U.S. DEPARTMENT OF ENERGY

Transmission Interconnection Roadmap

Transforming Bulk Transmission Interconnection by 2035

Interconnection Innovation e-Xchange (i2X)

Disclaimer

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List of Acronyms

AEMO	Australian Energy Market Operator
BESS	battery energy storage system
BIL	Bipartisan Infrastructure Law
BPA	Bonneville Power Administration
BPS	bulk power system
CAISO	California Independent System Operator
CEII	critical energy/electric infrastructure information
CESER	Office of Cybersecurity, Energy Security, and Emergency Response
CHP	combined heat and power
CIP	critical infrastructure protection
DLR	dynamic line rating
DOE	U.S. Department of Energy
EEJ	equity and energy justice
EERE	DOE Office of Energy Efficiency and Renewable Energy
EIA	U.S. Energy Information Administration
EJE	Office of Energy Justice and Equity
EMT	electromagnetic transient
EPRI	Electric Power Research Institute
ERCOT	Electric Reliability Council of Texas
ERIS	energy resource interconnection service
ESIG	Energy Systems Integration Group
EV	electric vehicle
FACTS	flexible alternating current transmission systems
FERC	Federal Energy Regulatory Commission
FPL	Florida Power & Light
GET	grid-enhancing technology
GDO	DOE Grid Deployment Office
GIP	generator interconnection procedure

GRIP	Grid Resilience and Innovation Partnerships Program
GTO	Geothermal Technologies Office
GW	gigawatt
i2X	Interconnection Innovation e-Xchange
IA	interconnection agreement
IBR	inverter-based resource
IEDO	Industrial Efficiency and Decarbonization Office
IEEE	Institute of Electrical and Electronics Engineers
IRA	Inflation Recovery Act
IREZ	interregional renewable energy zone
ISO	Independent System Operator
ISO-NE	Independent System Operator New England
IT	information technology
JTIQ	Joint Targeted Interconnection Queue
kW	kilowatt
LGIA	Large Generator Interconnection Agreement
LGIP	Large Generator Interconnection Procedures
LRTP	Long Range Transmission Planning
LSE	load serving entity
MISO	Midcontinent Independent System Operator
MVP	Multi-Value Project
MW	megawatt
NERC	North American Electric Reliability Corporation
NOPR	notice of proposed rulemaking
NREL	National Renewable Energy Laboratory

NRIS	network resource interconnection service
NYISO	New York Independent System Operator
OE	Office of Electricity
OEM	original equipment manufacturer
OPP	Office of Public Participation
PJM	PJM Interconnection
PMA	Power Marketing Administration
POI	point of interconnection
RD&D	research, development, and demonstration
RFI	request for information
RTO	Regional Transmission Organization
RMS	root-mean-square
SETO	Solar Energy Technologies Office
SPP	Southwest Power Pool
UMTDI	Upper Midwest Transmission Development Initiative
UNIFI	Universal Interoperability of Grid-Forming Inverters
U.S.	United States
V2G	vehicle to grid
VTO	Vehicle Technologies Office
WETO	DOE Wind Energy Technologies Office
WHP	waste heat to power
WPTO	Water Power Technologies Office

Executive Summary

The U.S. electricity system is amid a rapidly occurring and widespread energy transition. Regional, Tribal, state, and customer demand for clean energy resources, combined with favorable policies, is driving a rapid rise of interconnection requests. From 2000 to 2010, the United States averaged between 500 and 1,000 new transmission interconnection requests each year, corresponding to around 150 to 200 gigawatts (GW)/year of proposed generation. Over the last decade, however, new requests have significantly risen to 2,500 to 3,000 each year, representing anywhere from 400 to 750 GW/year of proposed capacity, a three to five times expansion.[1] Interconnection processes will need to evolve to handle this larger number of requests today and into the future, as policy and economic drivers continue to motivate significant resource development. This roadmap identifies and organizes nearer- and longer-term solutions to enable transmission interconnection processes to meet this expected demand, and it is intended for a diverse audience of stakeholders participating within transmission interconnection processes.

While improvements to the transmission interconnection process have been ongoing in the United States since the 2000s, the backlogs in current queues motivate efforts to develop novel solutions. In addition, innovations in data collection, analysis, and software management systems are creating new opportunities for automating parts of the interconnection process to handle larger interconnection requests while also reducing interconnection study process timelines. This roadmap focuses on high-voltage electric transmission interconnections in the bulk power system (BPS), and compiles solutions that provide a comprehensive set of opportunities for industry collaboration within the interconnection process. At the same time, the interconnection solutions identified in this roadmap are intended to be a collection of strategies rather than a rigid package of prescriptive fixes. Therefore, this document presents multiple paths that stakeholders within the industry may consider when determining the interconnection reform activities that best suit their situations. The solutions developed focus on interconnection challenges. Broader issues of supply chain, permitting, and siting were considered out of scope.

This roadmap is a result of the Interconnection Innovation e-Xchange (i2X) program launched by the U.S. Department of Energy (DOE) in June 2022 to convene stakeholders and address interconnection challenges. As this roadmap was being developed, the Federal Energy Regulatory Commission (FERC) issued Order 2023, which aims to reform generator interconnections. Though this roadmap contains some solutions that relate to Order 2023, it also introduces additional ideas that support longer-term interconnection process evolution. The solutions in this roadmap are intended to complement and support, not impede, Order 2023 implementation. They focus on issues that may still be unresolved in implementing Order 2023, such as how to balance stricter requirements for interconnection customers with open access and

[1] Rand, J., et al. April 2024. "Queued Up: Characteristics of Power Plants Seeking Transmission Interconnection as of the End of 2023," slide 8. Lawrence Berkeley National Laboratory. emp.lbl.gov/queues.

equity considerations, incentivize minimizing interconnection study delays, and better coordinate affected system studies. However, the solutions in this roadmap also go beyond Order 2023, addressing issues that were not raised in the order, such as data transparency, automation, interconnection studies, cost allocation, and workforce development. These latter solutions are intended to be pursued in concert with Order 2023 implementation, and in many cases, transmission providers already have some initiatives in these areas underway. This comprehensive approach is important not only to facilitate industrywide discourse that builds upon Order 2023 implementation but also to maintain relevance for transmission providers that are not FERC jurisdictional.

FERC is also in the process of another related rulemaking on transmission planning.[2] Enhanced transmission planning has been identified as a core element for improving the efficiency of interconnection processes. DOE's *National Transmission Needs Study* shows reliability and resilience benefits from additional transmission investment.[3] Because of the close relationship between interconnection process and transmission planning, this roadmap includes some solutions that involve improvements in transmission planning. However, the focus of the roadmap is on interconnection reforms.

Throughout much of the U.S., interconnection reforms are shaped by transmission providers' stakeholder processes. Transmission providers thus play a central role in managing and implementing interconnection process improvements. However, ideas and actions often come from other stakeholders: interconnection customers, state agencies, federal regulators, transmission owners, load serving entities (LSEs), equipment manufacturers, consumer advocates, equity and energy justice (EEJ)[4] communities, advocacy groups, consultants, and the research community, which includes DOE. Members from all these stakeholder groups contributed to brainstorming and developing the solutions described in this roadmap via participation in DOE's i2X program and should continue to participate in the implementation of the solutions described in this roadmap. Reform is thus a group effort. The roadmap outlines specific actions each stakeholder group can take to contribute to a collaborative improvement process. These stakeholder groups are described in the introduction section of the roadmap in more detail. This document provides a starting point for enhanced conversations between these groups that should facilitate coordination and collaboration.

[2] Read more on FERC's *Transmission NOPR Addressing Planning, Cost Allocation* at www.ferc.gov/news-events/news/ferc-issues-transmission-nopr-addressing-planning-cost-allocation.

[3] Read more about U.S. transmission needs in DOE's October 2023 *National Transmission Needs Study* at www.energy.gov/gdo/national-transmission-needs-study.

[4] Equity and energy justice includes, but is not limited to, all definitions and designations by government screening tools such as the Justice40 Initiative (www.energy.gov/justice/justice40-initiative), the White House Council on Environmental Quality's Climate and Economic Justice Screening Tool (screeningtool.geoplatform.gov/en/#14.03/15.03469/-84.98955), DOE's Energy Communities (arcgis.netl.doe.gov/portal/apps/experiencebuilder/experience/?id=a2ce47d4721a477a8701bd0e08495e1d), and the Environmental Protection Agency's EJScreen (ejscreen.epa.gov/mapper/).

The roadmap is organized into four primary goal areas, each important to the overall i2X mission to enable a simpler, faster, and fairer interconnection of clean energy resources while enhancing the reliability, resiliency, and security of our electric grid.

Goal #1: Increase Data Access, Transparency, and Security for Interconnection

Improvements to interconnection data transparency, beyond those in recent FERC Orders 845 and 2023, would help improve interconnection customers' ability to screen and site potential projects, better enable third-party modeling, facilitate more process automation, enhance competition while ensuring equitable outcomes, and enable benchmarking, tracking, and auditing of interconnection processes and reforms. This goal recognizes the need to maintain the security of the data provided, by considering appropriate data access controls programs, and also covers increased transparency around timelines, costs, and delays in the period after an interconnection agreement (IA) is signed. Increasing transparency should generally increase fairness, equity, and competition in the interconnection process while lowering the number of exploratory, ultimately withdrawn projects and increasing the proportion of high-quality, well-sited projects in the queue.

Solutions:

Solution 1.1: Improve the scope, accessibility, quality, and standardization of **data on projects already in interconnection queues**, including project attributes, cost estimates, and post-IA information. (short-term)
Solution 1.2: Enhance the scope, timeliness, accuracy, and consistency of **interconnection study models and modeling assumptions** that transmission providers make available to interconnection customers. (short-term)
Solution 1.3: **Develop tools** to manage, analyze, and visualize transmission and interconnection data made available in first two solutions, while ensuring secure data-sharing processes. (medium-term)

Goal #2: Improve Interconnection Process and Timeline

Interconnection backlogs and delays are often the result of rapid growth in interconnection requests, inefficiencies in interconnection processes, and staffing constraints. For the United States, interconnection queue volumes are likely to be large and potentially volatile for the foreseeable future. This section covers solutions to improve queue management practices, affected system studies, inclusive and fair processes, and workforce development.

Queue Management

Several incremental queue management solutions—from automation and expanded access to fast tracks to more stringent commercial readiness requirements and study timelines—may help reduce queue volumes and interconnection delays in the near term and enable transmission providers to handle larger and variable queue volumes in the longer term. In the near term, transmission providers may face a trade-off between rationing interconnection queue space and maintaining open access.

Solutions:

Solution 2.1: Implement and enforce more stringent **commercial readiness requirements, financial commitments**, withdrawal penalties, and time limits that balance effectiveness, equity, and open access principles. (short-term)
Solution 2.2: Implement and enforce **interconnection study timelines and use incentives** for minimizing delays in completing studies. (short-term)
Solution 2.3: Continue to **automate parts of the interconnection process**, such as data input and validation, some customer communications, and data sharing across processes and models. (short-term)
Solution 2.4: Continue to monitor interconnection processing times and, as needed, **develop one-off interventions for mitigating queue backlogs**, such as additional temporary staff, outsourcing, temporary fast-tracking, and temporary rationing of queue space. (short-term)
Solution 2.5: Create new and better use existing **fast-track options for interconnection**, such as surplus interconnection service, generation replacement service, and energy-only interconnection service. (medium-term)
Solution 2.6: Consider **market-based approaches to rationing interconnection** access. (long-term)

Affected System Studies

Improvements to transmission provider coordination and methods for affected system studies—including Order 2023's requirements but also voluntary collaboration and joint planning that go beyond them—will remove a significant obstacle to timely processing of interconnection requests. Work is needed to enhance coordination with non-FERC jurisdictional entities.

Solutions:

Solution 2.7: Increase voluntary **collaboration on affected system studies**, including harmonization of study procedures, study methods, data inputs, software tools, study criteria, and mitigation options. (short-term)
Solution 2.8: Conduct affected system studies using an **energy-only modeling standard**, unless interconnection customers have requested deliverability to the affected system. (short-term)
Solution 2.9: Develop a process to **investigate new interregional transmission solutions** through joint transmission planning efforts between neighboring affected systems. (medium-term)

Inclusive and Fair Process

While all solutions of the roadmap aim to promote a fair interconnection process, not all stakeholders start with the same tools and resources. Enhancements to interconnection and, relatedly, transmission planning processes can help achieve inclusive and fair interconnection outcomes. Energy equity in interconnection requires intentionally designing systems, technologies, procedures, and policies for all types of interconnection stakeholders, including EEJ communities. An equitable interconnection process could be made more inclusive and fairer by developing strategies to expand transmission connection access opportunities. In addition to the two solutions below, which exclusively focus on inclusivity and fairness in interconnection, many more solutions of the roadmap aim to, in part, resolve current issues of equity within the interconnection process.

Solutions:

Solution 2.10: Incorporate **equity goals in transmission planning and valuation** efforts. (short-term)
Solution 2.11: Provide access to **independent engineering, administrative, and legal services** to support the navigation of interconnection processes. (medium-term)

Workforce Development

Interconnection requires technical expertise across many professions in the electric industry, from utility engineers to regulatory officials. There is a high degree of competition for these skill sets, especially given they require both engineering and policy experience. Targeted efforts to increase training opportunities for and improve compensation of existing staff will improve workforce capabilities, increase retention, enhance diverse and equitable representation across the interconnection workforce, and, as a result, expand processing of interconnection applications. Better advertisement of current interconnection-related positions and new outreach in higher education settings are needed to highlight the important role of interconnection policy and practice in the clean energy transition.

Solutions:

Solution 2.12: Assess the scale of interconnection **workforce growth requirements**. (short-term)
Solution 2.13: **Upskill the existing workforce** through continuing education programs. (short-term)
Solution 2.14: Consider improvements to **compensation and benefits** while enhancing the **advertisement and hiring process** for interconnection-related positions. (short-term)
Solution 2.15: Grow the number of workers in the interconnection workforce via **outreach, career counseling, apprenticeships, and curriculum development** in postsecondary education. (medium-term)
Solution 2.16: **Expand education opportunities** relevant to interconnection for under-resourced and EEJ communities. (medium-term)

Goal #3: Promote Economic Efficiency in Interconnection

This section describes solutions that aim to improve cost allocation, reduce costs to electricity consumers, enhance the coordination between transmission planning and the interconnection process, and optimize the rightsizing of transmission investment through improvements in interconnection studies.

Cost Allocation

Expanding options for interconnection service and proactive transmission investments should reduce uncertainty and improve allocative efficiency. If current efforts to reduce interconnection bottlenecks prove unsuccessful, transmission providers may need to consider more radical departures from the current participant funding model of interconnection cost allocation.

Solutions:

Solution 3.1: Explore options for identifying and allocating the costs of **proactive transmission investments**, including different options for state, federal, and participant funding. (short-term)
Solution 3.2: Ensure that generators have the option to elect energy-only interconnection and **be re-dispatched rather than paying for network upgrades**. (medium-term)
Solution 3.3: Explore and evaluate potential options for **delinking the interconnection process and network upgrade investments** to increase up-front interconnection cost certainty. (long-term)

Coordination between Interconnection and Transmission Planning

Closer alignment in the data inputs, assumptions, and process timelines between interconnection and long-term transmission planning can help ensure that transmission solutions that would have been more efficiently identified in transmission plans are not instead triggered through the interconnection process.

Solution:

Solution 3.4: More closely **align data inputs, assumptions, and process timing** between interconnection and transmission planning processes. (medium-term)

Interconnection Studies

Interconnection study methods will also need to continue to adapt to a changing generation mix, with a greater emphasis on more realistic dispatch assumptions, consideration of multiple time periods rather than static snapshots, and inclusion of all potential mitigation options to relieving transmission constraints. Interconnection study solutions could help right size transmission upgrades and reduce electricity consumer costs. As methods change, greater harmonization across transmission providers would help ensure more consistent outcomes across regions.

Solutions:

Solution 3.5: Evaluate **all effective mitigation options** during interconnection studies, incorporating alternative transmission technologies as well as control options for inverter-based resources (IBRs). (short-term)
Solution 3.6: Continue to develop and harmonize **new, transparent best-practice study methods** to adapt to a changing generation mix and changes in load as well as to facilitate consistent outcomes across transmission providers. (medium-term)

Solution 3.7: Explore options to allow interconnection customers to **self-fund and provide their own interconnection studies**, subject to transmission provider oversight, rules, and requirements. (long-term)

Goal #4: Maintain a Reliable, Resilient, and Secure Grid

In recent years, there has been a series of large disturbance events leading to significant IBR disconnection. These performance issues were not identified during interconnection studies of the involved plants. The solutions under this goal aim to reduce these gaps by updating technical requirements within interconnection studies, models, and tools while also improving industry interconnection standards.

Interconnection Reliability Assessment Models and Tools

Improvements to the models and tools used in interconnection studies and reliability assessments are needed to avoid large disturbance events that may threaten grid reliability. Collection and assessment of electromagnetic transient (EMT) models are needed today, while screening tools should be developed to determine when EMT studies become necessary in a specific region in the future. Aligning the interconnection study process flow with project development timelines will ensure that the appropriate, site-specific models are used in system impact studies. Leveraging modern computing technologies should increase modeling capabilities.

Solutions:

Solution 4.1: Require **submission of verified EMT models** for all IBRs during the interconnection process and **develop screening criteria** to determine when EMT studies are necessary within a region. (short-term)
Solution 4.2: Develop rules for **dynamic model quality testing and validation** for both root-mean-square (RMS) and EMT simulations, ensuring that plant performance conforms with applicable interconnection requirements. (short-term)
Solution 4.3: Develop a **study process flow** that is better aligned with project development timelines. (medium-term)
Solution 4.4: Advance the **computational speed** of interconnection reliability assessments. (medium-term)

Interconnection Standards

To ensure reliable and secure operation of newly interconnecting plants, comprehensive interconnection standards are necessary. Interconnection requirements specifying IBR capabilities and expected project performance remain a work in progress. Furthermore, current requirements lack performance specifications for accompanying phenomena during voltage or frequency disturbances such as transient overvoltage, voltage phase angle jump, and high rate of change of frequency. Finally, development of and compliance with cyber and physical security standards needs to be incorporated into the interconnection process.

Solutions:

- Solution 4.5: Adopt and implement a harmonized and comprehensive set of **generation interconnection requirements or standards,** consistent with Institute of Electrical and Electronics Engineers (IEEE) Standard 2800-2022. (short-term)
- Solution 4.6: Adopt and implement harmonized requirements for **plant conformity assessment** as a part of generator interconnection procedures (GIPs) and consistent with IEEE P2800.2, once approved. (medium-term)
- Solution 4.7: Assess need for new interconnection requirements and standards to cover expected performance from **emerging technologies**. (medium-term)
- Solution 4.8: Evaluate **cyber and physical security concerns** during the interconnection process. (medium-term)
- Solution 4.9: Investigate the relationship between the **interconnection process and system reliability** issues. (long-term)

Measurable Targets for Interconnection Reform

This roadmap includes four target metrics that can be measured using publicly available data. They include:

1. Shorter interconnection times
2. Lower interconnection cost variance for all projects
3. Increased completion rates
4. Lower disturbance events

These targets are for 2030, which implies that they could be achieved with medium-term (3- to 5-year) interconnection reforms, and they are based on a mix of historical values and industry expectations. Table ES-1 shows 2030 target values. The table reports recent and historical best values for reference and comparison purposes. Over the longer term (2030–2040), the electricity industry could target outcomes that are better than these values. A more complete description of these targets can be found in the Introduction.

