withdrawal decisions do not appear driven by interconnection costs



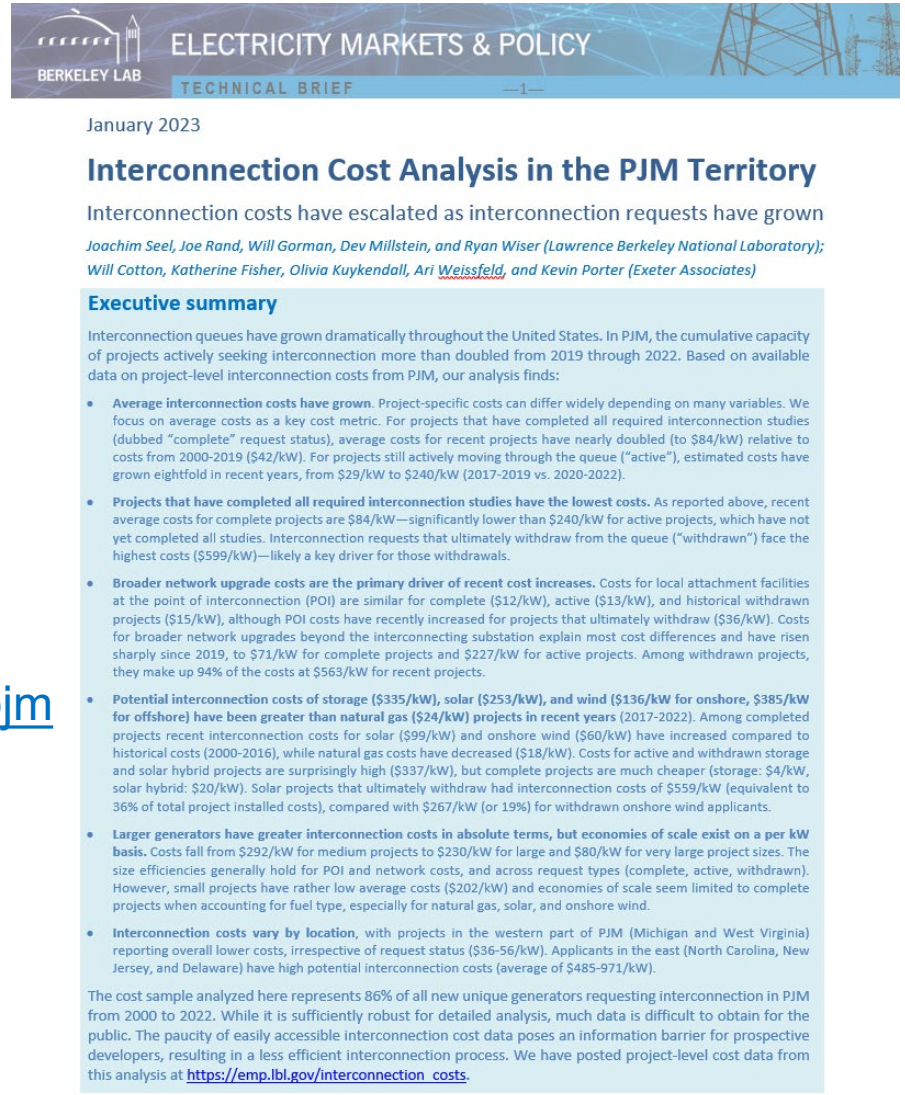
Economies of scale exist on a per kW basis for solar and onshore wind projects

- Larger projects have greater interconnection costs
- On a per-kW capacity basis, some resources show economies of scale, while others do not
- **Solar** costs fall from an average of $224/kW for small projects (1-50 MW) to $70/kW for the largest projects (250-1650 MW)
- **Onshore wind** costs fall from an average of $396/kW for small projects (1-50 MW) to $45/kW for the largest projects (250-1650 MW)



PJM

See Briefing and Data at:
https://emp.lbl.gov/publications/interconnection-cost-analysis-pjm



BERKELEY LAB ELECTRICITY MARKETS & POLICY
TECHNICAL BRIEF —1—

January 2023

Interconnection Cost Analysis in the PJM Territory

Interconnection costs have escalated as interconnection requests have grown

Joachim Seel, Joe Rand, Will Gorman, Dev Millstein, and Ryan Wiser (Lawrence Berkeley National Laboratory); Will Cotton, Katherine Fisher, Olivia Kuykendall, Ari Weissfeld, and Kevin Porter (Exeter Associates)

Executive summary

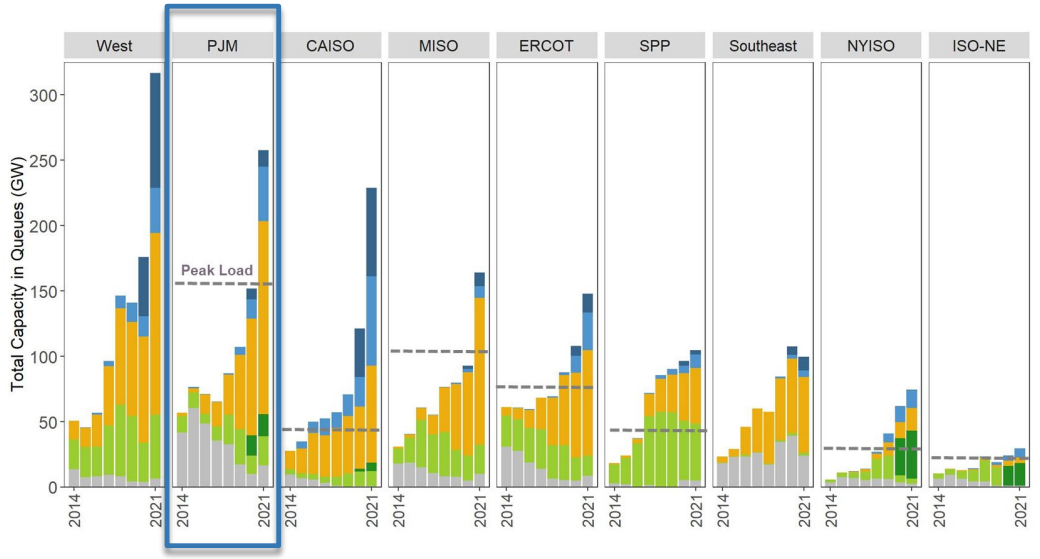
Interconnection queues have grown dramatically throughout the United States. In PJM, the cumulative capacity of projects actively seeking interconnection more than doubled from 2019 through 2022. Based on available data on project-level interconnection costs from PJM, our analysis finds:

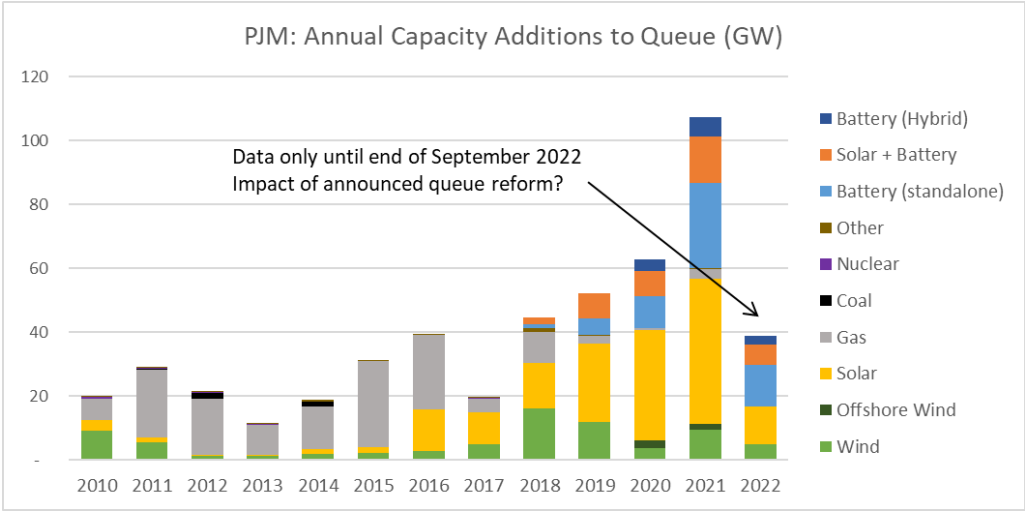
- **Average interconnection costs have grown**. Project-specific costs can differ widely depending on many variables. We focus on average costs as a key cost metric. For projects that have completed all required interconnection studies (dubbed "complete" request status), average costs for recent projects have nearly doubled (to $84/kW) relative to costs from 2000-2019 ($42/kW). For projects still actively moving through the queue ("active"), estimated costs have grown eightfold in recent years, from $29/kW to $240/kW (2017-2019 vs. 2020-2022).
- **Projects that have completed all required interconnection studies have the lowest costs.** As reported above, recent average costs for complete projects are $84/kW—significantly lower than $240/kW for active projects, which have not yet completed all studies. Interconnection requests that ultimately withdraw from the queue ("withdrawn") face the highest costs ($599/kW)—likely a key driver for those withdrawals.
- **Broader network upgrade costs are the primary driver of recent cost increases.** Costs for local attachment facilities at the point of interconnection (POI) are similar for complete ($12/kW), active ($13/kW), and historical withdrawn projects ($15/kW), although POI costs have recently increased for projects that ultimately withdraw ($36/kW). Costs for broader network upgrades beyond the interconnecting substation explain most cost differences and have risen sharply since 2019, to $71/kW for complete projects and $227/kW for active projects. Among withdrawn projects, they make up 94% of the costs at $563/kW for recent projects.
- **Potential interconnection costs of storage ($335/kW), solar ($253/kW), and wind ($136/kW for onshore, $385/kW for offshore) have been greater than natural gas ($24/kW) projects in recent years** (2017-2022). Among completed projects recent interconnection costs for solar ($99/kW) and onshore wind ($60/kW) have increased compared to historical costs (2000-2016), while natural gas costs have decreased ($18/kW). Costs for active and withdrawn storage and solar hybrid projects are surprisingly high ($337/kW), but complete projects are much cheaper (storage: $4/kW, solar hybrid: $20/kW). Solar projects that ultimately withdraw had interconnection costs of $559/kW (equivalent to 36% of total project installed costs), compared with $267/kW (or 19%) for withdrawn onshore wind applicants.
- **Larger generators have greater interconnection costs in absolute terms, but economies of scale exist on a per kW basis.** Costs fall from $292/kW for medium projects to $230/kW for large and $80/kW for very large project sizes. The size efficiencies generally hold for POI and network costs, and across request types (complete, active, withdrawn). However, small projects have rather low average costs ($202/kW) and economies of scale seem limited to complete projects when accounting for fuel type, especially for natural gas, solar, and onshore wind.
- **Interconnection costs vary by location**, with projects in the western part of PJM (Michigan and West Virginia) reporting overall lower costs, irrespective of request status ($36-56/kW). Applicants in the east (North Carolina, New Jersey, and Delaware) have high potential interconnection costs (average of $485-971/kW).