Table ES-1: 2030 Roadmap Targets, Target Values, Recent Values, and Historical Best Values

Target	Target Value	Recent Value	Historical Best Value
(1) Average time from interconnection request to IA for completed projects	< 12 months	33 months (2022)	18 months (2005–2008; best since 2003)
(2) Standard deviation of interconnection costs for all projects	< $150/kW	$551/kW (2020–2021)	$154/kW (2010–2011; best since 2007)
(3) Completion rate for projects that enter the facility study phase	> 70%	45% (2016)	55% (2007; best since 2006)
(4) Annual NERC disturbance events	0	4 (2022)	0 (2019)

Target	Target Value	Recent Value	Historical Best Value
involving unexpected tripping of IBRs not identified in offline analysis due to inaccurate IBR models.			

Sources: Recent and historical best values for targets 1, 2, and 3 are based on Rand et al. (2024) and Seel et al. (2023). Recent and historical best values for standard deviation costs use multiple years to increase sample size. Recent and historical best values for IBR disturbance events are from event reports on NERC's website.

Table of Contents

List of Figures

List of Tables

Introduction

The U.S. electricity system is amid a rapidly occurring and widespread energy transition. Regional, state, Tribal, and customer demand for clean energy resources combined with favorable policies is driving a rapid rise of interconnection requests. From 2000 to 2010, the United States averaged between 500 to 1,000 new transmission interconnection requests each year, corresponding to around 150 to 200 GW per year of proposed generation. Over the last decade, however, new requests have significantly risen to 2,500 to 3,000 each year, representing anywhere from 400 to 750 GW per year of proposed capacity, a three- to fivefold expansion.[5] Interconnecting resources to the electrical grid involves multiple parties and numerous laws, regulations, and technical study processes. The combination of limited transmission capacity, increased request volume, and interconnection complexities has led to uncertainties, delays, and higher costs for interconnection customers and translates to higher costs for electricity consumers.[6] Interconnection challenges may also fall disproportionately on under-resourced groups such as Tribal Nations, smaller utilities, smaller developers, and others.

Interconnection processes will need to evolve to handle the larger number of requests today and into the future. State and federal policies,[7] continued declines in the cost of wind, solar, energy storage, and other technologies, rates of power plant retirements, and transportation and industrial electrification[8] will likely sustain large volumes of interconnection requests for the foreseeable future. Managing large interconnection queues and a changing resource mix will require more effective and efficient interconnection processes. In addition, advances in high-performance computing and innovations in data collection, analysis, and software management systems are creating new opportunities for automating parts of the interconnection process to handle larger interconnection queues while also reducing interconnection timelines. This roadmap identifies and organizes nearer- and longer-term solutions that would enable interconnection processes to meet this expected interconnection demand by increasing data access and transparency, improving process and timing, promoting economic efficiency, and maintaining reliability, all while supporting more equitable access to the transmission system.

[5] See Rand et al., "Queued Up." emp.lbl.gov/queues.
[6] This document defines "interconnection customers" as groups, organizations, and businesses who either have submitted a formal interconnection request or are considering a formal interconnection request. This definition is meant to be inclusive of the full ecosystem of communities trying to develop new transmission-level resources. The roadmap uses "interconnection customers" interchangeably with "resource developers" throughout.
[7] For instance, the Infrastructure Investment and Jobs Act, Pub. L. 117-58 (Nov. 15, 2021), commonly known as the Bipartisan Infrastructure Law (BIL), and the Inflation Reduction Act, Pub. L. 117-169 (Aug. 16, 2022) are major federal laws contributing to an evolving electricity sector.
[8] Read more about future electricity demand increases in DOE's 2023 Pathways to Commercial Liftoff (liftoff.energy.gov/) and 2022 Industrial Decarbonization Roadmap (energy.gov/industrial-technologies/doe-industrial-decarbonization-roadmap) reports.

This roadmap focuses on bulk transmission-level interconnection issues.[9] "Transmission interconnection" is defined as the practice of connecting projects that generate electricity, provide storage capacity, service large loads,[10] or expand transmission service to the transmission system. Like roads and highways, the grid is designed to accommodate different volumes and distances of flow. The interconnection process includes a set of procedures and studies that determine whether there is capacity in the existing system to accommodate the flows from a new resource or whether additional transmission infrastructure investments are needed to meet reliability requirements. This process involves multiple stakeholders, including but not limited to interconnection customers (such as clean energy resource developers), transmission providers and system operators, consumer groups, equipment manufacturers, state agencies, federal regulators, EEJ communities, advocacy groups, consultants, and the research community (including DOE). Members from all these stakeholder groups will need to take action to implement the solutions described in this roadmap.

In 2010, there was less than 500 GW of capacity waiting in the interconnection queues across the country. Today, that number has quadrupled to 2,600 GW, more than 95% of which is for zero-carbon electric generation and storage capacity (see Figure 1).[11] This amount is larger than the installed capacity of all power plants currently operating in the United States. Correspondingly, the time to interconnect has more than doubled across the United States.[12] This roadmap should be used to establish a key set of priorities over the coming years for stakeholder collaboration on the interconnection process that will ensure the electric system evolves to handle these significantly larger quantities of resource development.

[9] The bulk power system includes (1) facilities and control systems necessary for operating an interconnected electric energy transmission network (or any portion thereof) and (2) electric energy from generation facilities needed to maintain transmission system reliability. The term does not include facilities used in the local distribution of electric energy. Future work by DOE will consider interactions between the distribution and transmission systems and coordination efforts within the interconnection process that might be needed as distributed energy resources become more commonplace. Such discussion is out of scope for this document.

[10] Large-load interconnection processes typically exist outside of the traditional generation, storage, and transmission interconnection queues that DOE focuses on in this document and thus are governed by different, oftentimes idiosyncratic procedures. DOE only briefly includes discussion of interconnection issues specific to large loads in this document.

[11] Data sources provided in Rand et al., "Queued Up." emp.lbl.gov/queues.

[12] Ibid.

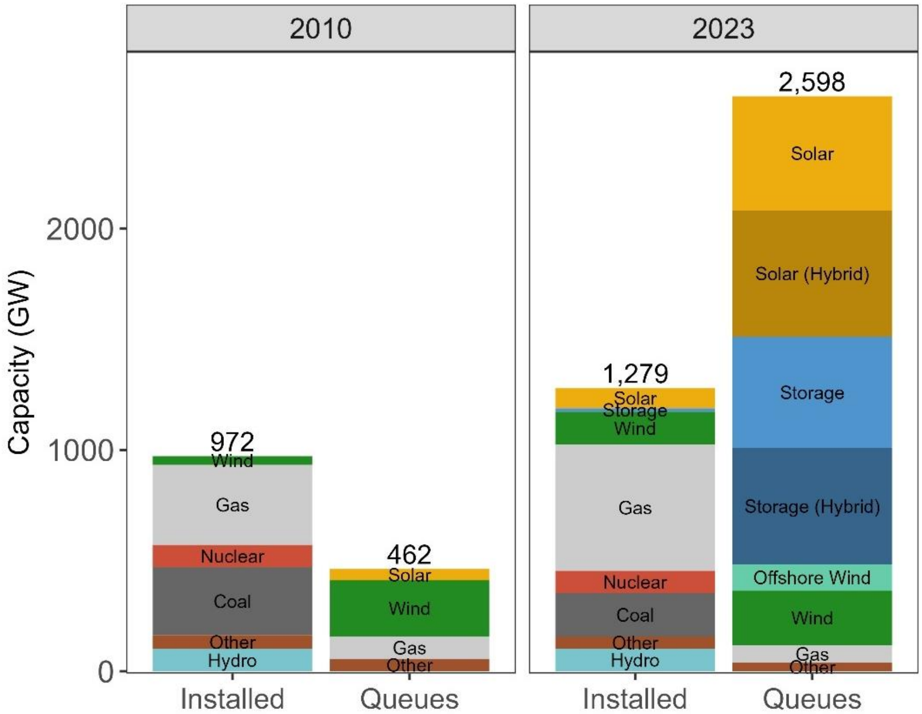

Figure 1: Entire U.S. Installed Generating Capacity Compared to Active Queue Capacity

Roadmap Goals and Organization

The roadmap serves as a guide to key actions that stakeholders should take within the next 5 years and beyond to implement solutions to current interconnection challenges. While interconnection reform has been ongoing in the United States since the 2000s,[13] the backlogs in the queues motivate continued efforts to propose novel solutions. This document serves as a starting point for future conversations around these solutions. This roadmap also identifies and develops solutions that can provide a more comprehensive set of reforms and is organized into four primary goal areas:

1. Increase Data Access, Transparency, and Security for Interconnection
2. Improve Interconnection Process and Timeline
3. Promote Economic Efficiency in Interconnection
4. Maintain a Reliable, Resilient, and Secure Grid

Increasing Data Access, Transparency, and Security for Interconnection

This goal centers on improving data availability that informs better interconnection decision-making and facilitates accurate monitoring of queue reform outcomes. This section of the roadmap discusses interconnection project data, interconnection study models and assumption transparency, and the development of new tools that will increase access to the interconnection data, information, and process for all interconnection stakeholders. This includes increasing

[13] A table summarizing important FERC orders aimed at reforming interconnection is provided in the Appendix.

transparency around timelines, costs, and delays in the period after an IA is signed. Increasing transparency should generally increase fairness, equity, and competition in the interconnection process while hopefully lowering the number of nonviable, ultimately withdrawn projects and increasing the proportion of high-quality, well-sited projects in the queue. This section also includes how improved access and transparency must preserve competitively sensitive information and secure critical energy/electric infrastructure information (CEII).

Improving Interconnection Process and Timeline

This goal focuses on the process itself and provides solutions to streamline interconnections as the quantity of projects applying for interconnection remains high. This section covers topical areas of queue management, affected system studies, inclusive and fair process, and workforce development. Addressing these areas could help mitigate existing queue backlogs and decrease the time required to interconnect to the transmission system, while maintaining open-access principles that remain central to resource development.

Promoting Economic Efficiency in Interconnection

This goal seeks to improve interconnection outcomes that meet market and policy objectives at lower costs to ratepayers with fair allocation between producers and consumers and among Tribal Nations and states. Cost allocation issues have proven to be some of the most difficult challenges, requiring decision-makers to carefully vet diverse stakeholder perspectives and weigh those perspectives according to specific objectives. Solutions related to issues of cost allocation, such as enhancing energy-only[14] interconnection procedures, are discussed. Furthermore, this section describes improvements to interconnection study methods and enhanced coordination efforts between the interconnection and long-term transmission planning processes that aim to reduce interconnection costs. This section discusses that while significant transmission investment may be needed to reliably and economically bring new generation onto the grid, it is also important to develop institutions that will optimize the use of, and therefore appropriately rightsize, the transmission system (e.g., through re-dispatch or grid-enhancing technologies)[15] to reduce costs to end consumers of electricity.

Maintain a Reliable, Resilient, and Secure Grid

Lastly, but of prime importance, this section focuses on issues to prevent unnecessary system disturbances and cascading transmission impacts resulting from IBR deployment. This section

[14] "Energy-only" interconnection provides interconnection customers non-firm interconnection status that does not ensure deliverability during severe grid conditions. The energy-only approach is contrasted with "capacity" or "network" interconnection, which aims to ensure deliverability of an interconnecting resource during severe grid conditions. FERC pro forma language refers to "energy-only" interconnection as "energy resource interconnection service," or ERIS. Due to differences in transmission-provider-specific rules and definitions of ERIS, DOE defaults to the more generic "energy-only" language in this document.

[15] DOE uses the terms "grid enhancing technologies" and "alternative transmission technologies" interchangeably throughout the document to refer to non-traditional enhancements to the transmission network that increase operational efficiency.

discusses how to proactively obtain models and systematically use them when needed for advanced studies.

Furthermore, improvements to the models and tools used in interconnection studies and reliability assessments are needed to avoid large disturbance events that may threaten grid reliability. This section also discusses the evolution of standards, including critical field verification and validation, as well as the application of modern computing capabilities.

Each section of the roadmap contains a collection of solutions that make progress toward each goal described above. Of course, some solutions could provide improvements across more than one goal area. Specific solutions are placed in the section of the roadmap that aligns most closely with the potential outcomes of the solution. When multiple goals might be achieved for a given solution, that is noted in the specific solution's description.

While all the goals of this roadmap aim to promote a fair interconnection process for all stakeholders, it is important to acknowledge that not all stakeholders start with the same tools and resources. Energy equity in interconnection requires intentionally designing systems, technologies, procedures, and policies for all types of interconnection stakeholders, including EEJ communities. Interconnection customers from socioeconomically disadvantaged or Tribal communities may lack the financing, resources, and capacity needed to navigate the interconnection landscape. Interconnection processes could be made more inclusive and fairer by acknowledging these barriers and developing strategies to expand transmission connection access opportunities.

Importantly, DOE does not separate equity as a standalone goal in this document, because these challenges permeate through all the goals outlined above and thus deserve more comprehensive treatment throughout the roadmap. DOE includes a specific section that discusses two solutions that focus exclusively on enhancing equitable outcomes (see Section 2.3), but this document also contains solutions in multiple additional sections that, in part, aim to resolve current issues of equity within the interconnection process. Furthermore, the roadmap identifies how non-equity-specific interconnection solutions might serve to enhance or interact with equitable outcomes of the interconnection process. Where appropriate, these solutions reference key FERC activities published in its Equity Action Plan[16] that are relevant to BPS interconnection.

Measurable Targets for Interconnection Reforms

This roadmap seeks to support the i2X vision of simpler, faster, and fairer interconnection of clean energy resources while enhancing grid reliability, resilience, and security. Some, but not all, elements of this vision lend themselves to measurable targets. For instance, fairness and equity are more difficult to measure quantitatively using currently available data, but costs and timelines are more easily translated into targets that can be tracked over time. The targets in this roadmap are intended not to be authoritative or exhaustive, but instead to provide a vision for

[16] FERC. Equity Action Plan. www.ferc.gov/equity.

interconnection reforms and high-level, measurable targets to gauge progress. This roadmap includes targets for the United States as a whole, but transmission providers could consider developing their own measures of success to track outcomes in their regions as they proceed with reforms.

The four targets in this roadmap can be measured using publicly available data. They include:

1. Shorter interconnection times
2. Lower interconnection cost variance for all projects
3. Increased completion rates
4. Lower disturbance events[17]

These targets are for 2030, which implies that they could be achieved with medium-term (3- to 5-year) interconnection reforms, and are based on a mix of historical values and industry expectations. These measures should be tracked annually, as incremental progress can be achieved every year until 2030. Over the longer term (2030–2040), the electricity industry could target outcomes that are better than these values. Table 2 shows 2030 target values. The table reports recent and historical best values for reference and comparison purposes.

Table 2: 2030 Roadmap Targets, Target Values, Recent Values, and Historical Best Values

Target	Target Value	Recent Value	Historical Best Value
(1) Average time from interconnection request to IA for completed projects	< 12 months	33 months (2022)	18 months (2005-2008; best since 2003)
(2) Standard deviation of interconnection costs for all projects[18]	< $150/kW	$551/kW (2020-2021)	$154/kW (2010-2011; best since 2007)
(3) Completion rate for projects that entered the facility study phase	> 70%	45% (2016)[19]	55% (2007; best since 2006)

[17] For this context, disturbance events refer to nonconsequential (i.e., not directly caused by the initial event) loss of IBRs, also known as category 1i NERC disturbance events.
[18] The costs reported in these rows represent points of interconnection (POIs) and network upgrades as reported within interconnection studies and do not include the cost of conducting the interconnection studies. Values are based on the best available sets of interconnection cost data for Independent System Operator New England (ISO-NE), Midcontinent Independent System Operator (MISO), New York Independent System Operator (NYISO), PJM Interconnection (PJM), and Southwest Power Pool (SPP) (available here) and are reported in 2022 dollar amounts. Importantly, the data are incomplete in these regions given not all studies are publicly available (30-80% of studies available, depending on ISO). Furthermore, while these regions represent more than 60% of active requests across the U.S., they may not be representative of interconnection costs in all regions of the U.S.
[19] Projects remain active in the queue for many years, so the recent value is pulled from a time period where little active projects remain. Values from more recent years cannot be calculated given many projects are still actively working through the interconnection queues.

Target	Target Value	Recent Value	Historical Best Value
(4) Annual NERC disturbance events involving unexpected tripping of IBRs not identified in offline analysis due to inaccurate IBR models.	0	4 (2022)	0 (2019)

Sources: Recent and historical best values for targets 1, 2, and 3 are based on Rand et al. (2024) and Seel et al. (2023). Recent and historical best values for standard deviation costs use multiple years to increase sample size. Recent and historical best values for IBR disturbance events are from event reports on NERC's website.[20]

The average interconnection time target in Table 2 is lower than historical values but was informed by key stakeholder input. It is measured as the duration between an interconnection request and an executed IA for generation and storage projects that complete the interconnection study process. Many of the solutions in this roadmap will contribute to shorter interconnection times. This target does not cover the time between IA and commercial operation, which is impacted by resource developers, energy buyers, permitting agencies, and supply chain issues, which are also important but more difficult to evaluate. Although these specific issues are largely out of scope for this roadmap, the lack of transparency around post-IA delays and complications can negatively affect both transmission providers and interconnection customers by delaying projects, impeding other interconnection requests, and exacerbating uncertainty. Improvements to these issues are discussed in Solution 1.1 and 2.3 and are more broadly reflected in the third target in Table 2, which captures completion rates.

Cost variance is a proxy for cost certainty. More cost certainty should, in principle, encourage higher project completion rates and shorter interconnection times. By using one standard deviation, the target in Table 2 focuses on reducing cost variance for average customers rather than for outlying projects. It aims to bring the variance in interconnection costs more in line with historical values. Most of the solutions that would reduce cost variance would also reduce overall interconnection costs.

Completion rates measure the share of interconnection requests that achieve commercial operation and do not withdraw from the queue. Completion rates can be measured during different stages (e.g., overall completion rates or late-stage completion rates). The target for this roadmap focuses on completion rates of projects that have entered later phases of the interconnection process (i.e., projects that entered the facility study phase). Completion rates are a derivative target: most parties are interested in completion rates due to their perceived impact on interconnection delays and costs. Nevertheless, completion rates are a useful independent target because they measure efficient use of the interconnection process as a common resource. Lower completion rates during early study phases can be a sign of an active interconnection

[20] Read about historical disturbance events here.

process and competitive market entry, but completion rates that are too low are a drain on transmission provider resources, which could be a sign of excessive speculation, and pose an obstacle to timely processing of interconnection queues. Late-stage withdrawals from the interconnection process, in particular, are problematic, given their impact on other projects in the queue. Completion rates for projects entering the later stage of the interconnection process, defined as projects that enter the facility study phase, have hovered around 50% since 2009, though in recent years these completion rates have been trending lower.[21] It is important to note that there are development risks to project completion that are outside of the interconnection process (e.g., permitting, supply chains, offtake) and are, therefore, not directly addressed by solutions in this roadmap.

Although it can be difficult to draw direct links between system reliability and interconnection, inverter tripping and other more specific reliability issues may have direct links to interconnection standards, including modeling standards. As the number of IBRs on the system increases dramatically over the next decade, Table 2 targets the elimination of these unexpected, large disturbance events (involving multiple IBRs) that are not captured in planning and real-time system studies due to inaccurate IBR models. Solutions in Chapter 4 of the roadmap aim to reduce the frequency of IBR disturbance events via new interconnection requirements and standards. Given new requirements will likely only apply to new equipment, disturbance events for legacy equipment may continue in the future. Nevertheless, efforts should be made to improve models for legacy equipment, especially for plants involved in previous disturbance events for improved fidelity of system studies.

Other measurable targets may be possible with more data collection and analysis. For instance, additional reliability metrics might also be desirable as new issues arise. Furthermore, a target focusing on supplier concentration in interconnection requests could capture fairness, equity, and open-access concerns, but the data to set this target is not currently publicly available (see Solution 1.1 for data transparency recommendations). Similarly, no industrywide data on the interconnection workforce is available to track turnover and retention or gaps with a specific skill set, but it could be important to develop.

Roadmap Scope

This roadmap is a result of the Interconnection Innovation e-Xchange (i2X),[22] launched by DOE in June 2022 to address interconnection challenges. Importantly, as this roadmap was being developed, FERC issued Order 2023,[23] which requires a first-ready, first-served clustering

[21] See slide 27 in Rand et al., "Queued Up." emp.lbl.gov/queues.
[22] Office of Energy Efficiency and Renewable Energy (EERE). i2X. www.energy.gov/eere/i2x/interconnection-innovation-e-xchange.
[23] FERC. July 2023. "Improvements to Generator Interconnection Procedures and Agreements," Order No. 2023, 184 FERC ¶ 61,054. www.ferc.gov/news-events/news/fact-sheet-improvements-generator-interconnection-procedures-and-agreements.

process for bulk power generator interconnections, deadlines for the cluster process and affected systems studies, and technology advancement.

Though this i2X roadmap contains some solutions that relate to Order 2023, it also introduces additional ideas that support longer-term interconnection process evolution. Overall, the solutions in this roadmap are intended to complement and support, not impede, Order 2023 implementation. They focus on issues that may still be unresolved in implementing Order 2023, such as how to balance stricter requirements for interconnection customers with open-access and equity considerations, how to incentivize minimizing interconnection study delays, and how to better coordinate affected system studies. However, they also go beyond Order 2023, addressing issues that were not raised in the order, such as data transparency and security, automation, interconnection studies, cost allocation, and workforce development. These latter suggestions are intended to be pursued in concert with Order 2023 implementation, and in many cases, transmission providers already have initiatives in these areas underway. Such a comprehensive approach is important not only to facilitate industrywide discourse that builds upon Order 2023 implementation but also to maintain relevance for transmission utilities that are not FERC jurisdictional. A table is included in the appendix that relates the roadmap solutions to corresponding rules in Order 2023.

FERC is also in the process of another related rulemaking on transmission planning. Enhanced transmission planning has been identified as a core element for improving the efficiency of the interconnection process.[24] Because of the close relationship between interconnection process and transmission planning, this roadmap includes some solutions that involve improvements in transmission planning (see portions of Chapters 2 and 3). However, the main focus of the roadmap is on interconnection reforms.

There are often a variety of paths forward, and real trade-offs between these paths should be considered. For instance, desires to ration interconnection queue entry need to be balanced with requirements to ensure open access to transmission interconnection. Similarly, requests to facilitate interconnection customer choice and control over individual project proposals could conflict with a capability to provide up-front outcome certainty about the interconnection process. This document presents information on multiple paths that industry stakeholders could consider when determining the solution set that best suits their situations. Regional differences will need to be accommodated when solutions are implemented.

Additionally, the current requirements, processes, and gaps for the interconnection of large loads, such as electric vehicle (EV) charging installations, was assessed through i2X. The growing electrification of the transportation sector, coupled with higher-power charging technology, is leading to a greater demand for high-capacity travel plazas and charging depots that provide charging capacities greater than 10 MW for the full set of vehicle classes: light-duty, medium-duty, and heavy-duty. This document includes a few future considerations and recommendations

[24] Read more about U.S. transmission needs in DOE's October 2023 *National Transmission Needs Study*, www.energy.gov/gdo/national-transmission-needs-study.

that could generally support load service connection at the transmission level, but as discussed above, it only briefly touches on these topics.

For the reasons above, the interconnection solutions identified in this roadmap are intended to be a collection of viable strategies rather than a rigid package of prescriptive fixes. Some of the solutions in the roadmap are complementary: to be effective, they would need to be implemented in tandem with other solutions. For instance, many of the solutions within the data transparency section of the roadmap are needed to most effectively implement solutions related to interconnection study improvements. Other solutions are exclusive: adopting one solution might obviate the need for or even preclude another. For instance, more coordinated and comprehensive transmission planning could alleviate the need for one-off actions to ration queue capacity. Finally, some solutions should only be considered as longer-term, last-resort ideas to explore if shorter- and medium-term efforts fail, such as market-based approaches to rationing interconnection. The roadmap aims to clearly articulate where these interrelationships among different solutions exist. Some regions have already adopted a subset of these ideas, while other regions have not, and the roadmap refers to such regional variation, where possible, when describing the variety of solution ideas.

This roadmap does not assess the cost of implementing the solutions or categorize which solutions can be relatively easy or hard to implement, as such assessments depend on the particulars of each region and their relative progress in already implementing a subset of these ideas. When discussing solutions, stakeholders will need to account for the costs and challenges of interconnection reform.

Roadmap Timelines

Each solution has a timeframe that indicates how long the solution might take to implement, or at least have its activities mostly completed. The roadmap uses three timeframes:

Short-term (1–3 years): Solution can be implemented within the next 1 to 3 years (by 2027).
Medium-term (3–5 years): Solution can be implemented within the next 3 to 5 years (by 2029) but will likely require activities to begin soon to enable eventual implementation.
Long-term (> 5 years): Solution would require additional exploration and development, which could begin today, but would require more than 5 years to implement (after 2030).
Some solutions may require ongoing activities. For example, a solution that involves evaluating the need for new interconnection standards would require ongoing efforts to monitor emerging technologies and determine whether their potential impacts to the transmission system are best managed through standards or during operations. In these cases, the roadmap highlights that solutions may be ongoing.

Long-term solutions may be futuristic ideas that require more development and rely on continued technological progress, or they may be ideas that would only be pursued if nearer- to medium-term solutions are not successful. In the latter case, for instance, if nearer-term reforms are not successful, it may be necessary to reconsider the relationship between interconnection and transmission rights and the participant-funding model of network upgrades.

A Roadmap for Stakeholders

This roadmap incorporates interconnection community ideas and potential solutions gathered from stakeholder workshops from 2021 to 2023, a series of virtual meetings called Solution e-Xchanges[25] held from April to August 2023, and an RFI published by DOE in November 2023 to solicit public feedback and comments on a draft version of this document. More than 40 organizations submitted comments.

The Solution e-Xchange topic areas included:

1. Queue Management & Cost Allocation
2. Grid Engineering Practices & Standards
3. Equity & Energy Justice
4. Grid Data Transparency
5. Interconnection Workforce & Training

These meetings engaged a diverse set of stakeholders. Throughout most of the United States, interconnection reforms are informed by transmission providers' stakeholder processes. Beyond transmission providers' stakeholder processes, FERC technical conferences, electric industry events, advocacy work, and research studies all contribute to the generation and dissemination of new ideas that eventually converge across different regions. Reform is thus a group effort. Transmission providers play a central role in managing the reform process, but often ideas and actions come from other stakeholders, such as: interconnection customers, state agencies, federal regulators, LSEs, equipment manufacturers, consumer advocates, EEJ communities, advocacy groups, consultants, and the research community, which includes DOE. Members from all these stakeholders engaged in the Solution e-Xchanges, and the solutions described in this roadmap are for this broader community of actors, rather than just transmission providers.

Each solution in this roadmap contains a table that identifies specific stakeholders (actors) and is assigned suggested actions. The actions are broken out into three categories of work: (1) engineering and technical (e.g., developing generator models, standards, study methods), (2) markets and regulatory (e.g., designing and implementing cost allocation policies, new regulatory structures, and ensuring compliance), and administrative and organizational (e.g., interconnection process changes, developing and identifying workforce needs). Specific actors that are referenced include:

Transmission Providers and Operators: including transmission owners, Independent System Operators (ISOs)/Regional Transmission Organizations (RTOs), non-ISO/RTO balancing area authorities, and government utilities.

[25] EERE. i2X Solution e-Xchanges. www.energy.gov/eere/i2x/i2x-solution-e-xchanges.

Interconnection Customers and Resource Developers: including generation, storage, large loads, and transmission developers and their original equipment manufacturers (OEMs).
Consumer Groups: including LSEs, such as investor-owned utilities, public utilities, and rural cooperatives, as well as consumer advocates in both wholesale and retail markets.
Research Community: including universities, research institutes, government agencies (including but not limited to DOE), and think tanks involved in creating new analyses, reports, and solutions.
Software Vendors: referring to companies that develop software products for other actors within the interconnection process.
Federal/state entities: Various government entities with authority on interconnection policy or to support funding initiatives. For example, FERC, NERC, the Energy Information Administration (EIA), the DOE, utility commissions, among others.

Many of these stakeholder categories incorporate a diverse range of actors that may not always represent the same point of view or be subject to the same regulatory authority, making clear categorization imperfect. For instance, transmission providers include both FERC-jurisdictional ISOs/RTOs and non-ISO/RTO regions as well as an ISO (Electric Reliability Council of Texas [ERCOT]) and government-owned balancing area authorities with limited FERC jurisdiction, such as the Bonneville Power Administration (BPA) and Tennessee Valley Authority. Additionally, interconnection customers include independent power producers, resource-owning utilities, Tribal energy developers and other EEJ communities, large-load developers (e.g., data centers), and transmission developers that may need to submit their projects within a transmission provider's interconnection queue.26 Furthermore, some utilities and cooperatives can be transmission providers, interconnection customers, and LSEs at the same time.

Because of this diversity, not all the solutions identified in the roadmap will be relevant to all actors, or in some instances, solutions may imply different actions or levels of effort by the same category of actor. For instance, transmission providers have different interconnection practices and currently have different levels of compliance with Order 2023. Similarly, interconnection customers have different capabilities and information needs and may be more or less active in contributing to improvements in interconnection processes through stakeholder and other initiatives. State lawmakers and agencies may have different perspectives on proactive transmission investments and cost allocation. While LSEs and consumer groups may be sensitive to the cost implications of interconnection, which ultimately will be passed on to their ratepayers, they could have different perspectives on the best strategies to keep costs low. Activities undertaken by different stakeholders tend to be interdependent, and the most comprehensive and effective change will require leadership, coordination, and collaboration between and within each category of actor. Finally, trade and industry associations and consultants are rarely explicitly referenced in the tables that exist throughout the roadmap. It is expected that these

[26] Transmission projects that are not included in transmission providers' transmission plans are studied through the interconnection process.

stakeholders would be directly supporting all the actors mentioned above in a variety of different roles and responsibilities, depending on their specific area of expertise.

DOE has multiple roles in implementing the identified solutions in the roadmap: convening stakeholders, facilitating solution adoption, providing technical assistance, providing loans and supporting the research community. Many DOE offices have interconnection-related activities, including the Office of Cybersecurity, Energy Security and Emergency Response (CESER), the Office of Electricity (OE), the Office of Energy Justice and Equity (EJE), the Grid Deployment Office (GDO), the Loan Programs Office (LPO), the Solar Energy Technologies Office (SETO), the Vehicle Technologies Office (VTO) and the Wind Energy Technologies Office (WETO). Through the funding of new research, pilot demonstrations, standards development, and stakeholder engagement these offices are supporting the implementation of many of the solutions identified in this roadmap. A more complete list of ongoing DOE interconnection-related activities and programmatic priorities is provided in Appendix A.

1. Increase Data Access, Transparency, and Security for Interconnection

Interconnection to the U.S. transmission system is premised on the notion that utility and market participants have sufficient information to make efficient generation siting and technology decisions. However, there has been continued concern that inadequate access to information is contributing to high volumes of interconnection requests, high project withdrawal rates, interconnection processing delays, and an overall inequitable system. Improved access to and quality of interconnection data also support other solutions, such as interconnection study automation. However, improved access and transparency must preserve competitively sensitive information and secure CEII by deploying appropriate data access controls programs.

Key Takeaways

Improvements to interconnection data transparency, beyond those required in FERC Orders 845 and 2023, would help improve interconnection customers' ability to screen and site potential projects, better enable third-party modeling, facilitate more process automation, enhance equitable outcomes, and enable benchmarking, tracking, and auditing of interconnection processes and reforms. Furthermore, improved data access and transparency support and underpin many of the other solutions identified throughout this roadmap.

Solutions Synopsis

Solution 1.1: Improve the scope, accessibility, quality, and standardization of **data on projects already in interconnection queues**, including project attributes, cost estimates, and post-IA information. (short-term)
Solution 1.2: Enhance the scope, timeliness, accuracy, and consistency of **interconnection study models and modeling assumptions** that transmission providers make available to interconnection customers. (short-term)
Solution 1.3: **Develop tools** to manage, analyze, and visualize transmission and interconnection data made available in the first two solutions, while ensuring secure data-sharing processes. (medium-term)

Solution 1.1: Improve the scope, accessibility, quality, and standardization of data on projects already in interconnection queues, including project attributes, cost estimates, and post-IA information. (short-term)

Regulators, transmission providers, resource developers, and other stakeholders can use interconnection data—data on queue volumes, processing times, estimated and final costs, project locations, and size and type of proposed power plants—to inform siting decisions, observe trends, monitor interconnection processes and outcomes, improve interconnection processes, evaluate EEJ metrics and outcomes, and track progress on reforms. Interconnection customers use these data to inform project siting and development timelines, and transmission providers can use them to support interconnection process automation. Interconnection data also provide indications of near-term electric sector trends, such as the volume, type, and location of new power plants being proposed and areas of emerging transmission constraints.

FERC currently requires transmission providers to collect and publish basic interconnection data.[27] Although transmission providers generally comply with basic requirements, there is still room to improve the scope, accessibility, quality, and standardization of interconnection data, while respecting proper data confidentiality. Transmission providers differ in the data that they make publicly available. For instance, some transmission providers include information on active, withdrawn, and operational projects, whereas others only include information on active projects. The latter limits retrospective analysis. Other examples of valuable data with limited availability are dates of key interconnection milestones, project location information (i.e., POI lat/long), additional detail and separation for hybrid or co-located power plants, interconnection customer name/organization, number of restudies required, and EIA plant identification to facilitate connection to other electricity sector datasets.

In addition, there is currently no requirement for transmission providers to collect, track, or make publicly available data on interconnection costs. Many transmission providers do make interconnection studies, which include interconnection cost information, available to the public. However, these data often only exist in PDF format, making it difficult to access and more comprehensively analyze cost data. Furthermore, they are often removed from public access over time.

There may also be limited information and transparency on timelines, progress, or costs after an IA is signed. Post-IA delays and escalating costs affect both transmission providers and interconnection customers. Basic data on post-IA timelines and costs could help monitor and address this problem.

Data accessibility is also an issue for non-ISO/RTO regions. Interconnection queue files are typically made available on transmission provider websites or Open Access Same-Time Information System pages. For ISOs/RTOs, these files are always provided in a machine-readable format (e.g., CSV or Excel file). For non-ISO/RTO transmission providers, however, files are more often provided in PDF format, which are cumbersome to process and analyze. Standardizing data reporting in tabular, machine-readable formats would improve accessibility. Such work may require improvements to information technology (IT) infrastructure if the data is not immediately available and easily accessible.

Addressing gaps and accessibility issues around interconnection data may require clearer guidelines and rules from FERC, efforts by transmission providers to take a user perspective so that the data can be useful, and engagement by interconnection customers and the research community so that it is clear how the data are being used and what format is best and so that

[27] Order 845 required transmission providers to report quarterly interconnection performance metrics, such as interconnection volumes, timelines, and delays. Order 2023 requires additional metrics reporting for cluster study and restudy processing times and volumes.

proper data confidentiality rules are upheld. As the agency charged with collecting, disseminating, and analyzing energy-related information, EIA could also play a key role in expanding and standardizing interconnection data reporting and then making that data available to the public.

Of course, providing better data transparency and access will need to balance any concerns over data confidentiality for cybersecurity and of competitively sensitive data, data security especially with regard to CEII, and data integrity to ensure that the data are accurate. Processes should be developed so that the data are not leveraged for malicious intent. Though the data discussed in this solution are less sensitive than the technical electric system data described in Solution 1.2 and 1.3, data availability must be done in a secure and repeatable way. More strategies to protect sensitive data are described in the next solution.

Table 3: Solution 1.1 Actors and Actions – Improve the scope, accessibility, quality, and standardization of data on projects already in interconnection queues, including project attributes, cost estimates, and post-IA information

Actor	Engineering and Technical	Market and Regulatory	Administrative and Organizational
FERC		- Expand and improve data reporting requirements	- Review and update guidelines for CEII and cyber-secure data access
EIA		- Expand and improve data reporting requirements	- Aggregate, organize, and publish interconnection data
Transmission providers	- Collect and organize data as needed, considering data confidentiality, security, and integrity - Automate data compilation and reporting	- Ensure compliance	- Share data management best practices across transmission providers - Determine whether information technology (IT) infrastructure requires updating
Interconnection customers	- Develop tools to leverage data to improve pre-request screening		- Participate in stakeholder discussions around data reporting requirements
Engineering, procurement, and construction entities		-Track and report on post-IA timelines, progress, and outcomes	
Research community (including DOE)	- Support data collection, compilation, and synthesis - Increase scope, depth, and frequency of data analysis	- Coordinate with FERC and transmission providers for data sharing - Measure and assess post-IA timelines and outcomes	- Engage with FERC, developers, and transmission providers to determine data needs and data security measures

Solution 1.2: Enhance the scope, timeliness, accuracy, and consistency of interconnection study models and modeling assumptions that transmission providers make available to interconnection customers. (short-term)

Order 845 already requires transmission providers to make a significant amount of information on interconnection study models and modeling assumptions ("study data") available to interconnection customers. This information is either available publicly or, for information that is deemed CEII, upon request through nondisclosure agreements.[28] Interconnection customers can use this information to evaluate potential sites for their projects before they submit an interconnection request.