The cost sample analyzed here represents 86% of all new unique generators requesting interconnection in PJM from 2000 to 2022. While it is sufficiently robust for detailed analysis, much data is difficult to obtain for the public. The paucity of easily accessible interconnection cost data poses an information barrier for prospective developers, resulting in a less efficient interconnection process. We have posted project-level cost data from this analysis at https://emp.lbl.gov/interconnection_costs.

Background: PJM's interconnection queue paused after record growth

- PJM Queue at end of 2021:
  - 259 gigawatts (GW) of project capacity actively seeking grid interconnection
  - Dominated by solar (116 GW), standalone storage (42GW), solar hybrids (32 GW) and wind (39 GW) energy capacity
  - Additional 432 GW of "withdrawn" projects and 79 GW of "in service" projects
- PJM's 2022 Generator Interconnection Queue:
  - Saw fewer new applications during process reform discussions
  - Working through backlog:
    - Fast lane till fall 2024 (no network upgrades required)
    - 2 transition cycles in 2024 and 2025
    - Review of new applications Nov 2025 – summer 2027
- PJM 2022 interconnection process reforms:
  - Aim to have review cycle taking ~ 2 years
  - shifted from a "first-come, first-served" serial approach to a "first-ready, first-served" cluster study approach
  - new milestones to demonstrate project readiness, requirements for project site control, and at-risk deposits in case of withdrawal



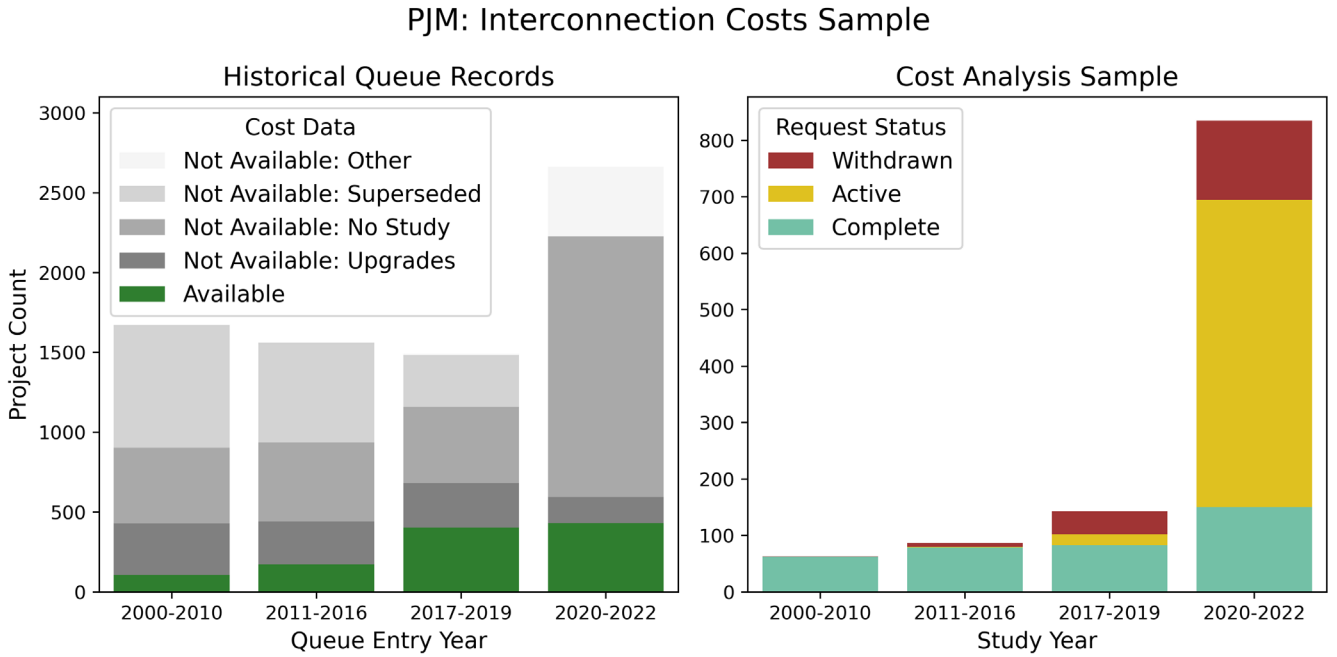


Cost sample represents 86% of projects requesting interconnection since 2000

- Interconnection costs sample of 1127 projects
  - 86% sample coverage 2000-2022 after:
    - Excluding upgrades to existing facilities
    - Excluding projects without at least feasibility study
    - Excluding superseded projects
  - Focus: 2017-2022 (robust data for all request status)

- Sources:
  - All cost data available online in the PJM system as of July 2022 (1073 projects).
  - Augmented with previously collected data of complete projects (55 projects)

- Methods:
  - Cost data were collected manually from public interconnection study reports.
  - Interconnection costs in real $2022-terms based on a GDP deflator conversion (assuming nominal dollars as of the time of the interconnection study)
  - Presenting simple means



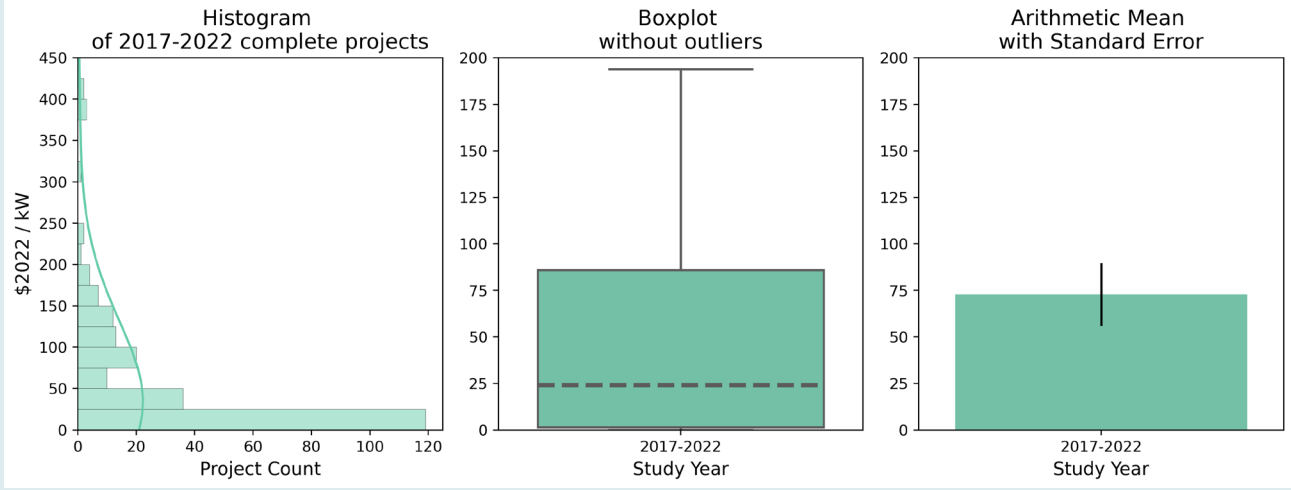
Interconnection Request Status Definitions

Complete: These projects have completed all of the interconnection studies, and have moved on to (or completed) the interconnection agreement phase. Includes plants that are now in service.

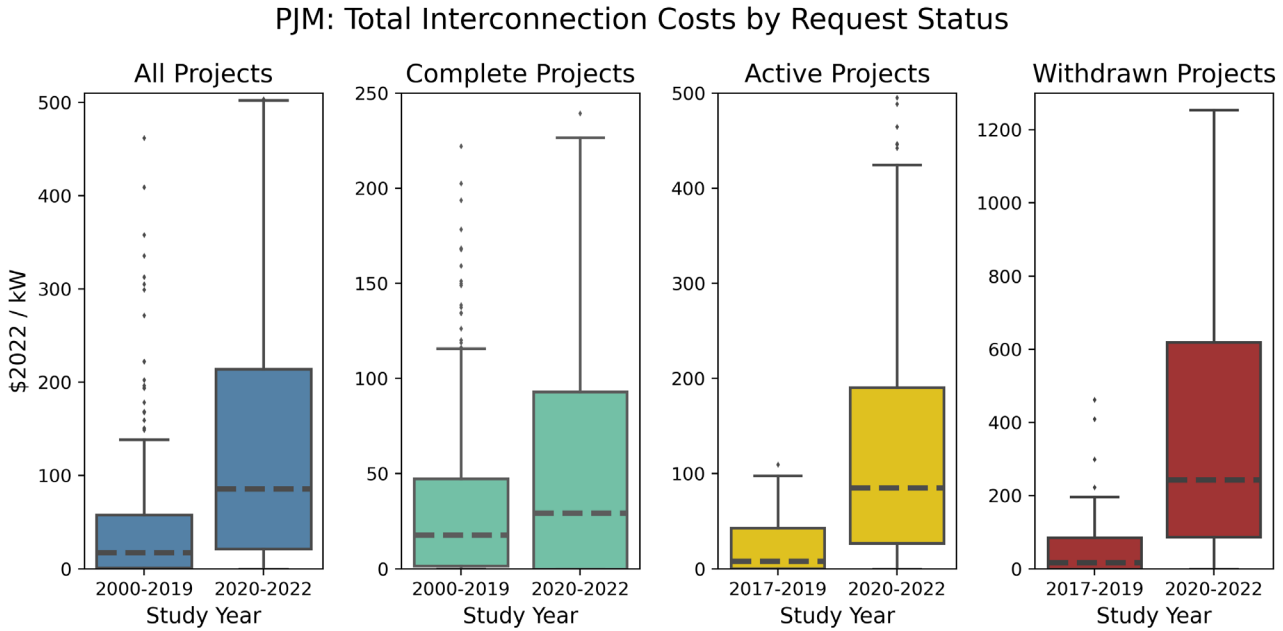
Active: These projects are actively working through the interconnection study process.

Withdrawn: These interconnection requests have been withdrawn (cancelled) from the queue.