Despite improvements in the transparency of study data, stakeholders engaged in i2X Solution e-Xchanges argued that information coverage, relevance, accuracy, standardization, and ease of access could be improved. In terms of information coverage, key areas included more detailed age and technical information on transmission equipment (as allowable with appropriate CEII precautions) to allow generation, large-load, and transmission resource developers to better assess where upgrades are likely needed to accommodate their projects. Stakeholders noted that it can be especially challenging to access critical data for non-ISO/RTO regions, including transmission line lengths, substation locations, transmission line routing, and generation plant locations. In terms of relevance and accuracy, key themes included better alignment between data updates and interconnection study cycles and automation of data updates and sharing. In terms of ease of access, key themes included more consistent processes for accessing CEII data.

Transmission providers are already incentivized to improve the timeliness and accessibility of study data, though structural improvements such as alignment between study cycles and information updates could further facilitate ensuring that the transparency of study data remains a priority. Improving the accuracy and consistency of solutions identified in interconnection studies could also aid in automation efforts (see more discussion on automation in Solution 2.3). For example, the process for identifying potential solutions to reliability issues and the list of potential solutions could be more standardized rather than custom designed for each study. Using consistent data, criteria, and methods across interconnection studies could allow for automation in more circumstances and improve transparency and confidence in study results (see more discussion on interconnection study assumptions and methods in Solution 3.6).

The extent to which resource developers can make use of study models and data varies. The cost of hiring and training staff or consultants to conduct interconnection studies is relatively high, which likely increases the chances that smaller or newer resource developers rely more on the interconnection queue than conducting their own pre-interconnection request studies to gain information about different sites, contributing to queue backlogs. Developing open-source short-circuit, power flow, and other engineering models of the transmission network could increase the number of interconnection study suppliers, reducing the cost and other barriers for generation, large-load, and transmission resource developers to undertake their own interconnection studies.

Transmission providers could also allow resource developers to run more detailed studies on their models for a fee, as the Australian Energy Market Operator (AEMO) does with its

[28] Order 845 requires that the base cases, models, and assumptions used in interconnection studies be made available to interconnection customers upon request. The Federal Power Act requires transmission providers to report a variety of planning and reliability data in Form 715; some of this data is publicly available, whereas other data is considered CEII and must be requested.

Connection Simulation Tool.[29] Tools to visualize available transmission capacity and other transmission and interconnection data (Solution 1.3) can complement resource developer interconnection studies.

FERC and DOE could also consider clarifying and expanding its guidelines for the scope, timeliness, and accuracy of this information, particularly for CEII data.[30] While there is an urgency associated with making this technical data available to interconnection stakeholders, it must be done securely such that data are not used for malicious intent by motivated actors leveraging advanced computer technologies.

To support this effort, DOE could review the interconnection data described above, evaluate its potential to impact the cybersecurity of electricity infrastructure, and then recommend tools, policies, and guidelines to aid the establishment of data-sharing agreements for appropriate and authorized interconnection stakeholders. NARUC recently developed a grid data sharing framework[31] as well as a set of cybersecurity baseline recommendations for distribution systems,[32] which could be referenced for corresponding best practices in transmission systems. Such recommendations would support enhancements to current data access controls programs that transmission providers use to ensure that data access is available to authorized users while protecting it from actors with malicious intent.

Table 4: Solution 1.2 Actors and Actions – Enhance the scope, timeliness, accuracy, and consistency of interconnection study models and modeling assumptions that transmission providers make available to interconnection customers

Actor	Engineering and Technical	Markets and Regulatory	Administrative and Organizational
FERC		- Expand and improve requirements for study data	- Review and update guidelines for CEII data access
State agencies		- Develop access control recommendations for all stakeholders	
Transmission providers	- Explore opportunities for automating study data updates	- Engage with market participants to determine additional information needs	- Better integrate data updates with queue cycles and transmission plan updates

[29] The Connection Simulation Tool allows developers to run EMT studies on AEMO's PSCAD model. It is unclear if this approach makes sense for less detailed studies. See the Energy Systems Integration Group (ESIG) webinar "AEMO's Connection Simulation Tool" (www.esig.energy/event/webinar-aemos-connection-simulation-tool/).
[30] FERC is responsible for establishing rules to determine the scope of CEII data and facilitating access to that data. However, scope and access vary by transmission provider. As an example, compare the different definitions of and processes for requesting accessing to CEII data in PJM (www.pjm.com/forms/ceii-form.aspx) and NYISO (nyiso.my.site.com/MemberCommunity/s/article/What-to-expect-when-submitting-a-CEII-Request-form). DOE also has procedures for the designation, sharing, and protection of CEII pursuant to section 215A(d) of the Federal Power Act (FPA), codified at 16 U.S.C. 824o–1(d).
[31] NARUC Grid Data Sharing Framework, November 2023, https://www.naruc.org/core-sectors/energy-resources-and-the-environment/electric-vehicles/grid-data-sharing/
[32] NARUC Cybersecurity Baselines for Electric Distribution Systems and DER, February 2024, https://www.naruc.org/core-sectors/critical-infrastructure-and-cybersecurity/cybersecurity-for-utility-regulators/cybersecurity-baselines/

Actor	Engineering and Technical	Markets and Regulatory	Administrative and Organizational
		- Ensure compliance with FERC rules and CEII guidelines	- Determine whether IT infrastructure requires updating -Enhance current data access control programs that authorize and administer external data securely
Interconnection customers	- Develop or support the development of open-source study models	- Engage with transmission providers to determine additional information needs	-Participate in development of data access requirements
Equipment manufacturers			- Provide relevant technical specifications of equipment in line with study timelines - Standardize technical documentation to better enable study standardization and automation
Research community (including DOE)	- Develop or support the development of open-source models - Develop tools to facilitate secure data sharing	- Support regulators, state agencies, and transmission providers to policies around data access control programs	

Solution 1.3: Develop tools to manage, analyze, and visualize transmission and interconnection data made available in the first two solutions, while ensuring secure data-sharing processes. (medium-term)

Although the availability of study and interconnection data has improved significantly over the past decade, these data are often still difficult for regulators, interconnection customers, and other stakeholders to access and use. Some transmission providers have developed online tools that allow resource developers to visualize and analyze available interconnection (transmission) capacity and interconnection queue data. Transmission providers are in the process of developing or already have an interactive visualization tool for available transmission capacity.[33] Order 2023 makes these tools mandatory.[34, 35] Some ISOs/RTOs also publish interactive queue data dashboards that allow resource developers to see the size, technology, and location of projects in the queue.[36] Yet there are opportunities to improve these tools. For example, some existing heatmap tools are not updated frequently enough to provide value to interconnection customers.

33 MISO already has such a tool (Points of Interconnection Tool). CAISO, PJM (Queue Scope), and SPP are in the process of considering or developing tools.
34 Order 2023, pp. 117–140.
35 More coordination work would be needed between transmission providers to consider affected system issues that might require a unified heatmap across the United States that considers multiple balancing areas.
36 See SPP's Generator Interconnection Queue Dashboard (app.powerbi.com/view?r=eyJrIjoiNWRlMjYyN2EtOTA2Ny00NTE0LWI2M2QtMGE3MTAxZTAxOGE0IiwidCI6IjA2NjVkY2EyLTExNDEtNDYyNS1hMmI1LTY3NTY0NjNlMWVlMSIsImMiOjF9) and ERCOT's Interconnection Queue Trends

Several software providers[37] have developed tools and systems that enable more automated, up-to-date, user-controlled, and confidential injection capacity calculations, similar to the interconnection model developed and utilized by AEMO.[38] Given the complex, dynamic, and evolving nature of interconnection, transmission providers should seek to test, improve, and deploy visualization tools that enable near-real-time data refresh and automated functionality for interconnection customers (the development of such capabilities could obviate the need to consider Solution 3.7 in the longer term). While compliance with Order 2023 will be the near-term priority for most transmission providers, the development and testing of these more sophisticated tools could happen in parallel with, as well as after, compliance.

Currently, assessments of available transmission capacity are based on analysis of thermal ratings and voltage criteria. As the quantity and capacity of IBRs continue to increase, grid strength will decline, and a greater understanding of system dynamics and stability is necessary.[39] In addition to transmission capacity data and basic information on interconnection queues, additional data analyses may be necessary to understand the stability impacts and mitigation strategies due to IBR deployment in specific areas of the system. Better transparency of grid stability via maps or other visualizations could be particularly valuable in guiding where synchronous, flexible, and/or storage technologies should be sited, especially considering FERC Order 901.[40] Due to the sensitive and confidential nature of some of these data, appropriate CEII precautions would be necessary. Solution 1.2 above provided more detailed guidance for DOE and FERC to ensure that advent of new data transparency tools does not jeopardize system cybersecurity.

Expanding and harmonizing these tools across transmission providers could help reduce speculative interconnection requests by providing easy-to-use tools to resource developers as well as enhance equity and competition by reducing the transaction costs of uncovering and interpreting information for smaller and less established resource developers. The enhanced transparency would contribute to leveling the playing field for EEJ projects from under-resourced communities and resource developers who currently struggle with engaging in the interconnection process.

(https://public.tableau.com/app/profile/ercot.resource.adequacy/viz/ERCOTInterconnectionQueueTrends/SuccessRatesDashboard).

[37] See, for example, Pearl Street Technologies and Nira Energy (www.canarymedia.com/articles/transmission/its-hard-to-connect-clean-power-to-the-grid-new-software-can-help) as well as related discussion in "What Clean Energy Developers Need to Know About Hosting Capacity Maps," *Renewable Energy World*, www.renewableenergyworld.com/solar/utility-integration/what-clean-energy-developers-need-to-know-about-hosting-capacity-maps/.

[38] ESIG. March 2023. "AEMO's Connection Simulation Tool." www.esig.energy/event/webinar-aemos-connection-simulation-tool/.

[39] MISO. February 2021. "MISO's Renewable Integration Impact Assessment (RIIA): Executive Summary." cdn.misoenergy.org/RIIA%20Executive%20Summary520053.pdf.

[40] FERC. October 2023. "Reliability Standards to Address Inverter-Based Resources," Order No. 901, 185 FERC ¶ 61,042.

Furthermore, visualizations of data made available by Solutions 1.1 and 1.2 that would be useful to resource developers and would not impose undue burdens on transmission providers could result in higher-quality interconnection applications. Developing tools to visualize and analyze transmission and interconnection data will likely require an industrywide effort as well as ongoing discussions among stakeholders to determine which kinds of data visualizations and analyses are best provided by transmission providers[41] and which are best left to resource developers, external data providers, and the research community.

Table 5: Solution 1.3 Actors and Actions – Develop tools to manage, analyze, and visualize transmission and interconnection data made available in the first two solutions, while ensuring secure data-sharing processes

Actor	Engineering and Technical	Market and Regulatory	Administrative and Organizational
Transmission providers	- Develop and support development of visualization tools - Develop, test, and deploy systems to ensure data used in visualizations are up to date	- Comply with requirements for visualization tools	- Convene stakeholders
Interconnection customers		- Propose additional visualization tools and metrics	
Software vendors	- Develop visualization software, giving due consideration to CEII concerns - Develop tools and systems to ensure models and data are up to date		
Research community (including DOE)	- Support software development	- Propose additional visualization tools and metrics	

[41] For another example of new analyses being provided by transmission providers, see MISO and CRA, "MISO Interconnection Queue: M2, M3 and M4 Security Deposits and Return Procedures," *cdn.misoenergy.org/20230719%20PAC%20Item%2006%20Charles%20River%20Associates%20Queue%20Reform%20Report629633.pdf*.

2. Improve Interconnection Process and Timeline

Interconnection backlogs and delays are often the result of rapid growth in interconnection requests, inefficiencies in interconnection processes, and staffing constraints. For the United States, interconnection queue volumes are likely to be large and potentially volatile for the foreseeable future. Developing more robust interconnection processes that can mitigate existing queue backlogs and be more robust for growth in interconnection requests will require improvements in interconnection process and timing. At the same time, enhancements to interconnection and, relatedly, transmission-planning processes can help make interconnection outcomes more inclusive and fairer.

This section focuses on four areas:

Queue management (Section 2.1) – how generation interconnection requests are managed, from the submission of an interconnection request to the final execution of an IA.
Affected system studies (Section 2.2) – the process and methods through which impacts on neighboring electricity systems are studied.
Inclusive and fair process (Section 2.3) – the extent to which different groups can access and receive fair treatment in interconnection and transmission-planning processes.
Workforce development (Section 2.4) – how professionals working on interconnection are trained, hired, and retained.
These four areas are not exhaustive in terms of improving interconnection process timing. Other solutions in this roadmap, such as interconnection study enhancements (Section 3.3), can also help improve process efficiency.

2.1. Queue Management

Key Takeaways

Several incremental queue management solutions—from automation and expanded access to fast tracks to more stringent commercial readiness requirements and study timelines—may help reduce queue volumes and interconnection delays in the near term and enable transmission providers to handle larger and variable queue volumes in the longer term. In the near term, transmission providers may face a trade-off between rationing interconnection queue space and maintaining open access.

Solutions Synopsis

Solution 2.1: Implement and enforce more stringent **commercial readiness requirements, financial commitments**, withdrawal penalties, and time limits that balance effectiveness, equity, and open-access principles. (short-term)
Solution 2.2: Implement and enforce **interconnection study timelines and use incentives** for minimizing delays in completing studies. (short-term)

Solution 2.3: Continue to **automate parts of the interconnection process**, such as data input and validation, some customer communications, and data sharing across processes and models. (short-term)
Solution 2.4: Continue to monitor interconnection processing times and, as needed, **develop one-off interventions for mitigating queue backlogs**, such as hiring additional temporary staff, outsourcing, temporary fast tracking, and temporary rationing of queue space. (short-term)
Solution 2.5: Create new and better utilize existing **fast-track options for interconnection**, such as surplus interconnection service, generation replacement service, and energy-only interconnection service. (medium-term)
Solution 2.6: Consider **market-based approaches to rationing interconnection** access. (long-term)

Solution 2.1: Implement and enforce more stringent commercial readiness requirements, financial commitments, withdrawal penalties, and time limits that balance effectiveness, equity, and open-access principles. (short-term)

At the time of Order 2003, the extent to which resource developers would use the interconnection process to obtain project cost and other siting information was not fully anticipated. However, because the interconnection process provides accurate, binding information on interconnection costs and operational requirements, resource developers often use the interconnection process to determine project viability. Additionally, due to long queue wait times, resource developers may also submit interconnection requests to maintain a place in line, to be able to turn around projects more rapidly if they can find a buyer. The growth of comparatively new technologies--such as wind, solar, and storage--that have different characteristics and generally shorter construction cycles exacerbated these tendencies, especially in the face of low barriers to entering and exiting the queue. These practices, often referred to as "speculative" or "exploratory" requests, contributed rapid growth in queue volumes, high rates of withdrawal, and longer timelines in the 2000s under Order 2003's serial, "first-come, first-served" approach to processing interconnection requests.[42]

In response, some transmission providers began to move toward a "cluster based, first-ready, first-served" approach that (1) processes multiple requests in clusters rather than serially and (2) conducts interconnection studies in phases, with progressively higher commercial readiness requirements and financial commitments for resource developers at each phase.[43] This approach is now standard among most ISOs/RTOs and is required for all transmission providers under FERC Order 2023.[44] Several larger non-ISO/RTO regions also have recently implemented

[42] For an overview of the challenges facing ISOs during the 2000s, see ISO/RTO Council, 2008, "Comments of the ISO/RTO Council," FERC Docket No. AD08-2-000. Also see Order 2023, paragraph 3, 27-28 for more discussions on the need for reform.
[43] CAISO, MISO, and SPP, for instance, adopted first-ready, first-served reforms in 2008 and 2009, following a 2007 technical conference on interconnection reforms. See Order 2023, pp. 14–15.
[44] With the implementation of PJM's approved interconnection reforms (181 FERC ¶ 61,162), all ISOs/RTOs will have some form of a first-ready, first-served interconnection process.

cluster study processes.[45] Most ISOs/RTOs have financial commitments that are significantly higher than the standard deposits in Order 2023, and some ISOs/RTOs have recently proposed increasing the level of these commitments given continued concerns about the volume of interconnection requests.[46] FERC and ISOs/RTOs will need to continuously assess trade-offs for such rules in the future, balancing interconnection process efficiency with open-access principles.

The goal of stricter readiness requirements, financial commitments, and withdrawal penalties is to incentivize interconnection customers to do more preparatory work before requesting interconnection and discourage later-stage withdrawals from the interconnection process. The first-ready, first-served design and its phased approach forces interconnection customers to decide whether to remove their projects from the queue, rather than letting them linger, and provides an off-ramp for nonviable projects to exit the queue. However, finding the right balance between stricter requirements and open-access principles will require ongoing discussions with stakeholders. Stricter requirements tend to shift more risk onto interconnection customers and may increase barriers for under-resourced resource developers (e.g., Tribal utility authorities and rural cooperatives).[47] Lower requirements reduce barriers to entry but may generally lead to higher queue volumes. This solution focuses on striking an appropriate balance through implementation.

An emerging concern is that projects fail to reach commercial operation even though they have signed IAs. Transmission providers' Large Generator Interconnection Agreements (LGIAs) stipulate the conditions under which an interconnection customer can extend its commercial operation date without the risk of having its IA terminated. However, both transmission providers and interconnection customers are concerned about the lack of transparency in process

[45] Examples include PacifiCorp and Duke Energy Carolinas.
[46] FERC. Order 2023 (184 FERC ¶ 61,054), paragraph 491. Order 2023 establishes an application fee of $5,000 alongside the following study deposit framework: $35,000 + $1,000/MW for projects > 20MW–< 80MW; $150,000 for projects ≥ 80MW–< 200 MW; $250,000 for projects ≥ 200MW. By contrast, SPP requires an initial security deposit of $4,000/MW to enter the queue, an additional deposit of $4,000/MW to advance to Study Phase Two, followed by a deposit equaling 20% of the project's allocated upgrade costs in order to enter into the facilities study. These security deposits are additional to study deposits, which range from $25,000 to $90,000 based on the requested interconnection capacity (see SPP, "Attachment V," *Open Access Transmission Tariff, Sixth Revised Volume 1*, opsportal.spp.org/documents/studies/SPP%20Tariff%20Attachment%20V%20Generator%20Interconnection%20Procedures.pdf). MISO requires a $4,000/MW deposit and a study deposit ranging from $50,000 to $640,000 (based on interconnection capacity) prior to initiating the phase 1 study (see MISO, Miso Transmission Expansion Plan [MTEP], www.misoenergy.org/planning/generator-interconnection/). MISO has proposed increasing the M2 milestone deposit from $4,000/MW up to $10,000–$14,000/MW (see MISO and CRA, "MISO Interconnection Queue," cdn.misoenergy.org/20230719%20PAC%20Item%2006%20Charles%20River%20Associates%20Queue%20Reform%20Report629633.pdf.)
[47] There are equity implications of the Order 2023 readiness requirement and financial commitment rules. Order 2023 allows for high deposit payments in lieu of site control/readiness requirements, but such a rule may risk equitable outcomes if only well-resourced developers can use it. Further discussions about whether lower deposit requirements for under-resourced developers, which might be taking up limited space in the queues today, could be warranted.

and progress after an IA has been signed. A potential solution to this issue is discussed in Solution 2.3.