Trend of increasing cost holds when looking at overall project distribution



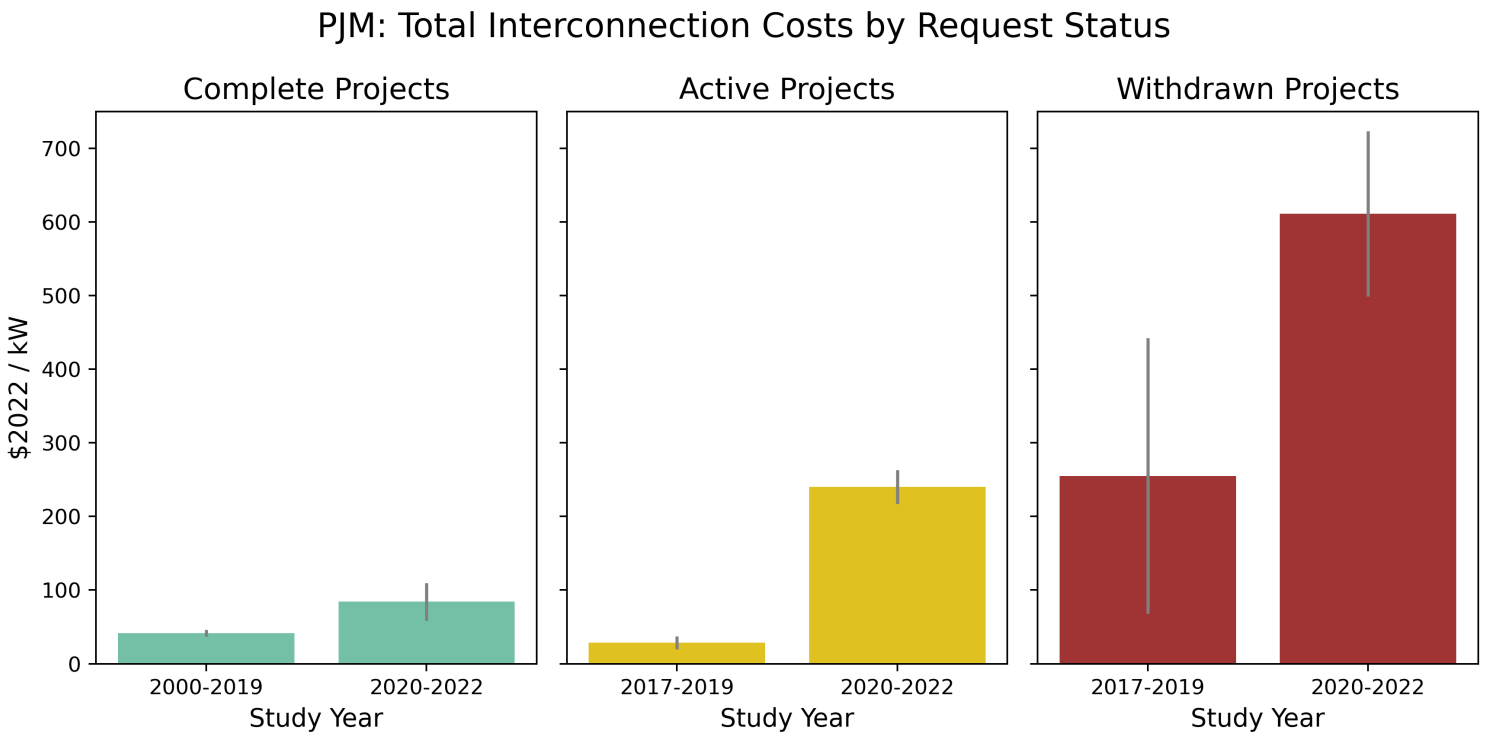
- Cost data do not have normal distribution:
  - Many projects with very low interconnection costs
  - Some projects with very high interconnection costs that influence sample mean



- Most trends presented today also hold when looking at typical (median) projects:
  - For example median total interconnection costs have also risen over time for each respective request status

Average interconnection costs have grown substantially over time

Interconnection costs increase in our sample after 2000, nearly quadrupling from $72/kW across the early years (2000-2019) to $275/kW (2020-2022).



By Interconnection Request Status

- **Complete:**
  - Costs double from $42/kW prior to 2020 to $84/kW between 2021 and 2022.
- **Active:**
  - Cost increase 8x from $29 to $240/kW (2017-2019 vs. 2020-2022).
- **Withdrawn:**
  - Cost more than double from $255 to $612/kW (2017-2019 vs. 2020-2022).
  - Nearly five times the costs of “complete” projects over the past five years ($531/kW vs. $73/kW).

Broader network upgrade costs are the primary driver of recent cost increases and dominate among withdrawn projects

By Interconnection Request Status

- **Complete:**
  - Local upgrades at POI are very modest in PJM (2017-2022: $12/kW) and have fallen a bit since early 2000s.
  - Network upgrade costs can cause large cost additions for some projects, recently growing (from $42 to $71/kW).
- **Active:**
  - Similar POI costs (2017-2022: $13/kW).
  - Greater network costs, rising strongly over the past few years (from $15 to $227/kW).
- **Withdrawn:**
  - Historically similar POI costs (2017-2019: $15/kW) but growing recently (2020-2022: $36/kW).
  - Network upgrades are commonly much larger and have grown in recent years (from $240 to $563/kW). The top 10% of network upgrade costs range between $928 and $10,164/kW.

Interconnection Cost Components

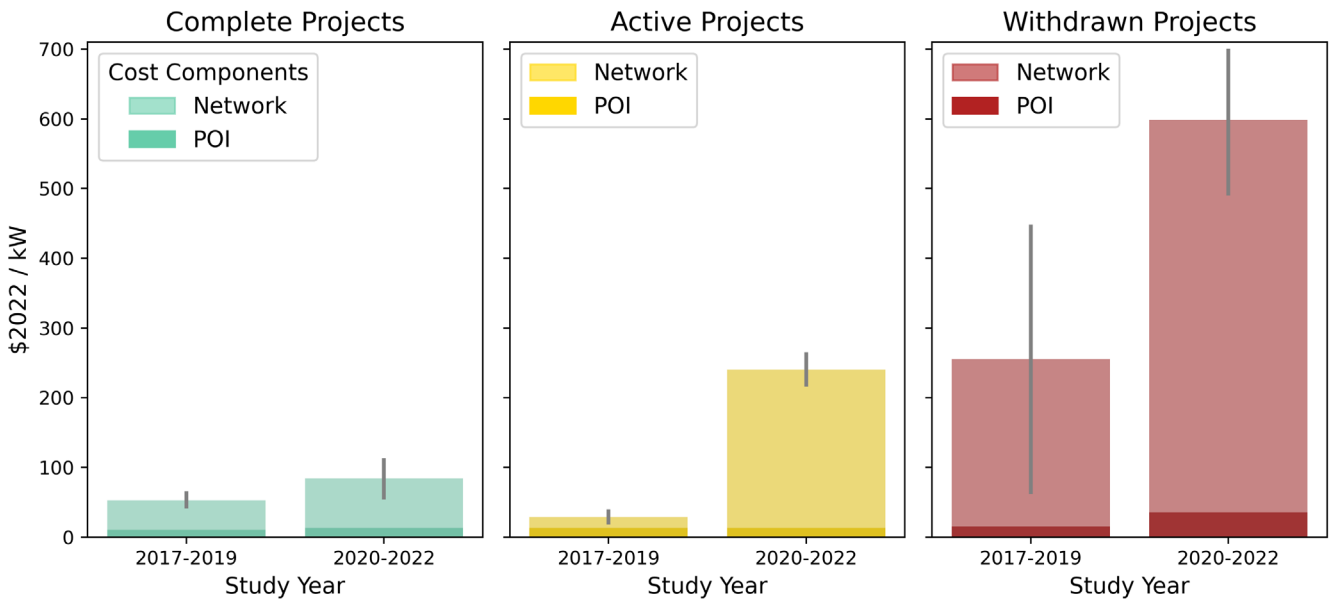
Point of Interconnection (POI) or Interconnection Facilities Costs:

- Interconnection station and transmission line extensions, referred to as "Attachment Facilities" in the interconnection studies. Often excludes other infrastructure (step-up transformer, spur lines…)

Network Costs:

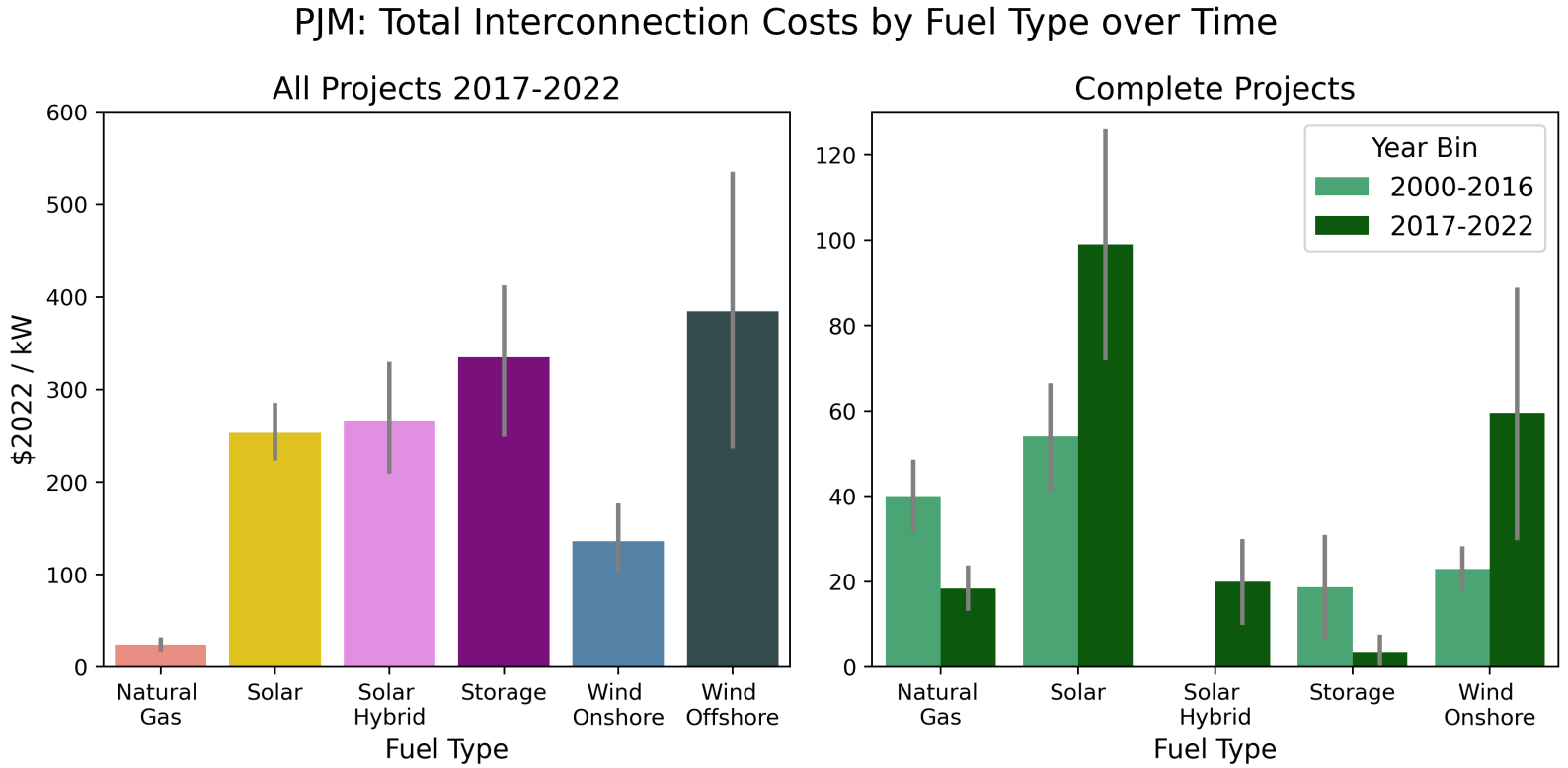
- Network Upgrade Charges ("Direct Connection Facilities", "Total Direct Connect Costs", "Direct Connection Network Upgrades", "Total Non-Direct Connection Costs", "Network Upgrade Facilities", "Non Direct Connection Facilities", "Non Direct Connection Network Upgrades")
- Other Network Costs ("Non-Direct Local Network Upgrades", "Allocation for New System Upgrades" (or System Network Upgrades, SNU), "Contribution for previously Identified Upgrades", and "Other Charges").

PJM: Interconnection Costs by Request Status and Cost Category



Interconnection costs for wind, storage, and solar are larger than for natural gas

Offshore Wind ($385/kW), **storage** ($335/kW), **solar hybrid** ($267/kW), **solar** ($253/kW), and **onshore wind** ($136/kW) costs are greater than **natural gas** interconnection costs ($129/kW) when looking at recent applicants, irrespective of their request status.



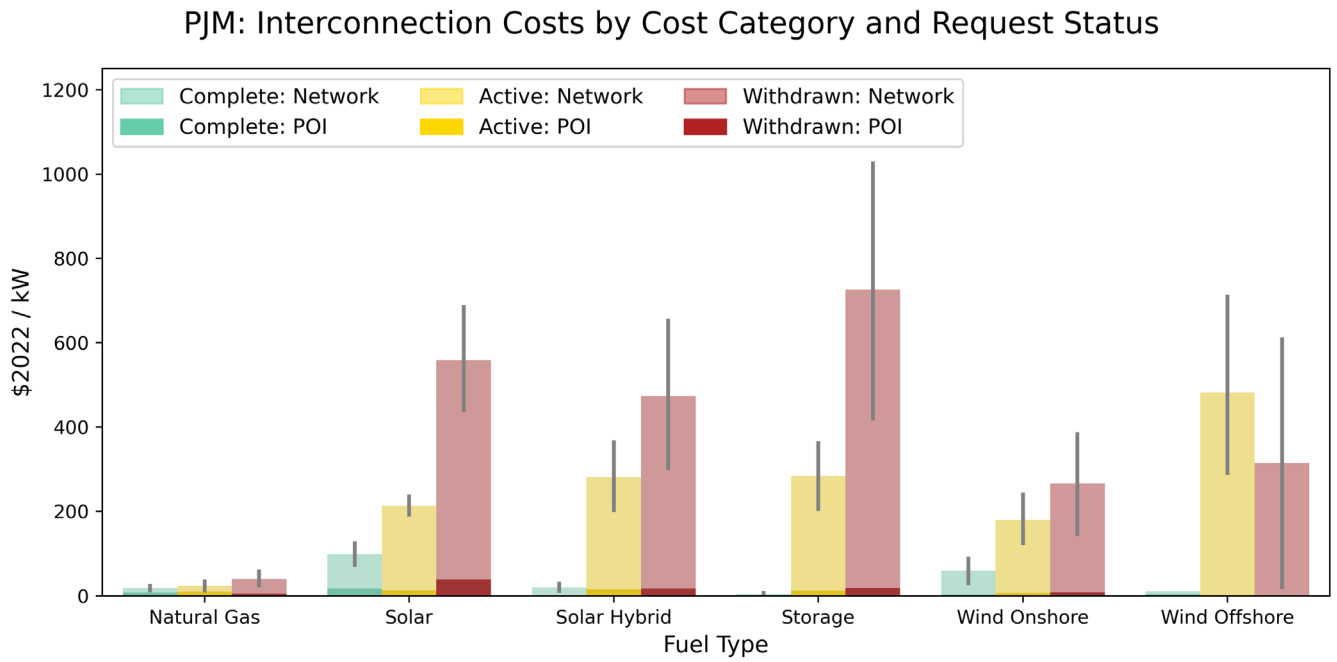
Longest time record for **complete** projects:

- Looking at projects studied before and after 2016 we find that:
  - Natural gas costs fall ($40 to $18/kW)
  - Solar cost grow ($54 to $99/kW)
  - Onshore wind cost rise ($23 to $60/kW)
  - Small complete storage/hybrid sample, but costs seem much lower than across all potential projects.

Network costs cause increase in interconnection expenses for renewables, especially for active and withdrawn projects

- POI costs don't vary much, except for rather low costs for complete wind projects ($3/kW) and unusually high costs for withdrawn solar projects ($39/kW).

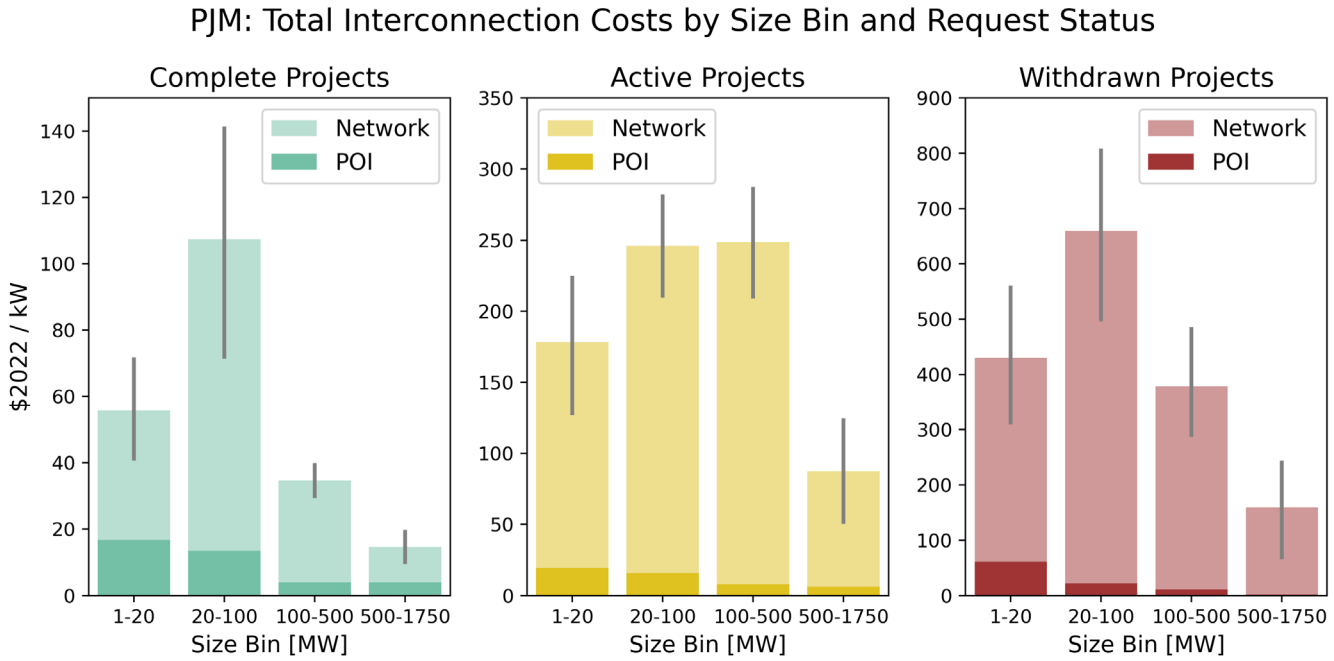
- Network costs increase dramatically for **active** and **withdrawn** projects.
  - Storage and solar hybrid network costs are negligible for complete projects but prohibitive for withdrawn projects (storage: $709/kW, solar hybrid: $457/kW)
  - Solar and wind projects bear some network costs for complete projects, but those costs rise for active and withdrawn projects
    - Solar: $82/kW vs. $520/kW
    - Onshore wind: $56/kW vs. $258/kW



- PJM interconnection costs represent modest share of overall project costs for those that have completed all studies, but are a development hurdle for those that withdraw:
  - **Onshore Wind:** Complete projects: 4% of total project capex, withdrawn projects: 19%.
  - **Solar**: Complete projects: 7% of total project capex, withdrawn projects: 38%

Larger generators have lower interconnection costs per kW

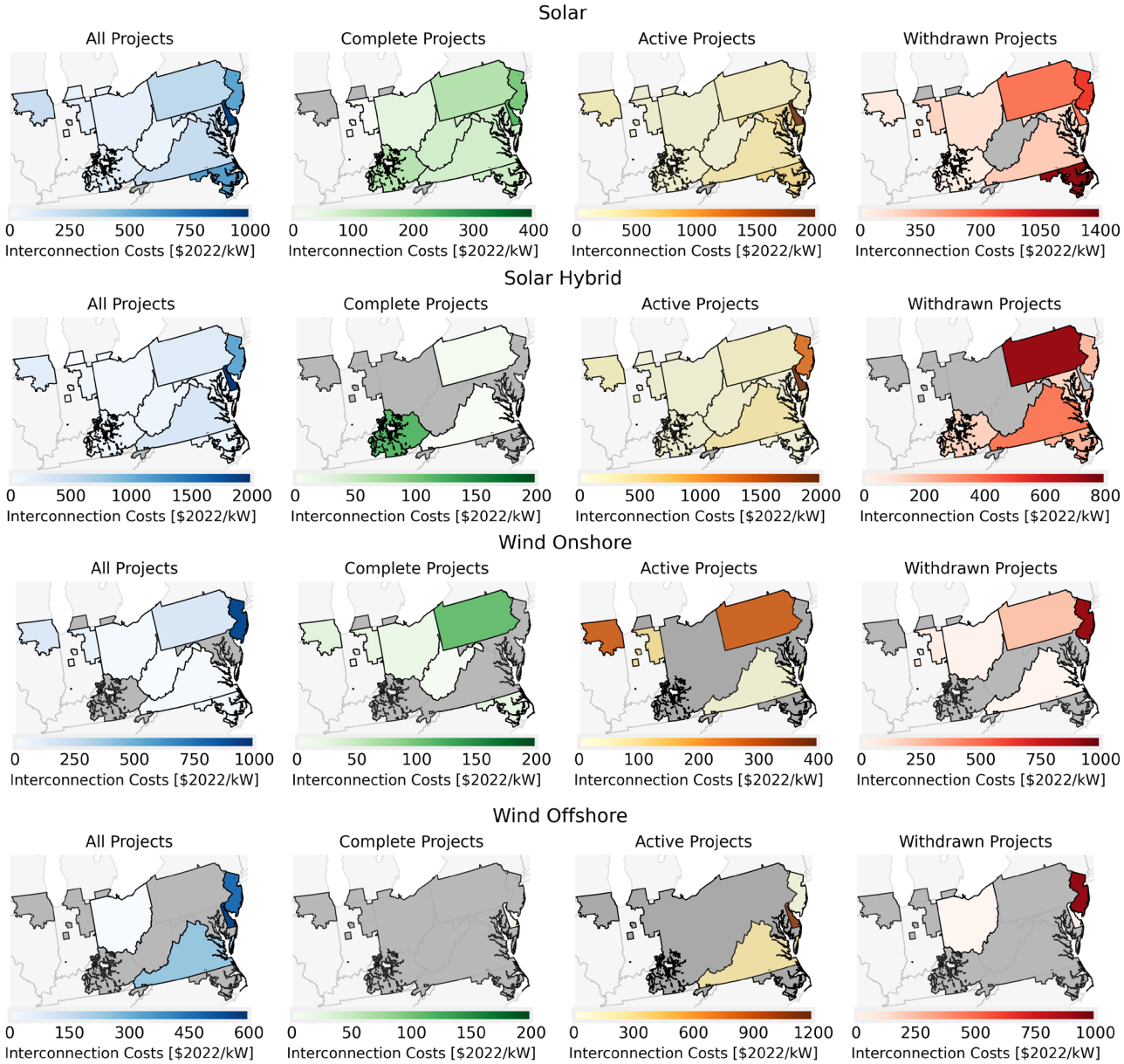
Projects with larger nameplate capacity have greater interconnection costs in absolute terms, but these costs do not scale linearly on a per kW basis, falling from $292/kW (medium), $230/kW (large), and $80/kW (very large project size).