Table 6: Solution 2.1 Actors and Actions – Implement and enforce more stringent commercial readiness requirements, financial commitments, withdrawal penalties, and time limits that balance effectiveness, equity, and open-access principles

Actor	Engineering and Technical	Market and Regulatory	Administrative and Organizational
FERC		- Consider and assess trade-offs in approving transmission provider filings	
Transmission providers		- Balance stricter requirements and penalties with open access	- Convene stakeholders
Interconnection customers	- Strengthen ability to evaluate projects before submitting requests	- Reduce number of exploratory requests	
Research community (including DOE)		- Monitor and document changes in requirements and penalties - Evaluate effectiveness and impacts on access	

Solution 2.2: Implement and enforce interconnection study timelines and use incentives for minimizing delays in completing studies. (short-term)

Order 2003 set a "reasonable efforts" standard for transmission providers to complete interconnection studies within the deadlines specified in their tariffs. Recognizing that this approach has not provided adequate incentives for timely completion of studies, Order 2023 establishes timelines for the pro forma cluster study process and penalties on transmission providers for missing study deadlines.[48] This solution focuses on the implementation (transmission providers) and enforcement (FERC) of these rules, including the pass through of incentives to neighboring transmission providers, transmission owners, and other entities that conduct interconnection studies. Solutions that transmission providers might use to ensure that studies can be completed within deadlines are described in this and other sections of the roadmap. Importantly, while reducing queue study delays could benefit all interconnection customers, it would also offer additional relief to EEJ resource developers who might lack the resources and capital to manage lengthy backlogs and higher uncertainty.

[48] Order 2023 (184 FERC ¶ 61,054) requires cluster studies to be completed in 150 calendar days (paragraph 324), cluster restudies to be completed in 150 calendar days (paragraph 329), affected system studies to be completed in 150 calendar days (paragraph 1134), and facilities studies to be completed in 90 or 180 days (depending on level of accuracy) (Appendix C). For penalty amounts, see FERC Order 2023 (184 FERC ¶ 61,054), paragraph 962. A penalty of $1,000 per business day will be incurred for delays of cluster studies beyond the tariff-specified deadline, $2,000 per business day for cluster restudies, $2,000 per business day for affected system studies, and $2,500 per business day for delays of facilities studies.

Table 7: Solution 2.2 Actors and Actions – Implement and enforce interconnection study timelines and use incentives for minimizing delays in completing studies

Actor	Engineering and Technical	Market and Regulatory	Administrative and Organizational
FERC		- Monitor compliance and enforce incentives	
Transmission providers		- Develop strategies for complying with study deadlines	- Assess penalties on study providers and affected systems, where applicable
Research community (including DOE)		- Track study timelines, compliance, and incentives - Assess effectiveness	

Solution 2.3: Continue to automate parts of the interconnection process, such as data input and validation, some customer communications, and data sharing across processes and models. (short-term)

Over the past two decades, transmission providers have made important strides in automating interconnection processing, through the creation of online portals to handle interconnection requests and the development of software for managing interconnection queues. Continued and targeted automation of interconnection processes could enable transmission providers to handle larger volumes of interconnection requests in the future by enabling them to process more requests without necessarily scaling up staff or resources. Automation of the interconnection process is also expected to reduce iterations of incomplete applications by requiring sufficient information before a project even enters the queue process.

Targeted areas for automation include application processing, data collection and validation, data management systems, customer interaction and other communication systems, model building for interconnection studies, and writing up of study results.[49] More discussion of the data transparency initiatives that would facilitate automation can be found in Solution 1.2.

Automation could also help facilitate transparency, communication, and accountability once IAs have been signed. Interconnection customers may face uncertainty in the timelines and costs for completing construction of interconnection facilities and network upgrades. Transmission providers face uncertainty in the progress of projects toward commercial operation. A potential strategy for reducing uncertainty on both sides might be web-based portals that allow regular updates from transmission owners and interconnection customers, coupled with regular reporting requirements. Such a portal could additionally be used for any necessary modeling updates prior to commercial operation, as discussed in Solution 4.3.

Transmission providers, market participants, and the research community could all play a role in identifying and prioritizing opportunities for automation, which in turn would help software

[49] For instance, SPP has been collaborating with Amazon Web Services to enhance the automation of the interconnection study process via multiple of these targeted areas. (Driscoll, W., October 2023, "Artificial Intelligence Could Speed Interconnection, Says Amazon Executive," *PV Magazine*, pv-magazine-usa.com/2022/10/17/artificial-intelligence-could-speed-interconnection-says-amazon-executive/.)

providers tailor products to transmission provider needs. Some kinds of automation could be paid for through federal grid modernization funding, with congressional approval, as automation of interconnection processes could have national benefits by increasing the competitiveness of U.S. wholesale markets. Though some automation can and should be implemented in the short term, efforts to automate the interconnection process are likely to be ongoing into medium and longer terms.

Table 8: Solution 2.3 Actors and Actions – Continue to automate parts of the interconnection process, such as data input and validation, some customer communications, and data sharing across processes and models

Actor	Engineering and Technical	Market and Regulatory	Administrative and Organizational
Federal entities		- Identify opportunities for federal funding for automation	
FERC		- Encourage transmission providers to identify opportunities for automation	
Transmission providers	- Identify needs and priority areas for automation	- Identify opportunities for federal funding for automation	
Interconnection customers			- Provide feedback to transmission providers and FERC on priority areas for automation
Research community (including DOE)	- Support software development for automation	- Identify needs and priority areas for automation	
Software vendors	- Develop and tailor queue software that automates queue functions		

Solution 2.4: Continue to monitor interconnection processing times and, as needed, develop one-off interventions for mitigating queue backlogs, such as hiring additional temporary staff, outsourcing, temporary fast-tracking, and temporary rationing of queue space. (short-term)

If current actions prove insufficient, transmission providers may need to undertake one-off interventions to reduce queue backlogs and interconnection delays, particularly if interconnection delays affect resource adequacy. These interventions might include hiring additional temporary staff, outsourcing more queue processing and study work, allowing some requests to be temporarily fast-tracked, and rationing queue space. For instance, PJM's FERC-approved proposal to reduce its queue backlog includes several temporary measures: consolidating different vintages of interconnection requests, shortening timelines for paying deposits and demonstrating site control for some customers, and allowing projects that do not trigger or trigger smaller network upgrades to be fast-tracked through the interconnection process.[50]

The California Independent System Operator (CAISO) and MISO have recently proposed strategies to administratively ration interconnection queue entry to reduce queue volumes, though MISO's proposal was rejected by FERC.[51] CAISO's proposal would prioritize interconnection in zones that currently have available transmission capacity or will have available capacity based on CAISO's transmission plan, and it would limit studies to projects that are aligned with California's resource planning portfolios.[52] MISO's proposal would have limited annual interconnection requests to its annual peak demand.[53] Administrative rationing may be a short-term strategy for temporarily clearing backlogs, but it would likely be inconsistent with open-access and competition policies and may have unintended consequences.[54] It would thus be more of a short-term, emergency solution rather than a longer-term one.

Table 9: Solution 2.4 Actors and Actions – Continue to monitor interconnection processing times and, as needed, develop one-off interventions for mitigating queue backlogs, such as hiring additional temporary staff, outsourcing, temporary fast-tracking, and temporary rationing of queue space

Actor	Engineering and Technical	Market and Regulatory	Administrative and Organizational
FERC		- Review solutions for mitigating backlogs	- Monitor progress in mitigating backlogs
Transmission providers, interconnection customers, research community (including DOE)		- Propose solutions	- Monitor progress in mitigating backlogs
Consumer groups		- Propose solutions	- Monitor ability to procure capacity and maintain resource adequacy

Solution 2.5: Create new and better utilize existing fast-track options for interconnection, such as surplus interconnection service, generation replacement service, and energy-only interconnection service. (medium-term)

FERC Orders 2003, 845, and 2023 created a framework for allowing interconnection customers to expedite interconnection requests if they choose to make use of existing transmission capacity.

[50] Read more about the PJM interconnection process reform task force here.
[51] These policies have been developed, in part, to avoid the creation of models and scenarios that do not provide reasonable, predictable, or meaningful outcomes. For instance, 171 GW of new interconnection requests were generated in the 2022 MISO interconnection cycle, exceeding the summer peak load in MISO and posing challenges to modeling reasonable interconnection impacts within one comprehensive cluster study.
[52] CAISO, 2023, *2023 Interconnection Process Enhancements Track 2 Discussion Paper*. For example, CAISO is considering only studying projects requested by LSEs or other offtakers.
[53] MISO, 2023, MISO and CRA, "MISO Interconnection Queue," cdn.misoenergy.org/20230719%20PAC%20Item%2006%20Charles%20River%20Associates%20Queue%20Reform%20Report629633.pdf.
[54] Some regions that have limited queue entry in the past have seen record numbers of queue applications in subsequent queue application windows.

Order 2003 allowed customers to select energy resource interconnection service (ERIS),[55] in which they would receive "as available" transmission service rather than having to wait for and pay for network upgrades. Order 845 created several pathways—requesting service below generating facility capacity, provisional service, and surplus interconnection service—in which new projects could come online without needing to first go through the full study process for new resources. Order 2023 enables co-located resources to share an interconnection request and allows customers to add a generating facility to a request if it does not change the customer's requested service level.

FERC has also recently approved several proposals for generator replacement processes, in which customers can request interconnection for a new project that is replacing an existing generator through a separate, expedited process.[56] Expedited replacement of thermal generators would benefit resource owners by allowing projects to move through the interconnection process more quickly, but it could also benefit local communities through improved air and water quality, which could offer opportunities for EEJ community partnerships. Given the large amount of generation that is expected to retire over the next decade, generator replacement processes may become an important avenue for bringing new generation online.[57]

In practice, transmission providers have taken different approaches to expediting interconnection requests, and several avenues for fast-tracked interconnection service remain underutilized. Order 2003 did not require a fast track for ERIS, and most FERC-jurisdictional transmission providers do not appear to allow ERIS (or energy-only interconnection) requests to move through the interconnection queue faster than capacity interconnection requests (network resource interconnection service [NRIS]).[58] Fast tracks could take the form of off-ramps for energy-only projects, after cluster reliability studies are complete, or separate study processes for energy-only and capacity requests. To preserve flexibility, interconnection rules could allow

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[55] Generally referred to as "energy-only service" in this roadmap.

[56] MISO and SPP have FERC-approved generator replacement processes. FERC has also approved expedited interconnection processes for non-ISO/RTO utilities, including Arizona Public Service, Dominion, Duke, and PacifiCorp. The rationale for allowing projects that replace retiring generation to receive expedited interconnection service is that studies for that POI have already been completed and thus the new projects do not necessarily need to undergo more detailed cluster study. In SPP's process, for instance, replacement projects are screened through a replacement impact study. If SPP determines that the replacement project will have a material adverse impact on its system, the project will be processed as a new interconnection request and undergo more detailed study.

[57] For instance, NERC's 2022 *Long-Term Reliability Assessment* reports 88 GW of confirmed generator retirements in North America over the next decade.

[58] ERCOT, which is not FERC jurisdictional, effectively fast-tracks interconnection requests because it does not study or charge customers for network upgrades. This approach is sometimes referred to as "connect and manage." ERCOT's approach would be difficult to replicate identically in other jurisdictions, particularly in multistate RTOs, due to (1) the challenges of allocating the costs of transmission owner-funded upgrades across states and (2) the presence of resource adequacy programs that require deliverability to participate (ERCOT has not historically had a resource adequacy program because of its energy-only market structure). Cost allocation issues associated with congestion upgrade-related elements of this approach are covered later in this roadmap (Solution 4.2). See Norris, Tyler, August 2023, "Beyond FERC Order 2023: Considerations on Deep Interconnection Reform," Duke University, nicholasinstitute.duke.edu/publications/beyond-ferc-order-2023-considerations-deep-interconnection-reform, for an overview of "connect and manage" and energy-only interconnection.

energy-only projects to request capacity service and obtain resource adequacy eligibility at a later date, as some ISOs/RTOs currently do.[59]

Most transmission providers have not yet, or have only recently, finalized rules to comply with Order 845, and business models that use service below full capacity and surplus interconnection service are still at an early stage.[60] Among ISOs/RTOs, only MISO and SPP have generator replacement processes in which resource owners can replace retiring generation with any technology type as long as the new resource does not have a material adverse impact on the transmission system. In other regions, more work is needed to improve what qualifies as a reasonable material modification when implementing a generator replacement or surplus interconnection service process (e.g., considering power capacity levels, short-circuit impacts, synchronous inertia, and voltage support).[61] Furthermore, in both ISO/RTO and non-ISO/RTO jurisdictions with vertically integrated utilities, there are still open questions about potential conflicts between generator replacement processes and competition policy that may require guidance and rules from state and potentially federal regulators.[62] Although there are many co-located projects in interconnection queues, there is likely potential to add storage to currently operating projects in ways that avoid system impacts and the need for interconnection studies.

Creating new and better utilizing existing fast-track options thus implies a range of actions by different actors that vary across avenues for expedited interconnection service and depend on market conditions and transmission providers' current rules. For instance, creating a separate fast-track lane for energy-only requests would likely need consideration from FERC, deeper examination of different options by transmission providers, and proposals and analysis from the research community. By contrast, most transmission providers have or are developing rules for requesting service below facility capacity and surplus interconnection service, but the maturity of these services varies across jurisdictions.

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[59] For instance, CAISO's *Generator Interconnection and Deliverability Allocation Procedures (GIDAP)* clearly describe the process through which energy-only projects can request deliverability. Anecdotally, other ISOs/RTOs also allow interconnection customers to change from energy-only service to capacity service and vice versa, but the processes for doing so are not always well documented.

[60] For an example of rules for surplus interconnection service, see section 3.3.1.1 of MISO's tariff. Most of MISO's proposals for surplus interconnection service are storage added to wind and solar facilities. See MISO, "Surplus Interconnection Service Requests," https://view.officeapps.live.com/op/view.aspx?src=https%3A%2F%2Fcdn.misoenergy.org%2FSurplus%2520Interconnection%2520Service%2520Requests458123.xlsx&wdOrigin=BROWSELINK.

[61] Some transmission providers allow replacement generation to receive expedited interconnection if the replacement is the same technology type as the original generator, but they require replacements with new technology types to submit requests for new interconnection service. MISO's and SPP's generator replacement processes allow expedited interconnection for any new technology type if it does not have an adverse material impact on the transmission system. For an overview of MISO and SPP's processes, see Greene, Ben, July 2023, "MISO/SPP Generator Replacement Process," American Electric Power, www.pjm.com/-/media/committees-groups/subcommittees/ips/2023/20230731/20230731-item-11---pjm-ips-transfer-of-cirs-education---miso_spp_pacificorp_pjm-ver-7-31-2023.ashx.

[62] For instance, incumbent utilities may be able to use generator replacement processes as a means to circumvent competitive procurement requirements. See FERC, January 2023, "Commissioner Clements Dissent Regarding PacifiCorp," in 182 FERC ¶ 61,003 (Docket ER23-407-000).

Fast-track options can be supported by improved data access and transparency (Solutions 1.1–1.3), which would provide interconnection customers with more information on where available transmission capacity exists and whether fast-track options might be economically attractive. Furthermore, fast-track options would benefit from improvements to interconnection study processes (as discussed in Solutions 3.5 and 3.6). As a general principle, the development of fast tracks should complement efforts to improve the interconnection process by reducing the volume of new service requests, but it should not unduly detract, distract, or divert resources away from these efforts.

Table 10: Solution 2.5 Actors and Actions – Create new and better utilize existing fast-track options for interconnection, such as surplus interconnection service, generation replacement service, and energy-only interconnection service

Actor	Engineering and Technical	Market and Regulatory	Administrative and Organizational
FERC		- Consider guidelines for energy-only fast tracks and generator replacement	
Transmission providers	- Explore technical options for fast-tracking energy-only requests - Develop "like-for-like" specifications for generator replacement - Develop fast-tracking for capacity additions that do not change the customer's requested service level		
Interconnection customers		- Explore business models for surplus interconnection service, co-located storage	
Research community (including DOE)	- Develop approaches for fast-tracking energy-only requests without affecting reliability	- Monitor use of fast-track options in interconnection queues	

Solution 2.6: Consider market-based approaches to rationing interconnection access. (long-term)

If nearer- to medium-term efforts to process large volumes of interconnection requests are not successful, an alternative approach may be to use market-based mechanisms to ration access to interconnection queues. For instance, in their 2023 *Interconnection Process Enhancements* document, CAISO proposed the use of zonal auctions to help achieve manageable queue volumes.[63] Variations on market-based approaches to rationing access might consider market

[63] Emmert, R., et al. September 2023. *2023 Interconnection Process Enhancements*. CAISO. *www.caiso.com/InitiativeDocuments/Straw-Proposal-Interconnecton-Process-Enhancements-2023-Sep212023.pdf*. CAISO proposed applying an auction if their viability scoring criteria were unable to limit the proposed capacity to 150% of available capacity within a given transmission zone; however, stakeholders have filed comments that do not support this approach (CAISO. 2023. Comments on Track 2 Straw Proposal. stakeholdercenter.caiso.com/Comments/AllComments/23aae20f-b09f-424c-821a-6d26ec74273f.)

mechanisms with project attribute-based rationing, such as CAISO's proposed project viability scoring criteria. Such variations could consider stability issues. If transmission is limited due to stability concerns, resources with attributes that can address those concerns (e.g., synchronous generators, grid-forming IBRs, HVDC transmission) may be given priority. Related ideas about considering specific attributes of different resources within the interconnection process are discussed in Solutions 2.5, 3.5, and 4.9.

Market-based approaches to rationing raise difficult questions about how to determine and set available capacity, what buyers receive in exchange for their payments, the relationship between interconnection and transmission rights, and open access and fairness. ISOs/RTOs, for instance, do not offer physical transmission rights within their transmission systems and instead relieve congestion through bid-based security-constrained economic dispatch. If a transmission provider decides to limit all interconnection access—both for energy-only and capacity interconnection service—to a multiple of deliverable transmission capacity, however, it would create a form of transmission right beyond just the right to submit an interconnection request. It also gives the transmission provider a larger role in setting desired levels of transmission congestion or, in the case of attribute-based rationing, in prioritizing access for certain kinds of resources.[64]

Market-based approaches to rationing interconnection access may imply larger changes in wholesale market design and operations. They may also imply changes in transmission access and industry structure, as firms with larger balance sheets may be able to disproportionally participate in such processes and increase market share relative to less resourced interconnection customers who might find participation in potentially complex market constructs difficult. Discussions on the potential benefits and shortcomings of different approaches and the changes in markets and operations they imply will take time, though as in CAISO's case, these discussions have already begun in the nearer term.