- Economies of scale are present for POI and network costs, and across requests status.
- Among our long time series of completed projects we find that larger projects have consistently lower interconnection costs than smaller projects on a per kW basis.
- No consistent economies of scale across all fuels. Only among complete projects do we see some evidence for natural gas, solar and onshore wind:

Fuel	1-20MW	200-100MW	100-500MW	500-1750MW
Natural Gas	$30/kW		$15/kW	$15/kW
Solar	$81/kW	$123/kW	$45/kW	$14/kW
Onshore Wind	$712/kW	$37/kW	$24/kW	

Interconnection costs tend to be higher in the eastern parts of PJM



- Across all projects 2017-2022:
  - Western projects in Michigan ($36/kW) and West Virginia ($58/kW) reporting overall lower costs than eastern applicants in North Carolina, New Jersey, and Delaware ($485-971/kW).
  - Some alignment of higher high costs with little available transmission capacity and/or high levels of congestion in the east (e.g. higher zonal capacity prices).

- By fuel type:
  - Again, higher interconnection costs in the east for solar, solar hybrid, and storage.
  - Onshore wind has higher costs in the north (New Jersey, Pennsylvania, and Illinois) than in the south.
  - Offshore wind has higher costs in the east (Delaware, New Jersey, and Virginia) than Ohio.
  - Natural gas projects skew a bit differently, with higher costs both in the north (New Jersey, Ohio, and Pennsylvania) and south (Virginia).

Most generators request capacity (NRIS) interconnection services at higher costs

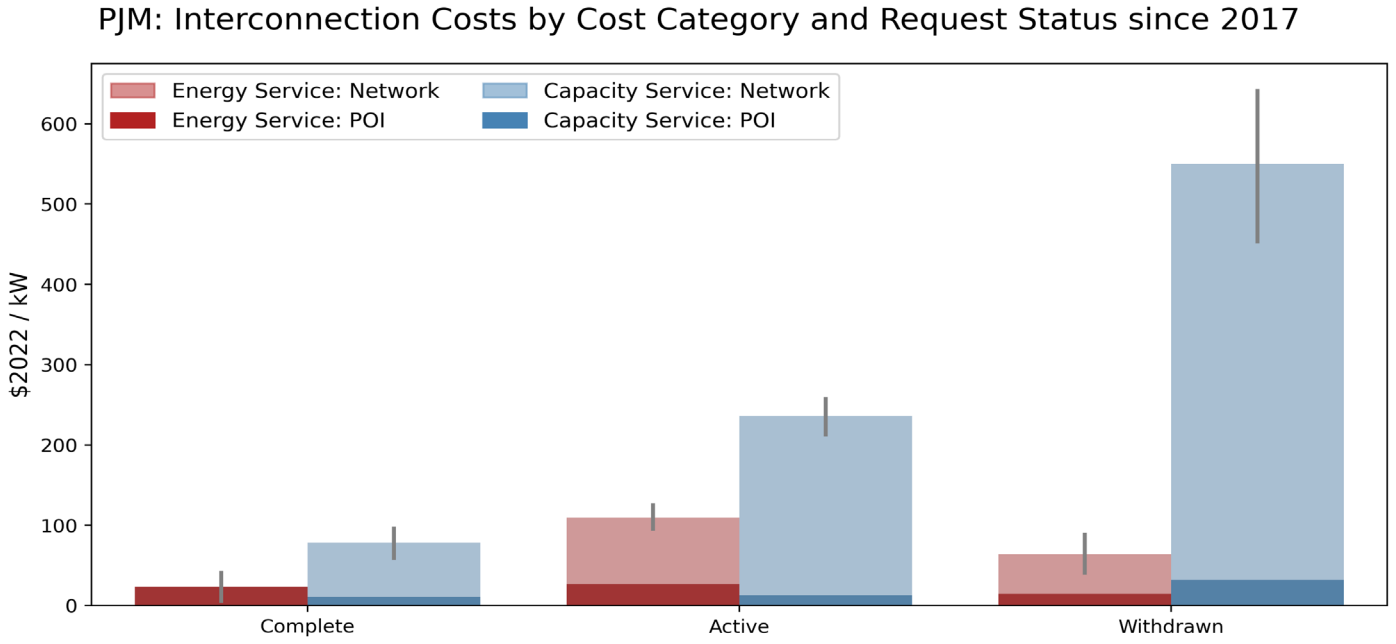
Interconnection Service Definitions

Capacity (Network resource interconnection service, NRIS): Transmission capacity reservation during high load hours, needed for bidding into resource adequacy markets. May need to pay for additional transmission upgrades.

Energy (Energy resource interconnection service, ERIS): Less preferential treatment, may be curtailed before capacity resources during emergency events.

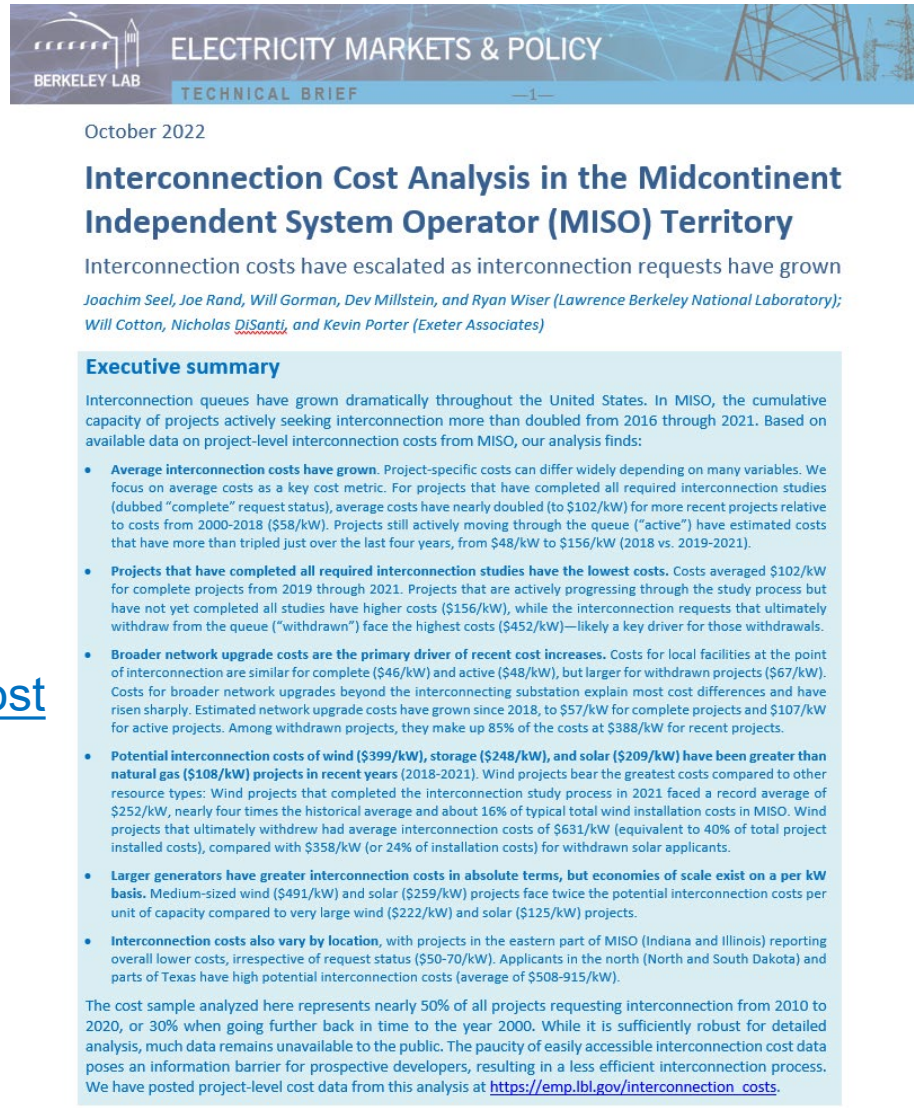
- POI costs don't differ much between service types
- Network costs for projects with capacity service have risen more than tenfold since 2017 (from $17/kW to $206/kW)
  - Complete capacity projects pay $67/kW network costs (energy: none!).
  - Active capacity network: $223/kW (energy: $83/kW)
  - Withdrawn capacity network: $518/kW (energy $49/kW)

- Nearly all generators choose capacity service (2017-2022: 95% of all projects)
  - Most renewable projects opt for the capacity status (wind offshore: 100%, solar: 99%, wind onshore: 98%)
  - Natural gas (95%) and storage (92%) stand-alone installations have slightly lower rates, as do solar hybrid projects (76%).



MISO

See Briefing and Data at:
https://emp.lbl.gov/publications/generator-interconnection-cost



BERKELEY LAB ELECTRICITY MARKETS & POLICY
TECHNICAL BRIEF —1—

October 2022

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Interconnection costs have escalated as interconnection requests have grown

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Executive summary

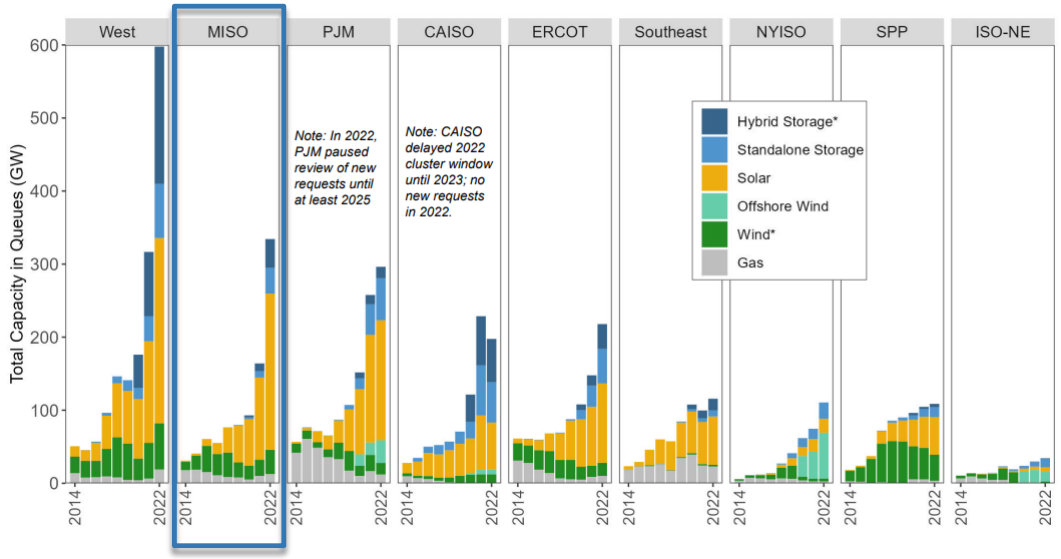
Interconnection queues have grown dramatically throughout the United States. In MISO, the cumulative capacity of projects actively seeking interconnection more than doubled from 2016 through 2021. Based on available data on project-level interconnection costs from MISO, our analysis finds:

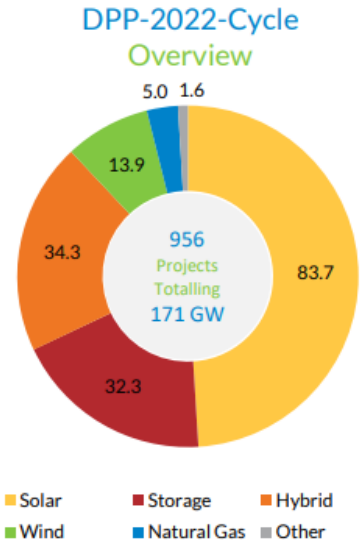
- **Average interconnection costs have grown**. Project-specific costs can differ widely depending on many variables. We focus on average costs as a key cost metric. For projects that have completed all required interconnection studies (dubbed "complete" request status), average costs have nearly doubled (to $102/kW) for more recent projects relative to costs from 2000-2018 ($58/kW). Projects still actively moving through the queue ("active") have estimated costs that have more than tripled just over the last four years, from $48/kW to $156/kW (2018 vs. 2019-2021).
- **Projects that have completed all required interconnection studies have the lowest costs.** Costs averaged $102/kW for complete projects from 2019 through 2021. Projects that are actively progressing through the study process but have not yet completed all studies have higher costs ($156/kW), while the interconnection requests that ultimately withdraw from the queue ("withdrawn") face the highest costs ($452/kW)—likely a key driver for those withdrawals.
- **Broader network upgrade costs are the primary driver of recent cost increases.** Costs for local facilities at the point of interconnection are similar for complete ($46/kW) and active ($48/kW), but larger for withdrawn projects ($67/kW). Costs for broader network upgrades beyond the interconnecting substation explain most cost differences and have risen sharply. Estimated network upgrade costs have grown since 2018, to $57/kW for complete projects and $107/kW for active projects. Among withdrawn projects, they make up 85% of the costs at $388/kW for recent projects.
- **Potential interconnection costs of wind ($399/kW), storage ($248/kW), and solar ($209/kW) have been greater than natural gas ($108/kW) projects in recent years** (2018-2021). Wind projects bear the greatest costs compared to other resource types: Wind projects that completed the interconnection study process in 2021 faced a record average of $252/kW, nearly four times the historical average and about 16% of typical total wind installation costs in MISO. Wind projects that ultimately withdrew had average interconnection costs of $631/kW (equivalent to 40% of total project installed costs), compared with $358/kW (or 24% of installation costs) for withdrawn solar applicants.
- **Larger generators have greater interconnection costs in absolute terms, but economies of scale exist on a per kW basis.** Medium-sized wind ($491/kW) and solar ($259/kW) projects face twice the potential interconnection costs per unit of capacity compared to very large wind ($222/kW) and solar ($125/kW) projects.
- **Interconnection costs also vary by location**, with projects in the eastern part of MISO (Indiana and Illinois) reporting overall lower costs, irrespective of request status ($50-70/kW). Applicants in the north (North and South Dakota) and parts of Texas have high potential interconnection costs (average of $508-915/kW).

The cost sample analyzed here represents nearly 50% of all projects requesting interconnection from 2010 to 2020, or 30% when going further back in time to the year 2000. While it is sufficiently robust for detailed analysis, much data remains unavailable to the public. The paucity of easily accessible interconnection cost data poses an information barrier for prospective developers, resulting in a less efficient interconnection process. We have posted project-level cost data from this analysis at https://emp.lbl.gov/interconnection_costs.

Background: MISO's interconnection queue doubled in capacity in the last year

- MISO Queue at end of 2022:
  - Over 340 gigawatts (GW) of project capacity actively seeking grid interconnection
  - Dominated by solar (210 GW) and storage (75 GW) energy
  - Additional 373 GW of "withdrawn" projects and 66 GW of "in service" projects
- MISO's 2022 Generator Interconnection Queue:
  - broke again all records, increasing by 220% over 2021 levels
  - 95% zero-carbon resources
- MISO has implemented numerous interconnection process reforms since 2008
  - shifted from a "first-come, first-served" serial approach to a "first-ready, first-served" cluster study approach
  - MISO introduced new milestones to demonstrate project readiness, requirements for project site control
  - Announced $10 billion new investments into bulk transmission system to integrate more renewables





Background: MISO's interconnection queue doubled in capacity over the past few years

- MISO Queue at end of 2021:
  - Over 160 gigawatts (GW) of project capacity actively seeking grid interconnection
  - Dominated by solar (112 GW) and wind (22 GW) energy capacity
  - Additional 373 GW of "withdrawn" projects and 66 GW of "in service" projects
- MISO's 2022 Generator Interconnection Queue:
  - broke again all records, increasing by 220% over 2021 levels
  - Active MISO queue may balloon to 289GW, more than 95% of which are either renewable or storage
- MISO has implemented numerous interconnection process reforms since 2008
  - shifted from a "first-come, first-served" serial approach to a "first-ready, first-served" cluster study approach
  - MISO introduced new milestones to demonstrate project readiness, requirements for project site control
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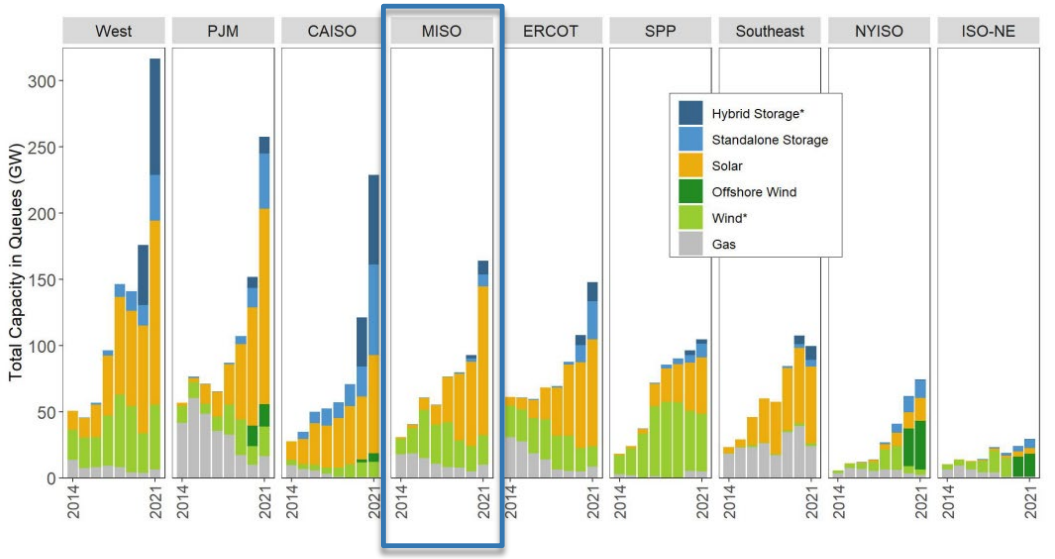
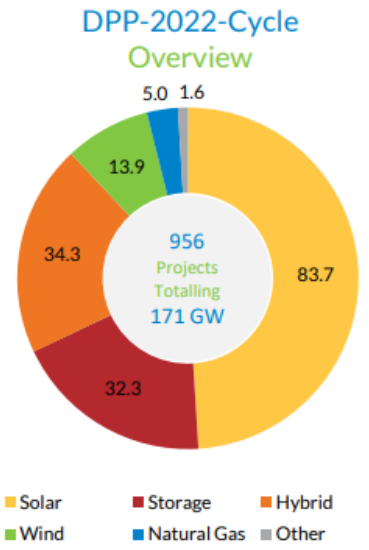
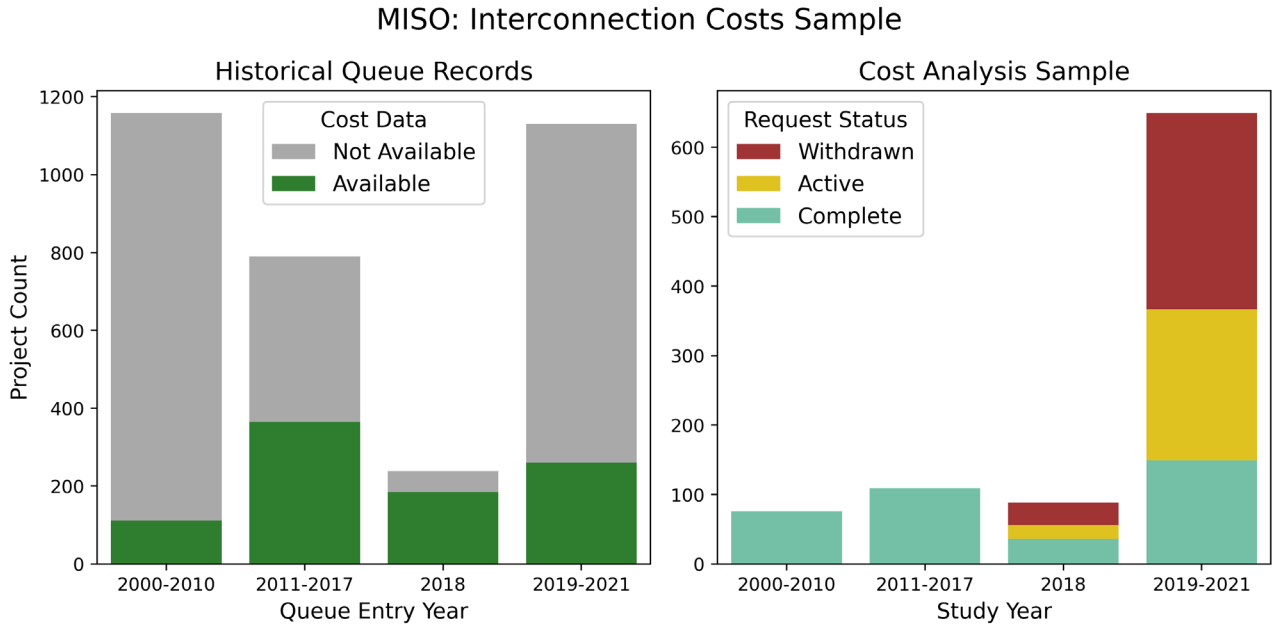




Cost sample represents nearly 50% of projects requesting interconnection over the past decade

- Interconnection costs sample of 922 projects
  - 28% sample coverage 2001-2021
  - 48% sample coverage 2011-2020
- Sources:
  - All cost data available online in the MISO system as of February 2022 (698 projects).
  - Augmented with previously collected data of complete projects (224 projects)
  - MISO removes detailed interconnection study information after a few years from publicly accessible records
- Methods:
  - Cost data were collected manually from public interconnection study reports.
  - Interconnection costs in real $2022-terms based on a GDP deflator conversion (assuming nominal dollars as of the time of the interconnection study)
  - Presenting simple means