Table 11: Solution 2.6 Actors and Actions – Consider market-based approaches to rationing interconnection access

Actor	Engineering and Technical	Markets and Regulatory	Administrative and Organizational
FERC		- Explore regulatory regimes in interconnection that leverage more market-based approaches	
Transmission providers	- Consider beneficial project attributes when exploring rationing mechanisms	- Explore the implications of market-based approaches to rationing access	- Convene stakeholders
Interconnection customers		- Consider and propose market-based approaches to rationing access	- Participate in transmission provider initiatives

[64] Through its limits on access, the ISO would determine the level of optimal re-dispatch rather than allowing market participants to do so. Limiting access to only capacity interconnection service would preserve existing approaches to transmission rights but may give the ISO or a resource planner a larger role in determining where to add transmission capacity for deliverability.

Actor	Engineering and Technical	Markets and Regulatory	Administrative and Organizational
Research community (including DOE)		- Study implications of market-based approaches to rationing access	

2.2. Affected System Studies

Key Takeaways

Improvements to transmission provider coordination and methods for affected system studies—including Order 2023's requirements, but also voluntary collaboration and joint planning that go beyond them—will remove a significant obstacle to timely processing of interconnection requests.

Solutions Synopsis

Solution 2.7: Increase voluntary **collaboration on affected system studies**, including harmonization of study procedures, study methods, data inputs, software tools, study criteria, and mitigation options. (short-term)
Solution 2.8: Conduct affected system studies using an **energy-only modeling standard**, unless interconnection customers have requested deliverability to the affected system. (short-term)
Solution 2.9: Develop processes to **investigate new interregional transmission solutions** through joint transmission planning efforts between neighboring affected systems. (medium-term)

Solution 2.7: Increase voluntary collaboration on affected system studies, including harmonization of study procedures, study methods, data inputs, software tools, study criteria, and mitigation options. (short-term)

Affected system studies often lag behind host system impact studies and are sometimes completed very late in the interconnection process, causing delays, cost uncertainty for interconnection customers, and consequently, late withdrawals and restudies. Additionally, there is no requirement for the transmission providers to post their process for coordination between host and affected transmission system operators, which creates confusion and uncertainty for the interconnection customers.[65] FERC Order 2023 introduces specific timelines and requirements for affected system studies that aim to address these gaps.[66]

Additional improvements in affected system study processes, beyond Order 2023's requirements, could be achieved through proactive collaboration between neighboring transmission providers. Where distribution systems in the host or affected system are impacted, the transmission providers should also coordinate with involved distribution systems. Collaboration could include periodic and ongoing engagement to better coordinate, harmonize, and document study

[65] Order 2023, pp. 667–668.
[66] Order 2023 introduces a pro forma procedure for affected system studies.

procedures, methods, data inputs, study assumptions, software tools, criteria, and mitigation options, in line with the proposal in Solution 3.5. Such efforts will also contribute to achieving the data transparency opportunities discussed in Solutions 1.1–1.3.

A key goal would be to ensure that affected system study results are delivered with reasonable timelines that align with primary system studies. Such an outcome would support certainty in generation developer decision-making and costs. NERC or other reliability coordinators could help facilitate coordination through convening stakeholders to establish system modeling guidelines and standards. For instance, the Florida Reliability Coordinating Council provides such coordination for utilities in Florida.[67] More consistent approaches would lead to more consistent outcomes, so generators would have comparable system impacts regardless of whether they were being studied from a host system or affected system perspective. Such voluntary collaboration efforts are particularly important in cases where a non-FERC jurisdictional entity is the affected system, because that entity will not be required to strictly follow the new affected systems study process outlined in section 9 of the Large Generator Interconnection Procedures (LGIPs).

A more challenging, but potentially more effective option for improving affected system studies would be to include relevant portions of affected systems in host system cluster studies, either as a screen or as a full-system impact study. At the start of each cluster study cycle, transmission providers of the host system and affected systems could collaborate and agree on the scope of the impact study, including the portion of affected systems that should be modelled in the study cases. Combining host and affected systems in one study would reduce study timelines and ensure consistency between host and affected system studies. This will require further work in data standardization and tool interoperability to ensure that network data and/or study cases from neighboring systems are readily available to be exchanged, key areas of work discussed in the Data Transparency section, particularly Solutions 1.1 and 1.2.

For neighboring transmission providers, the incentive to collaborate on affected system studies is to improve the efficiency and speed of interconnection processes. If this incentive is not sufficiently strong, FERC could intervene and require regular coordination among transmission providers.

Table 12: Solution 2.7 Actors and Actions – Increase voluntary collaboration on affected system studies, including harmonization of study procedures, study methods, data inputs, software tools, study criteria, and mitigation options

Actor	Engineering and Technical	Market and Regulatory	Administrative and Organizational
FERC		- Encourage voluntary collaboration on affected system studies	

[67] Harwood, P. October 2020. *Reliability Evaluation Process for Generator and Transmission Service Requests*. Florida Reliability Coordinating Council. frccmspl054_GISR_TSR_Regnl_Relibty_Eval_Process_clean_v1.pdf.

Actor	Engineering and Technical	Market and Regulatory	Administrative and Organizational
NERC			- Convene stakeholders to establish system modeling guidelines and standards to facilitate coordination
Transmission providers	- Harmonize study methods and mitigation options with affected systems - Explore options for combining host and affected system studies	- Ensure compliance with Order 2023 affected system study process requirements	- Establish regular meetings to coordinate affected system studies - Publish documentation of coordination process
Research community (including DOE)	- Carry out case studies demonstrating pros/cons of combining host and affected system studies - Provide guidance on data standardization and tools interoperability		

Solution 2.8: Conduct affected system studies using an energy-only modeling standard, unless interconnection customers have requested deliverability to the affected system. (short-term)

Order 2023 requires that affected system studies must use an energy-only standard when modeling affected system requests. FERC found that this requirement should reduce the complexity and time required for affected system studies and enable fairer cost allocation to generators in host systems that do not necessarily benefit from deliverability-related network upgrades in neighboring systems.[68] However, these rules should not prevent interconnection customers in a host system from requesting deliverability to a neighboring system to be eligible for resource adequacy payments in that system. Allowing customers to do so may require additional discussion by stakeholders and clarification from FERC.

Table 13: Solution 2.8 Actors and Actions – Conduct affected system studies using an energy-only modeling standard, unless interconnection customers have requested deliverability to the affected system

Actor	Engineering and Technical	Market and Regulatory	Administrative and Organizational
FERC		- Enforce energy-only standard in affected system studies - Clarify rules for deliverability requests to affected systems	
Transmission providers	- Implement energy-only standards in affected system studies		- Change tariffs to comply with energy-only standards - Discuss options for deliverability requests to affected systems

[68] Order 2023, p. 830.

Solution 2.9: Develop processes to investigate new interregional transmission solutions through joint transmission planning efforts between neighboring affected systems. (medium-term)

Rather than triggering cross-border network upgrades through affected system studies, transmission providers could plan for and build interregional transmission through periodic joint transmission planning efforts between neighboring systems. This collaboration may also facilitate harmonization of study methodology and assumptions and development of common procedures, tools, models, and data inputs (Solution 3.6) and would reduce the need for affected systems reinforcement for future generation projects. This integrated affected system transmission planning collaboration would facilitate the evaluation of larger, more strategic transmission projects, including higher voltage, new high-capacity transmission design, and HVDC solutions.

A successful example of such a planning process is SPP and MISO's JTIQ study, which showed that proactively studying a larger set of generation interconnection requests offers substantial cost and time savings, identifies more optimized network upgrades, and reduces uncertainty for the resource developers.[69] The costs of these projects would still be at least partly allocated to generators. However, instead of having these upgrades triggered and paid for by generators in a single cluster, they would instead be paid for by all generators that benefit from the upgrades, using a zonal, average cost-based tariff (more discussion of similar cost allocation ideas appears in Solution 3.3).[70]

This solution targets a medium-term timeframe for implementation, as it is likely to take different regions across the United States substantial coordination to implement joint planning exercises. Nevertheless, studies like the JTIQ process could and should be conducted on an ongoing basis every few years, once the joint planning efforts have been established. Solution 3.4 encourages broader transmission planning efforts that go beyond neighboring affected system collaboration and, therefore, could serve to augment or subsume this narrower solution.

Table 14: Solution 2.9 Actors and Actions – Develop processes to investigate new interregional transmission solutions through joint transmission planning efforts between neighboring affected systems

Actor	Engineering and Technical	Market and Regulatory	Administrative and Organizational
Transmission providers	- Develop scope and collaborate on periodic joint interregional transmission planning studies - Consider a variety of transmission reinforcement options, including, but not limited to, higher-voltage		- Engage stakeholders to inform joint interregional transmission studies

[69] The JTIQ study identified seven projects, representing $1.65 billion in transmission investments, that are able to support 9 GW of existing generator interconnection requests and enable an additional 20 GW of projects in both territories, as well as provide around $1 billion of production cost savings.

[70] SPP and MISO are currently working on a cost allocation approach but are considering assigning $/MW charge for a generator interconnecting into each zone commensurate with the benefits received.

Actor	Engineering and Technical	Market and Regulatory	Administrative and Organizational
	transmission, high-capacity transmission design, and HVDC connections		
Interconnection customers			- Inform transmission providers of areas of potential interest for new generation development
Consumer groups and states			- Participate in joint planning exercises and cost allocation discussions

2.3. Inclusive and Fair Process

Key Takeaways

While all solutions of the roadmap aim to promote a fair interconnection process, not all stakeholders start with the same tools and resources. Enhancements to interconnection and, relatedly, transmission planning processes can help make interconnection outcomes more inclusive and fairer. Energy equity in interconnection requires intentionally designing systems, technologies, procedures, and policies for all types of interconnection stakeholders, including EEJ communities. An equitable interconnection process could be made more inclusive and fairer by developing strategies to expand transmission connection access opportunities.

Solutions Synopsis

Solution 2.10: Incorporate **equity goals in transmission planning and valuation** efforts (short-term)
Solution 2.11: Provide access to **independent engineering, administrative, and legal services** to support the navigation of interconnection processes (medium-term)

Solution 2.10 Incorporate equity goals in transmission planning and valuation efforts (short-term)

Transmission planning has not historically focused on the role of EEJ projects and communities, both in considering the impacts of planning efforts on EEJ communities and in allowing EEJ communities to play an active role in these processes. Some Tribal Nation and other EEJ projects seeking interconnection have been forced to withdraw from the queue due to the high-cost upgrades assigned to their projects, in part due to limited transmission capacity in their regions. Centering equity goals in transmission planning efforts may lead to proactive infrastructure upgrades in regions where tribal and EEJ projects seek to interconnect. More proactive infrastructure upgrades can help reduce and make more certain upfront costs for interconnection, alleviating key barriers to connecting more clean energy projects.

For example, including projected Tribal clean power projects in Power Marketing Administration's (PMA) transmission plans would enable Tribal projects to interconnect to these transmission networks with reduced queue delays and interconnection costs. A significant fraction of the federally recognized Tribes in the United States are located within the service territory of the Western Area Power Administration, BPA, or Southwest Power Administration (SWPA). PMAs, given their efforts managing relationships with Tribes, are a natural party to engage in direct consultation to incorporate Tribal renewable energy development plans and include Tribes in regional and interregional transmission planning activities. Today, however, there is no formal consultative process to do such planning.

Additionally, research programs that aim to identify opportunities for generator development should better incorporate equity goals. For example, interregional renewable energy zones (IREZs) were established by NREL as part of a national effort to identify transmission infrastructure upgrades that would offer strategic support to the U.S. government's goal to decarbonize the electricity sector. An IREZ is a transmission hub identified as being a low-cost connection point for a large quantity of potential wind and solar generation. However, the IREZ locations currently identified are generally not located on or near Tribal lands, nor was support for Tribal energy development included as a factor in IREZ planning.[71] Siting one or more IREZ hubs on or near Tribal locations that have a desire to develop their renewable energy resources can help ensure that Tribal communities are able to benefit from federal investment in building out the infrastructure needed to decarbonize the grid. Of course, such planning would need to include sufficient tribal and community engagement to assess any negative impacts of any new generation and transmission development within their territories, an effort DOE could support.

Table 15: Solution 2.10 Actors and Actions – Incorporate equity goals in transmission planning and valuation efforts

Actor	Engineering and Technical	Market and Regulatory	Administrative and Organizational
Federal agencies		- Consider Tribes and EEJ communities in federal transmission planning	
Transmission providers			- Incorporate Tribal and EEJ communities in transmission planning activities
Consumer groups			- Partner with Tribal and EEJ communities in transmission planning activities
Research community (including DOE)	- Support open-source tools for identification of IREZs - Consider equity goals in transmission planning research projects		- Facilitate and support stakeholder planning sessions between PMAs and Tribes

[71] Find more information about the IREZ transmission analysis in Hurlbut, David, et al., 2022, "Interregional Renewable Energy Zones in National Transmission Analysis," NREL, www.nrel.gov/docs/fy22osti/83924.pdf. Page 16 describes future work that aims to provide preferences to hubs closer to Tribes.

Solution 2.11 Provide access to independent engineering, administrative, and legal services to support the navigation of interconnection processes. (medium-term)

EEJ project developers that are under-resourced or inexperienced in interconnection processes and vetting interconnection requirements have limited capacity to interpret interconnection application results or negotiate interconnection requirements. Developing customer protection and administrative and technical support services to navigate the interconnection process and FERC's dispute resolution procedures can mitigate knowledge and experience gaps for EEJ and EEJ-serving developers. Such an independent service supports justice in interconnection, working to ensure that all stakeholders can understand and negotiate the requirements for interconnection such that no one group is unduly burdened by or unable to meet those requirements. It is also important that any incentive and customer protection programs are clearly explained to all customers to ensure transparency and equitable access.

Analogs of such opportunities already exist for distribution system interconnection. Some states, such as Massachusetts, New York, California, Washington,[72] and Hawaii,[73] have established processes that may serve as an example of such services for EEJ interconnection customers. FERC could consider providing such independent engineer and/or legal services that could help customers interact with states and direct all stakeholders to relevant services, such as their Office of Public Participation (OPP), the Senior Counsel for Environmental Justice and Equity, and/or the Office of External Affairs Tribal Working Group. Such a role could serve one of FERC's key actions outlined in their Equity Action Plan to "expand the capabilities and size of the [OPP] … to facilitate public participation in Commission proceedings, including through assistance to underserved communities, which often face barriers to meaningful participation."[74]

OPP has publicly considered options for an intervenor funding program to support such technical assistance, covering attorney and witness fees and other expenses required for participation.[75] Continuing to develop these programs could provide the targeted assistance needed to increase EEJ intervenor participation in FERC proceedings, which could lead to more equitable policies and rulemaking.

Importantly, ISOs/RTOs typically already have robust forms of dispute resolution procedures in place, and care should be taken that any additional service does not duplicate roles and responsibilities, especially where it involves drawing from the already-finite labor force. However, it is unclear whether these current programs provide technical assistance services that, in coordination with Solution 2.16, could be critical for engaging underserved communities. Furthermore, ISOs/RTOs only cover a portion of service areas across the United States.

[72] Washington State Legislature. 2007. "WAC 480-108-100: Dispute Resolution." app.leg.wa.gov/wac/default.aspx?cite=480-108-100&pdf=true.
[73] Hawaii established an Interconnection Dispute Resolution Process under Order No. 39163.
[74] FERC. 2022. *Equity Action Plan*. www.ferc.gov/equity.
[75] Howland, E. April 2022. "FERC's Office of Public Participation Eyes Options for Intervenor Funding." *Utility Dive*. www.utilitydive.com/news/ferc-office-public-participation-intervenor-funding-compensation/621406/.

Providing these services in regions outside of organized markets could meaningfully impact interconnection issues in those regions.

Table 16: Solution 2.11 Actors and Actions – Provide access to independent engineering, administrative, and legal services to support the navigation of interconnection processes

Actor	Engineering and Technical	Market and Regulatory	Administrative and Organizational
FERC		- Consider customer protection and EEJ-focused dispute resolution programs and services	- Develop ombudsperson and/or independent engineer roles - Consider funding for technical assistance
Transmission providers		- Help design customer protection programs	- Support equitable customer protection programs - Develop technical assistance to support EEJ interconnection customers and communities
Interconnection customers			- Participate in development of technical assistance and educational programs
Research community (including DOE)	- Expand technical assistance programs and encourage alignment between utilities and developers		

2.4. Workforce Development

Key Takeaways

Interconnection requires technical expertise across many professions in the electric industry, from utility engineers to regulatory officials. There is a high degree of competition for interconnection-related positions, especially given that many require both engineering and policy experience. Targeted efforts to increase training opportunities for and improve compensation of existing staff will improve workforce capabilities, increase retention, enhance diverse and equitable representation across the interconnection workforce, and, as a result, expand processing of interconnection applications. Better advertisement of current interconnection-related positions and new outreach in higher education settings are needed to highlight the important role of interconnection policy and practice in the clean energy transition.

Solutions Synopsis

Solution 2.12: Assess the scale of interconnection **workforce growth requirements**. (short-term)

Solution 2.13: **Upskill the existing workforce** through continuing education programs. (short-term)

Solution 2.14: Consider improvements to **compensation and benefits** while enhancing the **advertisement and hiring** process for interconnection-related positions. (short-term)

Solution 2.15: Grow the number of workers in the interconnection workforce via **outreach, career counseling, apprenticeships, and curriculum development** in postsecondary education. (medium-term)

Solution 2.16: **Expand education opportunities** relevant to interconnection for under-resourced and EEJ communities. (medium-term)

Solution 2.12: Assess the scale of interconnection workforce growth requirements. (short-term)

There is significant uncertainty about the exact scale of increased interconnection workforce needs. Workforce scaling uncertainty is partly driven by the inherent uncertainty of the future amount of interconnection applications, given that interconnection process reform might reduce the current size of interconnection queues. Furthermore, opportunities and the potential success of automating some portions of the interconnection study process (discussed in Solution 2.3) contribute to workforce demand uncertainty. Nevertheless, given the ongoing energy transition and the expectation that wind, solar, storage, large loads, and transportation electrification interconnection requests will remain high because of both market and policy drivers, it is generally understood that the interconnection workforce will need to increase.

However, there are few sources of national data available to estimate this need more precisely. FERC Order 845 requires transmission providers to "post interconnection study metrics to increase the transparency of interconnection study completion timeframes."[76] If a transmission provider exceeds study deadlines "for more than 25 percent of any study type for two consecutive quarters,"[77] the transmission provider must "aggregate the total number of employee-hours and third party consultant hours expended towards interconnection studies."[78] While the reports submitted pursuant to FERC Order 845 may provide a helpful benchmark, they are limited. First, they are focused on the number of personnel hours associated with conducting interconnection studies rather than the whole process. Second, they don't disaggregate transmission provider staff, contractor, and transmission owner hours.