Interconnection Request Status Definitions

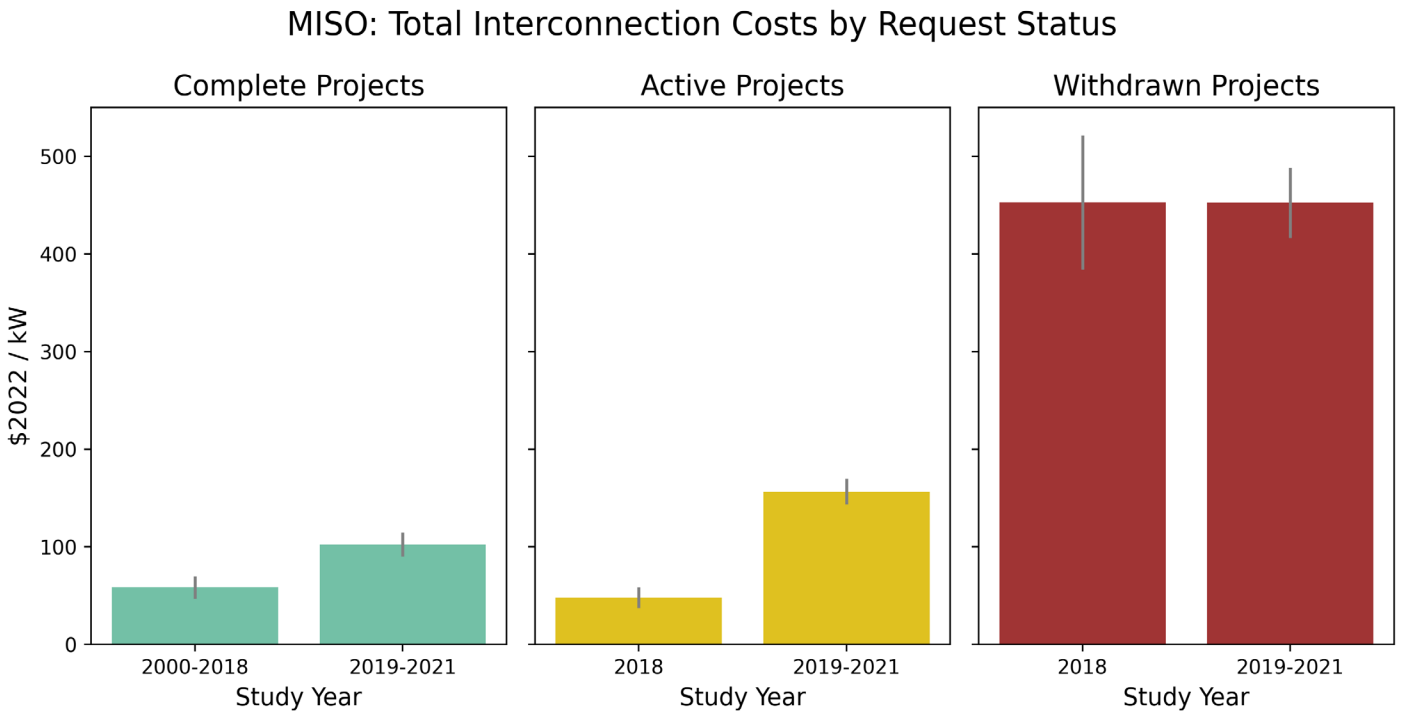
Complete: These projects have completed all of the interconnection studies, and have moved on to (or completed) the interconnection agreement phase. Includes plants that are now in service.

Active: These projects are actively working through the interconnection study process.

Withdrawn: These interconnection requests have been withdrawn (cancelled) from the queue.

Average Interconnection costs have grown substantially over time

Interconnection costs increase in our sample after 2000, more than doubling from $104/kW across the early years (2000-2018) to $273/kW (2019-2021).



By Interconnection Request Status

- **Complete:**
  - Costs nearly double from $58/kW prior to 2019 to $102/kW between 2019 and 2021.
- **Active:**
  - Cost triple from $48 to $156/kW (2018 vs. 2019-2021)
- **Withdrawn:**
  - Stable cost around $450/kW (2018 and 2019-2021).
  - More than four times the costs of “complete” projects over the past four years ($453/kW vs. $147/kW).

Broader network upgrade costs are the primary driver of recent cost increases and dominate among withdrawn projects

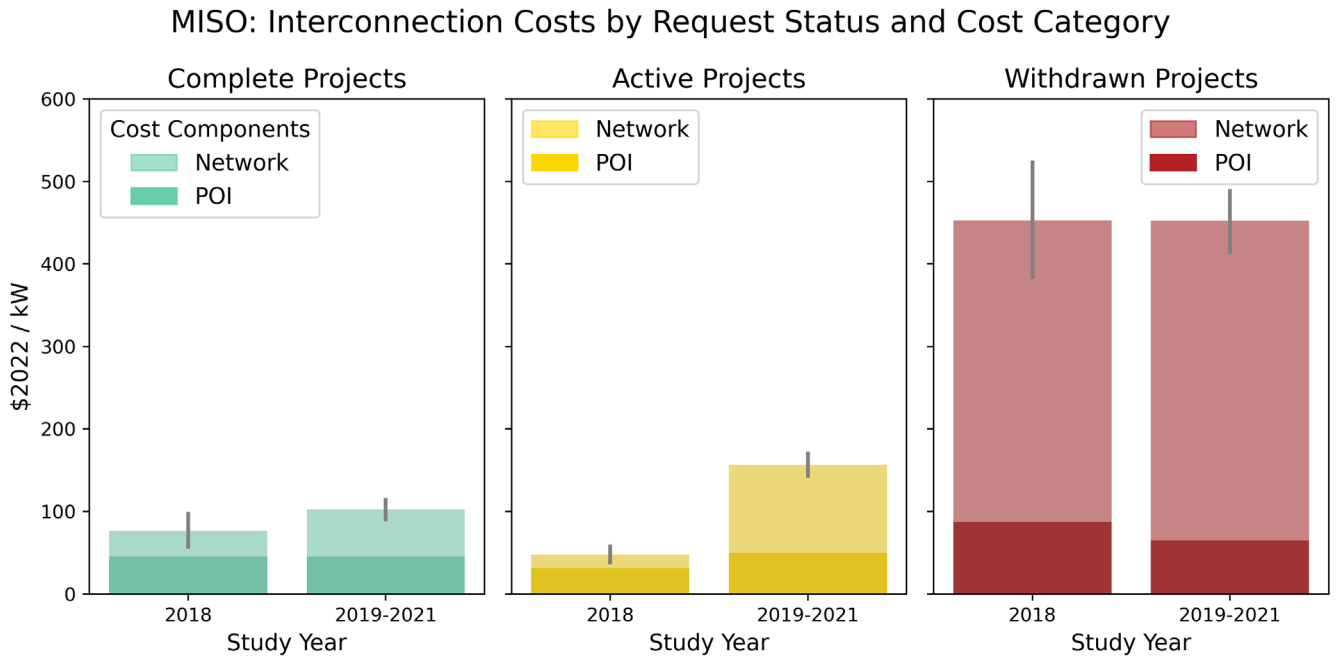
Interconnection Cost Components

Point of Interconnection (POI) or Interconnection Facilities Costs:

- Transmission Owner Interconnection Facilities (TOIF) and Transmission Owner Network Upgrades (substation and connection to transmission system)
- Often excludes additional project infrastructure (step-up transformer, spur lines…)

Network Costs:

- Upgrades for: Backbone Network, Thermal/ Voltage/ Steady State/ Reactive/ Transient Stability, Short Circuit, Local Planning Criteria, Affected System, Deliverability, Shared Network Upgrade

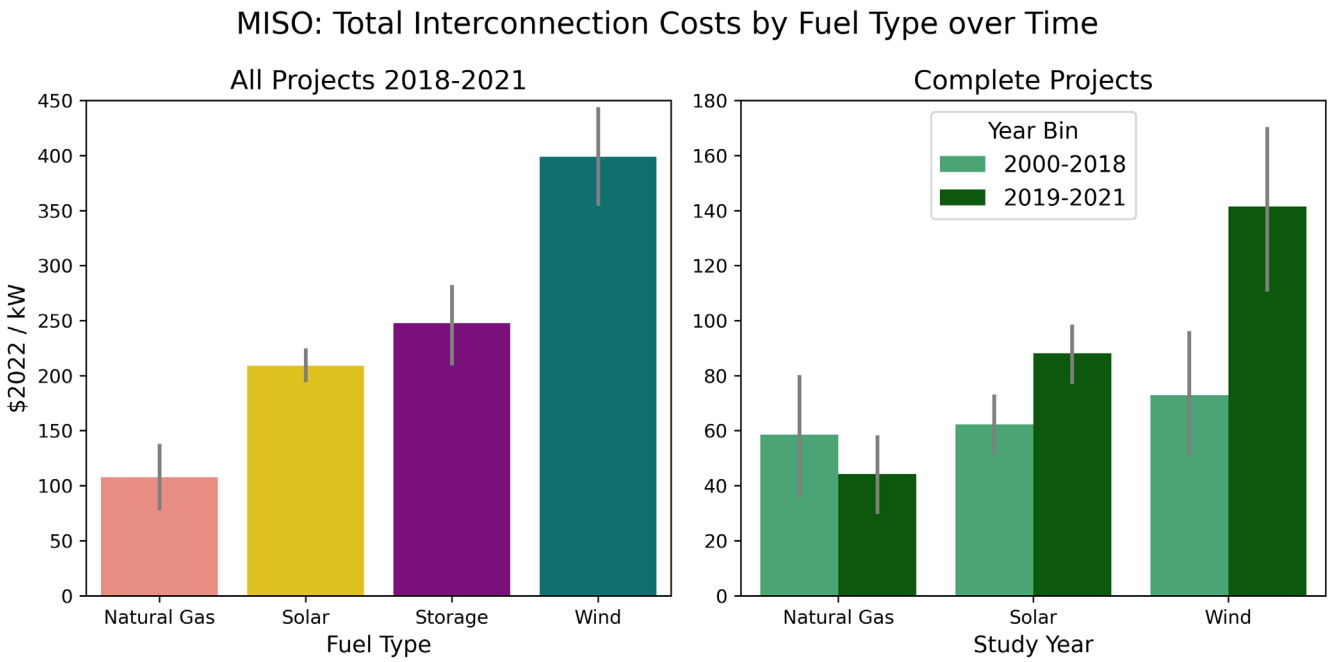


By Interconnection Request Status

- **Complete:**
  - Local upgrades at POI typical cost driver and primary reason for historical cost escalations since early 2000s (2018-2021: $46/kW).
  - Network upgrade costs can cause large cost additions for some projects, recently growing (from $31 to $57/kW)
- **Active:**
  - Slowly rising POI costs (from $31 to $50/kW)
  - Greater network costs, growing more than sixfold over the past few years (from $16 to $107/kW)
- **Withdrawn:**
  - Slightly higher POI costs (2018-2021: $67/kW)
  - Network upgrades are commonly much larger and have grown in recent years (from $366 to $388/kW). The top 10% of network upgrade costs range between $900 and $4600/kW.

Interconnection costs for wind, storage, and solar are larger than for natural gas

Wind ($399/kW), **storage** ($248/kW), and **solar** ($209/kW) costs are greater than **natural gas** interconnection costs ($108/kW) when looking at recent applicants, irrespective of their request status.