Additional quantification of interconnection workforce growth expectations will help prioritize the following solutions. For example, if anticipated growth is extremely high, it may be necessary to immediately undertake some of the following more long-term and intensive solutions described (Solution 2.15), such as working with middle school, high school, and higher education institutions to build the skills in regulation, economics, and engineering needed to grow the interconnection workforce.[79] If the scale of the need is less extreme, the short-term solutions that are less challenging to implement should be prioritized.

[76] FERC. April 2018. *Reform of Generator Interconnection Procedures and Agreements*, Docket No. RM17-8-000, Order No. 845, p. 184.
[77] Ibid. at p. 174.
[78] Ibid. at p. 368.
[79] There is a need to develop and expand, rather than shift, the electricity system workforce. Solutions discussed in this section are not intended to move engineers and planners from other functional areas within the current electricity system workforce to generation interconnection.

Table 17: Solution 2.12 Actors and Actions – Assess the scale of interconnection workforce growth requirements

Actor	Engineering and Technical	Market and Regulatory	Administrative and Organizational
National trade and utility associations			- Establish clear reporting requirements - Facilitate data gathering to allow cross comparisons
Research community (including DOE)			- Determine data requirements to identify workforce growth - Analyze data - Investigate causes of workforce challenges
Interconnection customers, transmission providers, regulators			- Provide data on workforce need expectations

Solution 2.13: Upskill the existing workforce through continuing education programs. (short-term)

Interconnection processes and technologies are constantly evolving. From a policy standpoint, as the demands of interconnection have changed over time, FERC has designed and implemented new interconnection rules (e.g., FERC Order 2003, 845, 2023) that require experienced regulatory and policy staff to engage with the rulemakings, communicate industry challenges, and propose innovative solutions. Continuing education programs that summarize and educate the interconnection workforce on key reforms and challenges could increase engagement and retention.

At the same time, interconnection technologies and engineering standards are constantly evolving. Recently the new IEEE 2800 standard for the "Interconnection and Interoperability of Inverter-Based Resources (IBRs) Interconnecting with Associated Transmission Electric Power Systems" was approved (as discussed in Solution 4.5). Furthermore, IEEE P2800.2, "Recommended Practice for Test and Verification Procedures for Inverter-based Resources (IBRs) Interconnecting with Bulk Power Systems," is under development (as discussed in Solution 4.6). A plant-level conformity assessment training and evaluation program would improve familiarity with these standards, help with information dissemination, and contribute to the development of a qualified workforce for plant-level conformity assessments.[80] This continuous education and workforce development will also be necessary as new standards are developed in the future (as discussed in Solution 4.7).

[80] One example is IEEE's Conformity Assessment Program for conformity of distributed energy resources with IEEE 1547-2018 (standards.ieee.org/products-programs/icap/). This program could be expanded to bulk system-connected IBR plants/systems for conformity with IEEE 2800-2022 based on IEEE P2800.2 in the medium term.

Furthermore, the rise of IBRs has changed some of the key modeling skill sets required to understand reliability impacts of new generators on the transmission grid.[81] For example, there are currently high workforce demands to build expertise in EMT modeling and simulations as transmission providers start collecting and quality testing EMT models and, eventually, performing EMT interconnection studies (as discussed in Solutions 4.1 and 4.2). However, there is a relative lack of expertise in EMT modeling within the industry today. To build up expertise with EMT models and studies, training and accreditation programs are needed. Beyond providing training, organizations should designate dedicated engineers who continuously work with EMT models and tools, so that after the training they keep using the tools in their daily jobs.

Additionally, the utilization of alternative transmission technologies (e.g., dynamic line ratings, advance power flow control technologies; discussed in Solution 3.5), grid-forming controls of IBRs, battery energy storage systems (BESSs) and hybrids, various types of large electronic loads, smart charge management, and other services for electric vehicle high-power charging depots (discussed in Solution 4.7) have created complexities to interconnection assessments and impact studies. For instance, there is a need to provide greater workforce development and training to build up expertise in multi-asset electric vehicle (EV) charging installation interconnection processes. Additional training and education for processing large-scale high-capacity charging installations with BESSs and other services will assist with reducing personnel hours spent processing interconnection applications.

Cybersecurity standards are also evolving rapidly. Training on cybersecurity practices is essential for asset owners, whether they are NERC registered[82] or not. Other stakeholders in the interconnection process should be trained as well. The workforce must be properly trained to develop and maintain cybersecurity plans.

In general, there are limited programs available to the interconnection workforce to participate in continuing education advancement. Training and education programs could potentially reduce the number of personnel hours necessary to process interconnection applications by enabling more streamlined and rapid review while continuing to ensure safety and reliability. Furthermore, better continuing education within the existing interconnection workforce will help close the skills gap and ensure ongoing investment in a diverse interconnection workforce. Educational content developers should work with disadvantaged and minority communities directly to identify more targeted education gaps.[83] Furthermore, all stakeholders within the

[81] For more technical detail on the needs for EMT models, see Section 4 on maintaining grid reliability.
[82] NERC requires adherence to critical infrastructure protection (CIP) standards. NERC. January 2024. *Reliability Standards for the Bulk Electric Systems of North America*. www.nerc.com/pa/Stand/Reliability%20Standards%20Complete%20Set/RSCompleteSet.pdf.
[83] Distinguishing between disadvantaged communities (as defined through the Justice40 Initiative) and minority communities is important in that supporting an equitable interconnection workforce can increase the diversity of the workforce (i.e., from a traditional workforce perspective, it can increase the number of women and Black and Indigenous persons and People of Color in the workforce, it can be more disability inclusive and accessible), and it can have broader individual and community benefits that redress systemic barriers and harms (i.e., socioeconomic and environmental justice burdens).

industry should periodically assess what new skill sets are needed for future interconnection needs.

Training opportunities will keep staff engaged beyond solely reviewing interconnection applications, which could be perceived as repetitive and monotonous (see Solution 2.3 for discussion of automation opportunities). There may be opportunities to develop such programs in coordination with educational, continuing education, licensing and accreditation, union, and trade and research association (e.g., National Association of Regulatory Utility Commissioners, Edison Electric Institute, Electric Power Research Institute [EPRI])[84] institutions.

Table 18: Solution 2.13 Actors and Actions – Upskill the existing workforce through continuing education programs

Actor	Engineering and Technical	Market and Regulatory	Administrative and Organizational
NERC, equipment manufacturers, software vendors, unions, research community (including DOE), trade associations	- Develop training materials for EMT modeling - Develop training materials on emerging technologies and standards		- Develop training materials on history of interconnection reform
Interconnection customers, transmission providers			- Encourage staff to develop and maintain new skill sets

Solution 2.14: Consider improvements to compensation and benefits while enhancing the advertisement and hiring process for interconnection-related positions. (short-term)

Retention and recruitment of interconnection staff has been a key challenge for the industry. As the number of interconnection applications has increased, more interconnection experts are needed across all employers within the industry, from resource developers to regulatory staff to transmission providers. Constraints on the interconnection workforce suggest that increased compensation is needed both to retain staff members who have already been trained and to signal to prospective employees that the interconnection skill set is valued. Employee benefits expand beyond health insurance and paid leave; workers are also interested in work-life balance, geographic freedom, work-from-home opportunities, and professional development plans for career growth. Creating opportunities for the industry to share best practices on workforce management could support higher retention rates and workforce satisfaction.

Attracting prospective applicants to interconnection work, however, does not solely require compensation and benefits improvement. Competition exists both for skilled workers with prior interconnection experience and for workers who might be considering other opportunities in clean energy or technology jobs. Improving the hiring process and communications for interconnection-related positions is needed to make interconnection-related jobs more attractive

[84] For instance, EPRI has established EPRI-U, which could be a useful model for developing interconnection-oriented training programs.

and exciting to prospective applicants. For instance, job postings could note the important role of interconnection policy and practice in the clean energy transition. Framing interconnection work in the context of bigger challenges and the opportunities to make a serious impact will help prospective applicants understand the job's purpose in a larger context. Providing quality content on marketing materials, websites, and company correspondence to expand awareness and build interest in sustainable and meaningful careers can have the further effect of making interconnection-related jobs more attractive and exciting to prospective applicants. University hackathons could be another useful model to attract engineers into the excitement of grid planning and clean energy development, while introducing them to relevant skills needed for the jobs.

Of course, competition also exists between key interconnection stakeholder groups. The skills and experience developed at transmission provider organizations to effectively manage the queue are desirable employee attributes for interconnection customers and other organizations that may have more flexibility on compensation and benefits. Such challenges require stakeholder groups to collaborate to reduce friction caused by employee turnover. Creating strong job trajectories could also help decrease turnover such that workers do not need to leave an organization to advance their career.

Table 19: Solution 2.14 Actors and Actions – Consider improvements to compensation and benefits while enhancing the advertisement and hiring process for interconnection-related positions

Actor	Engineering and Technical	Market and Regulatory	Administrative and Organizational
All stakeholders			- Increase compensation and benefits for key interconnection staff - Improve framing of interconnection-related jobs to showcase impact

Solution 2.15: Grow the number of workers in the interconnection workforce via outreach, career counseling, apprenticeships, and curriculum development in postsecondary education. (medium-term)

There is no established career or training pathway to interconnection. Many skills are often learned on the job, reducing the ability of new staff to ramp up quickly and increasing the negative impacts of low employee retention. While this issue makes it difficult to effectively make experienced hires in key positions, it also risks poor employee-to-employer fit if new staff members do not have full awareness of key job attributes in advance of accepting a position.

Key stakeholder groups should increase outreach and educational program development in institutions for higher education. Such collaborations could be as simple as introducing new content around the interconnection process in key technical and nontechnical electricity courses. Additionally, partnerships with specific programs educating future electrical engineers can be enhanced to increase the pipeline of interconnection-trained staff members.

To attract a more diverse workforce, special attention should be placed on establishing partnerships with historically Black colleges and universities, unions, professional associations such as the National Society of Black Engineers, Society of Women Engineers, and the American Association of Blacks in Energy, and other similar education-focused stakeholders.

Existing paid internship and fellowship programs can also be scaled, and new programs can be established. Stakeholders, especially large employers such as RTOs/ISOs, have well-established internal internship and staff training programs that result in full-time hires. There may be valuable best practices to draw from these programs, which other transmission-oriented institutions could adopt. An example of an existing fellowship program that could be scaled is DOE's Clean Energy Innovator Fellowship program.[85] Such programs need to be cognizant of existing workforce inequities (i.e., students or young professionals from low-income or disadvantaged communities may not be able—and shouldn't be asked—to intern without compensation, which only serves to exacerbate systemic barriers).

Paid apprenticeship models that focus on targeting skills and workforce development within the electricity system could also be developed. Apprenticeships are especially useful in contexts where there is not a set curriculum available, but there is extensive firm-specific knowledge that novices will need to learn to contribute effectively to tasks. The U.S. Department of Labor, Office of Apprenticeship has determined that electrical power-line installers and repairers, for instance, are apprenticeship occupations.[86] Stakeholders should draw from existing registered apprenticeship programs for these occupations, and, where necessary, collaborate to sponsor additional registered apprenticeship programs and new apprenticeship occupations.

Table 20: Solution 2.15 Actors and Actions – Grow the number of workers in the interconnection workforce via outreach, career counseling, and curriculum development in postsecondary education

Actor	Engineering and Technical	Market and Regulatory	Administrative and Organizational
Universities, unions, professional associations, community colleges			- Incorporate content on the interconnection process in key courses
Interconnection customers, transmission providers			- Establish partnerships with educational institutions promoting interconnection skills - Expand paid internship and fellowship programs
Federal entities			- Consider targeted apprenticeship programs within interconnection

[85] EERE. Clean Energy Innovator Fellowship. www.energy.gov/eere/clean-energy-innovator-fellowship.
[86] Review apprenticeship occupations at www.apprenticeship.gov/apprenticeship-occupations.

Solution 2.16 Expand education opportunities relevant to interconnection for under-resourced and EEJ communities. (medium-term)

Existing educational programs have limited programmatic reach, funds, and human resources to support EEJ communities, smaller developers, and smaller cooperative and municipal utilities navigating the complex interconnection process. Addressing the knowledge and capacity gaps supports procedural justice by ensuring equitable participation is accessible for all interconnection stakeholders. Small utilities and EEJ developers alike often view interconnection as a substantial barrier—collaboration and shared language and understanding would promote innovative solutions, EEJ initiatives, and interconnection reforms. Example workforce development mechanisms with these issues in mind are described below:

Workforce development programs should be built in partnership with universities, colleges, unions, trade schools, and other institutions focused on local capacity building to expand access and leverage the local expertise of existing educational institutions.

OPP was created to facilitate public participation in FERC proceedings and expand aid communities that face barriers to meaningful participation.[87] Such support would encompass a specific goal from FERC's Equity Action Plan to incorporate lessons learned from assessments of FERC's Tribal government consultation and engagement policy and processes to support developing key interconnection skill sets within underserved communities. See more details about facilitation of public participation in Solution 2.11.

Developing and disseminating publicly available educational resources can help create a level field for less resourced stakeholders and enable broader participation. Resources such as FERC's Energy Markets[88] and Energy Projects[89] pages, which provide explainers, participation guides, primers, and quick reference guides, could be used as a model.

The development mechanisms mentioned above can help ensure that EEJ communities are aware of the essential role of the interconnection process in allowing the timely retirement of legacy energy resources and the deployment of new energy resources to replace them. This solution, in combination with Solution 2.11, would contribute to important knowledge dissemination.

Table 21: Solution 2.16 Actors and Actions – Expand education opportunities relevant to interconnection for under-resourced and EEJ communities

Actor	Engineering and Technical	Market and Regulatory	Administrative and Organizational
All Stakeholders		- Prioritize partnerships with local EEJ community-serving universities and other institutions when establishing workforce development programs	
Transmission providers			- Develop educational programs for small municipal

[87] ERC. 2022. *Equity Action Plan*. www.ferc.gov/equity.
[88] FERC. Energy Markets. ferc.gov/energy-markets-0.
[89] FERC. Energy Projects. ferc.gov/energy-projects.

Actor	Engineering and Technical	Market and Regulatory	Administrative and Organizational
			and cooperative utilities that serve EEJ communities - Develop technical assistance to support EEJ interconnection customers and communities
EEJ interconnection customers			- Share workforce needs with regulatory and utility partners - Invest in worker certifications and career development
Research community (including DOE)	- Expand technical assistance programs that encourage alignment between utilities and EEJ developers		

3. Promote Economic Efficiency in Interconnection

Interconnection and transmission planning are closely related. New transmission facilities not selected through long-term transmission planning may be triggered as a network upgrade in the interconnection study process, with different implications for cost allocation and total transmission costs. Interconnection processes, in tandem with market prices, also provide incentives for resource siting and efficient use of the transmission system, which lowers costs to electricity consumers over the longer term.

This section describes solutions that aim to improve cost allocation (Section 3.1), solutions that aim to strike the right balance between transmission facilities built through long-term planning versus interconnection through better coordination between the two processes (Section 3.2), and solutions that aim to rightsize transmission investment in interconnection through improvements in interconnection studies (Section 3.3). Other solutions in the roadmap—such as process automation—could also promote economic efficiency but were covered in Section 2 above and are not a focus in this section.

3.1. Cost Allocation

Key Takeaways

Expanding options for interconnection service and proactive transmission investments should reduce uncertainty and improve allocative efficiency. If current efforts to reduce interconnection bottlenecks prove unsuccessful, transmission providers may need to consider more radical departures from the current participant funding model of interconnection cost allocation.

Solutions Synopsis

Solution 3.1: Explore options for identifying and allocating the costs of **proactive transmission investments**, including different options for state, federal, and participant funding. (short-term)
Solution 3.2: Ensure that generators have the option to elect energy-only interconnection and be re-dispatched rather than **paying for network upgrades**. (medium-term)
Solution 3.3: Explore and evaluate potential options for **delinking the interconnection process and network upgrade investments** to increase upfront interconnection cost certainty. (long-term)

Solution 3.1: Explore options for identifying and allocating the costs of proactive transmission investments, including different options for state, federal, and participant funding. (short-term)

Proactive transmission planning shifts the identification of some network upgrades and use of grid-enhancing technologies (GETs) from interconnection to transmission planning and builds transmission in advance of expected need, with different options for cost allocation. Network upgrades and use of GETs might still be triggered through interconnection, but proactive planning should reduce their frequency and magnitude. The proactive planning envisioned in this solution would be incremental to transmission planning processes, though, as discussed in the following, the boundaries are sometimes blurred.[90] Cost allocation options for proactive transmission investments can be grouped into three main categories: (1) state ratepayer funded, (2) federal government supported or funded, and (3) participant funded, whereby projects are funded by nonutility transmission developers or resource owners.[91] Activities in this solution might also include a review of barriers to participant-funded transmission.

There are multiple approaches for state ratepayer funding of proactive transmission investments (option 1). For instance, in 2020, the New Jersey Board of Public Utilities requested PJM to study and solicit proposals for transmission projects to deliver 7,500 MW of offshore wind to meet the state's offshore wind goals, under PJM's State Agreement Approach.[92] Costs for these projects will be allocated to ratepayers in New Jersey through their LSEs.[93] State-driven investment in transmission is by no means new: notable examples include Texas's Competitive Renewable Energy Zone initiative (CREZ, 2005–2014), California's Renewable Energy Transmission Initiative (RETI, begun in 2007), the Upper Midwest Transmission Development Initiative (UMTDI, begun in 2008), and New York's Public Policy Transmission Planning Process (PPTPP, begun in 2015).

Approaches to state funding differ in terms of which entity plans and solicits bids for the transmission, which process projects use to submit plans to transmission providers, and how costs are allocated across states. In a 2021 policy statement, FERC clarified that these voluntary agreements are not precluded by the Federal Power Act and encouraged individual states and groups of multiple states to use them.[94] States can also work with transmission utilities in their jurisdictions to submit transmission-owner-funded transmission projects that help meet state energy goals. Transmission providers can engage with state agencies to ensure that processes and rules for state investment are clear and efficient.

On a federal level, the government may be able to offer financial resources to support proactive transmission investments, or it could invest in and build transmission directly. For example, DOE is authorized to borrow up to $2.5 billion for financing tools under the BIL's Transmission Facilitation Program and $2 billion in loans under the IRA's Transmission Facility Financing Loan Program, subject to certain project qualifications.[95] Furthermore, the Energy Policy Act of

[90] In their transmission plans, transmission providers identify additional transmission needed to meet expected reliability, economic, and policy needs. As defined here, proactive planning would build transmission in advance of expected need in transmission plans, for instance, to access resource-rich regions before demand for expanded transmission to those regions has fully materialized.
[91] "Participant funding" here is distinct from participant funding in interconnection, in which interconnection customers are assigned costs for network upgrades. Here, participant funding refers to voluntary investments in transmission.
[92] PJM created the State Agreement Approach in 2013 in response to FERC Order 1000.
[93] A challenge of these approaches is that other states could benefit from these transmission initiatives while avoiding the requirement to pay for them, which could limit overall state appetite for developing them.
[94] FERC. 2021. *State Voluntary Agreements to Plan and Pay for Transmission Facilities*, PL21-2-000.
[95] DOE. 2023. "DOE Proposes National Interest Electric Transmission Corridor Designation Process." www.energy.gov/gdo/articles/doe-proposes-national-interest-electric-transmission-corridor-designation-process.