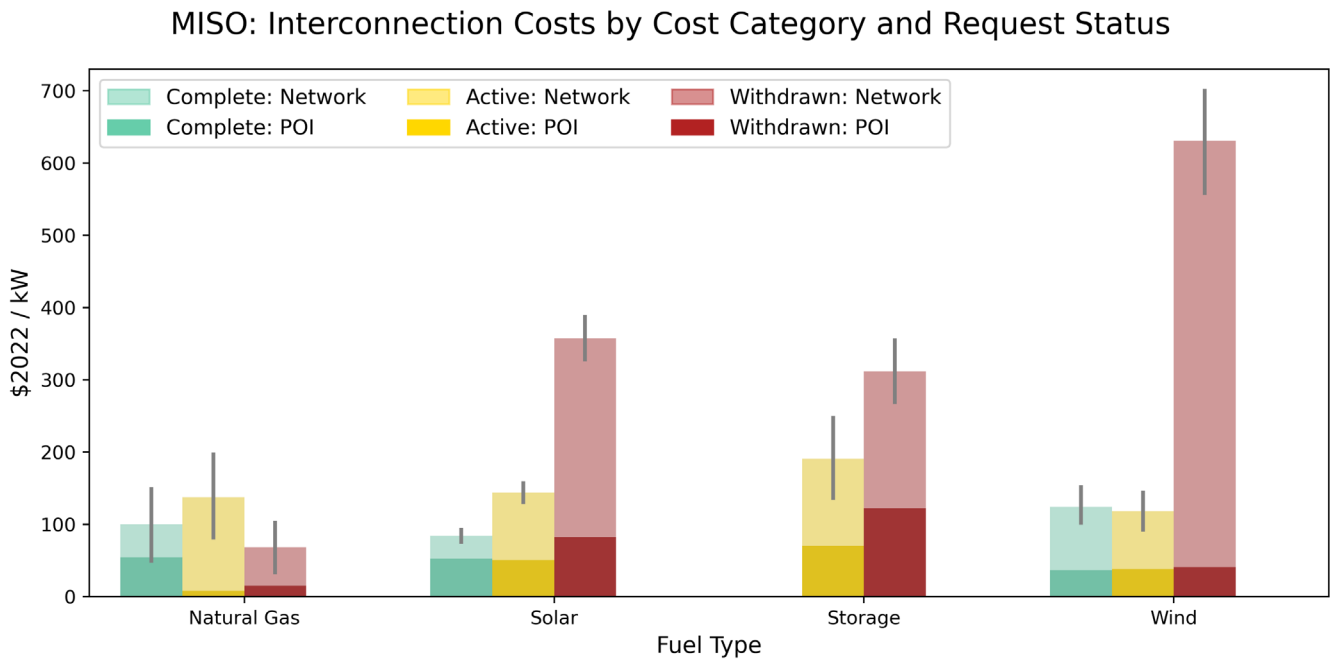
Longest time record for **complete** projects:

- Looking at projects studied before and after 2019 we find that:
  - Natural gas costs fall ($59 to $44/kW)
  - Solar cost grow ($62 to $88/kW)
  - Wind costs double ($73 to $141/kW)

- Renewable interconnection costs are even higher in 2021:
  - Wind costs escalate to $252/kW or nearly four times the historical average - adding 16% to wind project capex in MISO.
  - Solar costs also grow to $99/kW, but are a smaller fraction of overall project capex at 7%

Network costs cause increase in interconnection expenses for renewables, especially for active and withdrawn projects

- POI costs don't vary much, except for rather low costs for natural gas and unusually high costs for some storage projects (driven by dispatch assumptions).

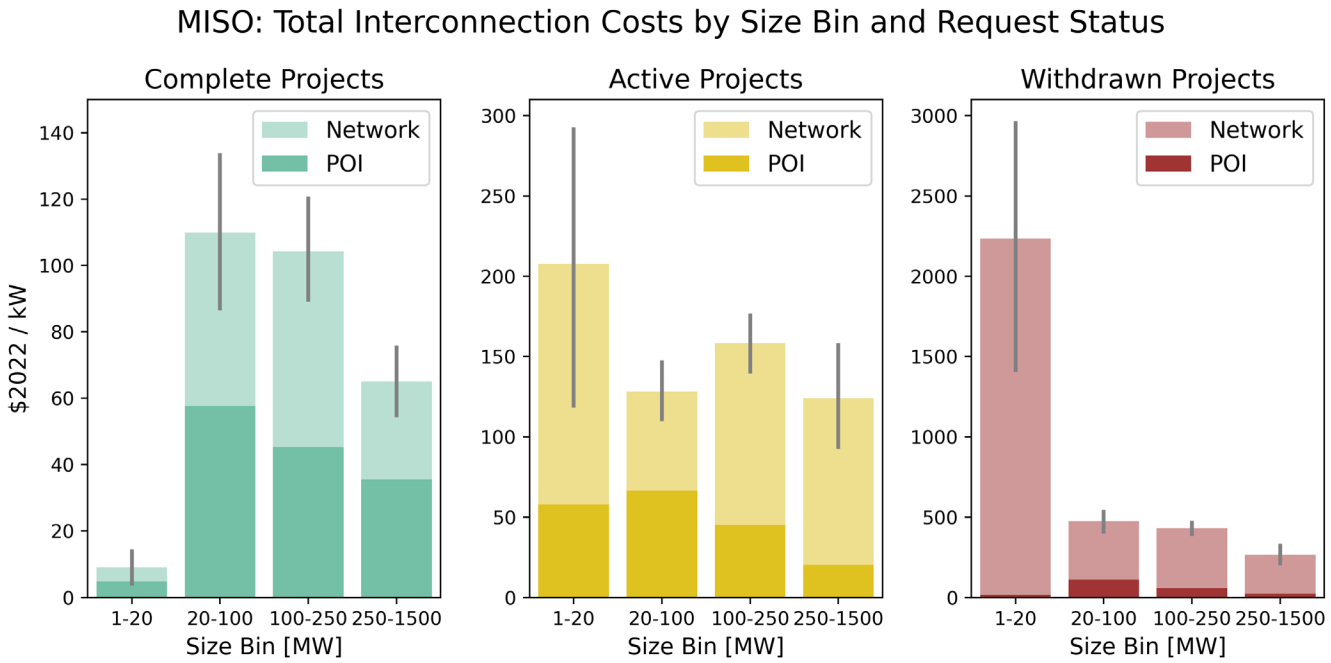


- Network costs increase dramatically for **active** and **withdrawn** projects.
  - Network costs are three times greater than POI costs for withdrawn solar projects ($275 vs. $82/kW) and fifteen times greater for wind projects ($590 vs $40/kW).

- Withdrawing renewables have high total interconnection cost:
  - High wind costs of $631/kW (or 40% of project capex) could explain why applicants withdraw from the queue.
  - Withdrawing solar costs are lower at $358/kW, but still account for 24% of project capex.

Larger generators have lower interconnection costs per kW

Projects with larger nameplate capacity have greater interconnection costs in absolute terms, but these costs do not scale linearly on a per kW basis, falling from $705/kW (small) to $283kW (medium), $259/kW (large), and $167/kW (very large project size).

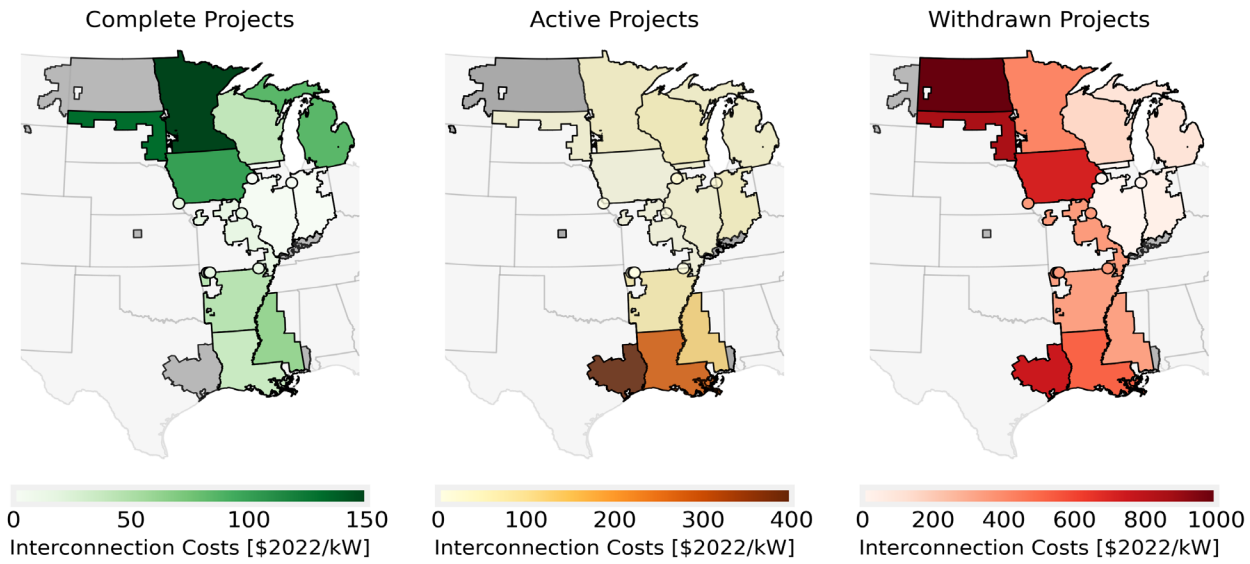


- Economies of scale hold
  - for POI and network costs,
  - across requests status,
  - Going back in time since 2010 (among complete subsample)
  - and largely by fuel type:

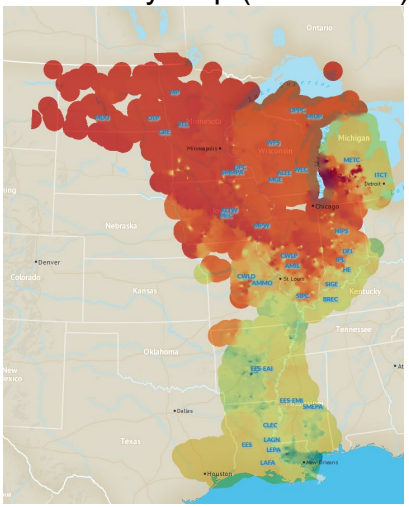
Fuel	20-100MW	100-250MW	250-1500MW
Solar	$237/kW	$194/kW	$120/kW
Onshore Wind	$463/kW	$377/kW	$222/kW

  - Costs for natural gas and storage do not vary significantly by size.

Interconnection costs vary by location



MISO Interactive Interconnection Capacity Availability Map (DPP-2020)



- Across all projects:
  - North and South Dakota and parts of Texas have high costs ($508-915/kW).
  - Indiana and Illinois report overall lower costs ($50-$69/kW).
  - States with limited availability of interconnection capacity are somewhat aligned with high cost areas
- By request status:
  - Northern states have high interconnection costs among complete (Minnesota : $159/kW) and withdrawn (North Dakota: $1001/kW) projects
  - Illinois and Indiana have lower costs ($42/kW for complete; $28 & $60/kW for withdrawn projects)
  - Louisiana ($306/kW) and Texas ($416/kW) have the greatest interconnection costs among active projects

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