2005 allows DOE to make loan guarantees[96] for efficient electrical transmission technologies. Additional dedicated funding to support transmission for high-priority interconnection areas is a potential option.[97] These federal financing models could also be used to support deployment of transmission resources that improve transmission access for certain EEJ communities and other underserved regions (e.g., rural Tribal areas) that want clean energy resources in their community. Solution 2.10 discusses equitable transmission planning in more detail.

In most ISOs/RTOs, transmission developers, generators, and other market participants can already propose new proactive, participant-funded transmission investments through transmission planning processes.[98] Typically, transmission developers plan and find customers for these projects, rather than having transmission providers do so. An alternative approach would be for independent transmission providers to play a larger role in planning proactive, participant-funded transmission investments needed to access resource zones or reduce congestion and soliciting interest from market participants willing to pay for them.[99] Transmission providers could also allow market participants to fund the residual parts of projects that do not pass a cost-effectiveness threshold in transmission plans.[100] For both existing and new avenues for participant-funded transmission, transmission providers and market participants may need to identify and address barriers to these kinds of projects. Participant-funded transmission is still a small part of transmission providers' transmission investment portfolios.[101]

In the approaches described above, planning takes place outside of transmission providers' transmission plans and costs are allocated to the project sponsor rather than to all beneficiaries. However, it is also possible for multiple states to come together, plan transmission in collaboration with one or more transmission providers, and then allocate the costs to all beneficiaries across multiple states through the transmission provider's or providers' cost allocation mechanisms. For instance, the UMTDI began as a multistate initiative with MISO support that became MISO's Multi-Value Project (MVP) portfolio of transmission projects, and the approach eventually became institutionalized as MISO's Long Range Transmission Planning (LRTP).[102] LRTP is a periodic, long-term, multistakeholder assessment of reliability and economic needs due to expected changes in generation and load, with the Tranche 1 study

[96] Loan Programs Office. *Loan Guarantee Solicitation Announcement*. https://www.energy.gov/lpo/title-17-clean-energy-financing
[97] Interested readers could review DOE's recent Transmission Facilitation Program as an example, at www.energy.gov/gdo/transmission-facilitation-program.
[98] Examples include sponsored upgrades in SPP, market participant-funded projects in MISO, and elective transmission upgrades in ISO-NE. These are distinct from projects proposed to ISOs/RTOs for the purposes of cost allocation.
[99] There are many examples of such projects today, which often employ HVDC technologies. See Power from the Prairie, SOO Green, Clean Path New York, and a number of projects from Grid United.
[100] For more on this idea, see Enel, 2022, *Plugging In: A Roadmap for Modernizing & Integrating Interconnection and Transmission Planning*, www.energy.gov/gdo/transmission-facilitation-program.
[101] For instance, market participant-funded projects accounted for 0.1% of MISO Transmission Expansion Plan 22's transmission projects.
[102] For a history, see Boyd, D., and E. Garvey, 2021, *A Transmission Success Story: The MISO MVP Transmission Portfolio*," www.aeslconsulting.com/wp-content/uploads/2021/11/MISO-MVP-History.pdf.

resulting in $10.3 billion in proposed least-regrets transmission solutions. MISO engaged stakeholders to develop a cost allocation methodology for LRTP projects through a regional working group.[103] Proactive transmission investments by states, the federal government, and market participants can be a complement to transmission provider planning processes. The JTIQ collaboration between SPP and MISO, discussed in more detail in Solution 2.9, is another important case study.[104]

Different options for allocating the costs of proactive transmission investments have multiple permutations that may need to be negotiated through stakeholder processes. Some transmission providers already have, or have recently begun, stakeholder discussions on cost allocation mechanisms for proactive transmission investments.[105]

Table 22: Solution 3.1 Actors and Actions - Explore options for identifying and allocating the costs of proactive transmission investments

Actor	Engineering and Technical	Market and Regulatory	Administrative and Organizational
Federal agencies		- Implement financing programs	
State agencies		- Make use of mechanisms for state transmission investment - Coordinate transmission needs with other states	- Participate in transmission provider stakeholder initiatives
Consumer groups			- Participate in transmission planning and cost allocation discussions
Transmission providers	- Integrate proactive investments into transmission planning	- Implement new models for proactive investment	- Convene stakeholders to discuss proactive investments
Interconnection customers		- Develop and propose new approaches	- Participate in stakeholder initiatives
Research community (including DOE)	- Document and evaluate proactive investments	- Develop and propose new approaches	- Participate in stakeholder initiatives

Solution 3.2: Ensure that generators have the option to elect energy-only interconnection and be re-dispatched rather than paying for network upgrades. (medium-term)

U.S. electricity markets were designed to provide locational price signals to allow market participants to manage congestion and other re-dispatch risk, rather than having transmission providers manage that risk on their behalf. Consistent with this approach and with the principles of competition underlying wholesale markets, interconnection customers should have the option

[103] For more on LRTP, see www.misoenergy.org/planning/long-range-transmission-planning/.
[104] For more on cost allocation of JTIQ, see *SPP-MISO Joint Targeted Interconnection Queue Cost Allocation and Affected System Study Process Changes*, cdn.misoenergy.org/20220822%20MISO%20SPP%20JTIQ%20DRAFT%20Study%20White%20Paper626025.pdf.
[105] MISO's MVP is an example of an FERC-approved mechanism for proactive transmission investments. Examples of recent initiatives include SPP's Strategic and Creative Re-engineering of Integrated Planning Team and discussions in PJM's interconnection policy workshop series.

to be re-dispatched, if possible, rather than paying for network upgrades to resolve potential reliability issues, issues that could be infrequent in nature.[106]

This option may become increasingly important as more energy-limited renewable and storage resources connect to the transmission system. It may not be cost-effective for hydro, solar, and wind generation and energy storage to pay for deliverability upgrades required for participation in resource adequacy programs, due to performance risk and the changing capacity value of these resources. Selecting energy-only interconnection with minimal upgrades could allow these resources to more cost-effectively connect to the transmission network (see Solution 2.5 for discussion on how this option may increase interconnection speed through fast-tracking interconnection requests).

Several transmission providers already provide interconnection customers with the option to connect under energy-only interconnection service with minimal upgrades as long as they meet basic reliability requirements, which in some cases are codified in minimum interconnection standards.[107] However, some transmission providers appear to trigger network upgrades in interconnection to resolve issues that could be managed through generator re-dispatch in day-ahead and real-time operations. Across transmission providers, NERC's transmission planning standards form a common basis for interconnection studies and the identification of network upgrades, but transmission providers interpret transmission planning standards differently in their interconnection studies for energy-only service, and there is often limited transparency in how TPL standards are applied (see Solution 3.6). In principle, as described in NYISO's tariff, interconnection facilities needed to support a minimum interconnection standard should not "… improve the deliverability of power, reduce congestion, or mitigate overloads associated with the delivery of power."[108]

Though transmission providers have provided energy-only interconnection service since FERC Order 2003, interconnection customers do not often select this service. Across CAISO, ISO-NE, PJM, SPP, and MISO, the number of projects requesting energy-only service dropped from roughly 25% of projects in the 2000s to less than 10% of projects in more recent years.[109] Selection of energy-only service tends to be regionally concentrated, though selection has trended toward network service in all ISOs in recent years.[110] Therefore, interconnection

[106] For regulatory precedent, see FERC, 1998, *New England Power Pool*, Docket No. ER98-3853-000.
[107] Examples of ISOs that explicitly allow interconnection customers to avoid network upgrades that create new transmission capacity through energy-only interconnection service include CAISO and NYISO (see Section 6.1.1 of CAISO's *Business Practice Manual for Generator Interconnection and Deliverability Allocation Procedures* and Section 3.6 of NYISO's *Transmission Expansion and Interconnection Manual*). For an example of an explicitly defined minimum interconnection standard, see Section 3.6.1 of the NYISO's *Transmission Expansion and Interconnection Manual* (Manual 23, January 2023). Such processes are similar to ERCOT's "connect and manage" approach discussed in Solution 2.5.
[108] NYISO. October 2022. "Minimum Interconnection Standard," Section 25.2, Open Access Transmission Tariff.
[109] Rand et al., "Queued Up." emp.lbl.gov/queues. The desire to participate in resource adequacy programs, which require capacity, not energy interconnection service, are commonly cited as the key reason for low participation in energy-only service.
[110] Ibid.

customers need to determine whether and how to use energy-only service and engage in discussions around appropriate assumptions for interconnection studies for energy-only interconnection service (details about interconnection study assumptions are discussed in Solution 3.6). Energy-only interconnection is closely related to congestion management, and customers who use this service must understand their congestion risk. Some congestion may be mitigated through reliability and economic transmission planning (see more on transmission planning in Solution 2.9, 3.1, and 3.4), but under current U.S. market designs, energy-only interconnection still confers significant risk on market participants (see Solution 3.3 for discussion on alternative approaches).

FERC could consider making the option to be re-dispatched rather than pay for network upgrades part of standard energy-only service by more explicitly codifying the right to re-dispatch in GIPs and by requiring that transmission providers either develop their own minimum interconnection standards, with FERC review, or by specifying the limits of what should be included in minimum interconnection standards.[111] FERC could also consider holding a technical conference on energy-only service to address confusion in terminology and concepts, establish economic principles, and harmonize interconnection study assumptions around energy-only interconnection service (see also Solution 3.6).[112] Implementing an energy-only interconnection service standard for affected system studies (Solution 2.8) should also reduce economic congestion-related upgrades triggered through these studies.

Table 23: Solution 3.2 Actors and Actions – Ensure that generators have the option to elect energy-only interconnection and be re-dispatched rather than paying for network upgrades

Actor	Engineering and Technical	Market and Regulatory	Administrative and Organizational
FERC		- Consider codifying the right to re-dispatch - Consider defining minimum interconnection standards in the GIP to ensure consistency	- Consider convening a technical conference on energy-only interconnection service
Transmission providers	- Review existing energy-only interconnection service - Develop process to manage interaction between energy-only and network service	- Develop and integrate minimum interconnection standards, where absent	
Interconnection customers			- More systematically evaluate energy-only interconnection options

[111] FERC's standard LGIPs already define ERIS as "as available" service (Section 3.2.1.1). However, they do not explicitly give interconnection customers the right to be re-dispatched rather than paying for congestion-related upgrades under this service. As discussed in the text, some transmission providers already provide this option, whereas others do not appear to.

[112] Further examples of how the industry could improve energy-only service are outlined in Norris, T., "Beyond FERC Order 2023," Duke University, nicholasinstitute.duke.edu/publications/beyond-ferc-order-2023-considerations-deep-interconnection-reform. .

Actor	Engineering and Technical	Market and Regulatory	Administrative and Organizational
Research community (including DOE)	- Review current approaches to energy-only interconnection - Develop generic minimum interconnection standard		

Solution 3.3: Explore and evaluate potential options for delinking the interconnection process and network upgrade investments to increase upfront interconnection cost certainty. (long-term)

The hybrid nature of U.S. electricity markets has posed an ongoing challenge for interconnection. Most new generation in the United States is procured via long-term contracts through competitive solicitations. Resource developers that bid into these solicitations typically need to have a reasonably accurate sense of what their interconnection costs and possible commercial operation dates will be before they bid, creating a chicken-and-egg problem: resource developers would ideally not submit interconnection requests before they have confidence that they will build their projects, but they will not have that certainty until they complete the interconnection process and receive their interconnection cost assignment. The localized nature of procurement and the relatively limited number of buyers in a location exacerbates this problem.[113] The historical result has been speculative interconnection requests, large queue volumes, and interconnection delays.[114]

If the current round of interconnection reforms is not successful in addressing queue bottlenecks, and if competitive solicitations continue to be the main avenue for procuring new generation, it may be useful to consider alternatives that delink interconnection processes from planning for network upgrades. For instance, one potential option might be to create zonal or systemwide interconnection tariffs on interconnection customers to fund network upgrades and then separately and, to some extent, proactively identify necessary network upgrades through transmission plans or in interconnection studies (see further discussion in Solutions 2.9, 3.1, and 3.4).[115] Other options might also include moving network upgrades needed for deliverability to resource adequacy planning, rather than interconnection, or changing methods and metrics around deliverability.

The goal of these strategies would be a delinking of interconnection and network upgrades, which would likely create greater certainty for sellers and buyers in longer-term contract markets. Greater certainty may come at a cost of economic efficiency, however, if the price

[113] For instance, integrated resource planning and competitive procurement for vertically integrated utilities will often focus on resources within their service territory, rather than cross-state resources.
[114] ISO/RTO Council Whitepaper on Interconnection Queue Management Process. 2008. www.spp.org/documents/7546/ferc%20filing%20-%20ad08-2%20irc%20whitepaper%20on%20interconnection%20queue%20management%20process%20-%20filed%20011008.pdf.
[115] SPP's proposed entry fee and the United Kingdom's Transmission Network Use of System Charge are examples of average cost-based transmission charges on interconnection customers. This approach is in contrast to the incremental cost basis that currently exists as part of study clusters.

signals for siting are diluted. Delinking interconnection and network upgrades would be a radical departure from current practice in most jurisdictions and may thus require extensive discussions with stakeholders and policy change by FERC.[116]

Table 24: Solution 3.3 Actors and Actions – Explore and evaluate potential options for delinking the interconnection process and network upgrade investments to increase upfront interconnection cost certainty

Actor	Engineering and Technical	Market and Regulatory	Administrative and Organizational
FERC, federal agencies, state agencies, transmission providers, transmission owners, interconnection customers, consumer groups, research community (including DOE)		- Begin to consider alternative cost allocation models for network upgrades	

3.2. Coordination between Interconnection and Transmission Planning

Key Takeaways

In addition to proactive transmission planning cost allocation solutions discussed in the above section, closer alignment in the data inputs, assumptions, and process timelines between interconnection and long-term transmission planning can help ensure that transmission solutions that would have been more efficiently identified in proactive transmission plans are not instead triggered through interconnection.

Solutions Synopsis

Solution 3.4: More closely **align data inputs, assumptions, and process timing** between interconnection and transmission planning processes. (medium-term)

Solution 3.4: More closely align data inputs, assumptions, and process timing between interconnection and transmission planning processes. (medium-term)

Interconnection and regional transmission planning both aim to maintain reliable real-time operation of the transmission system, and both can result in the building of new transmission infrastructure. Ensuring that these two processes produce consistent outcomes requires coordination between them or even integrating and interlinking them. More narrowly, coordination implies that the inputs, assumptions (as discussed in Solution 3.6), and alternative mitigation options (as discussed in Solution 3.5) used in each process are consistent and that process timelines are aligned so that outputs from one process can be used in the other—for instance, that planned transmission upgrades from the most recent plan are included in interconnection studies and that generation that has completed or nearly completed an IA can be included in transmission plans. Some transmission providers have, or are in the process of

[116] Delinking interconnection and network upgrades would require changes in FERC's "but for" policy, which has been industry standard since Order 2003.

developing, closely coordinated assumptions and processes for interconnection and transmission planning.[117]

Deeper coordination could include combining the two processes into a single integrated process. SPP's proposed consolidated planning process, for instance, aims to merge generator interconnection, integrated transmission planning, interregional planning, and transmission services into one consolidated process.[118] SPP is first targeting better integration between generation interconnection and integrated transmission planning because these two processes, while generating the largest number of network upgrades, are also the most siloed. Regardless of the depth of coordination, clear communication of transmission planning results to stakeholders can also help better align transmission planning and interconnection by providing clear signals for areas of future transmission capacity (see the data transparency section for more on how providing clear signals can improve interconnection applications).

Changes in transmission planning will also affect coordination between interconnection and planning. For instance, FERC's transmission notice of proposed rulemaking (NOPR) would require that transmission providers use multiple scenarios in their transmission plans, which implies that they should also consider incorporating transmission expansion from scenario planning in base cases used in interconnection studies.[119] This would help ensure that transmission that would have been selected in planning is not instead triggered through interconnection. FERC also proposed that transmission providers consider interconnection-related upgrades in regional planning processes if the upgrade has been identified multiple times but has never been built. Transmission planning reforms at FERC will thus have important implications for interconnection reforms.

Table 25: Solution 3.4 Actors and Actions – More closely align data inputs, assumptions, and process timing between interconnection and transmission planning processes

Actor	Engineering and Technical	Market and Regulatory	Administrative and Organizational
FERC		- Encourage interconnection planning coordination - Continue progress on transmission planning reforms	
Transmission providers	- Ensure coordinated inputs, assumptions, and mitigation options		- Develop coordinated process timelines - Convene stakeholders to discuss coordination options

[117] Transmission providers generally use base cases from transmission plans in interconnection studies, though the degree of coordination in study assumptions, data updates, and process timing varies among providers. For an example of explicit coordination requirements for interconnection study assumptions and considerations, see Section 7.2 of the CAISO tariff.
[118] For more on the consolidated planning process, see SPP, Consolidated Planning Process Task Force, www.spp.org/stakeholder-groups-list/organizational-groups/board-of-directorsmembers-committee/consolidated-planning-process-task-force/.
[119] FERC. April 2022. *Building for the Future Through Electric Regional Transmission Planning and Cost Allocation and Generator Interconnection*. 179 FERC ¶ 61,028.

Actor	Engineering and Technical	Market and Regulatory	Administrative and Organizational
Interconnection customers			- Participate in and inform stakeholder discussions
Research community (including DOE)	- Document emerging practices for coordination		

3.3. Interconnection Studies

Key Takeaways

Interconnection study methods will need to continue to adapt to a changing generation mix, with a greater emphasis on more realistic dispatch assumptions and consideration of multiple time periods rather than static snapshots. As methods change, greater harmonization across transmission providers would help ensure more consistent outcomes across regions. When system impacts do occur, considering other available transmission upgrade options, including grid-enhancing technologies and control tuning, may help identify more cost-effective solutions, as required by FERC Order 2023. Over the longer term, allowing interconnection customers to self-fund and provide their own interconnection studies could help better align incentives for transmission providers, ensuring that studies are completed on time and that facility costs and network upgrades identified in studies are least-cost solutions.

Solutions Synopsis

Solution 3.5: Evaluate **all effective mitigation options** during interconnection studies, incorporating alternative transmission technologies as well as control options for IBRs. (short-term)

Solution 3.6: Continue to develop and harmonize **new, transparent best-practice study methods** to adapt to a changing generation mix and changes in load and to facilitate consistent outcomes across transmission providers. (medium-term)

Solution 3.7: Explore options to allow interconnection customers to **self-fund and provide their own interconnection studies**, subject to transmission provider oversight, rules, and requirements. (long-term)

Solution 3.5: Evaluate all effective mitigation options that should be tested during interconnection studies, incorporating alternative transmission technologies as well as control options for IBRs. (short-term)

Historically, the main solution for mitigating system impacts has been building new transmission facilities. Emerging grid-enhancing technologies (GETs), such as dynamic line ratings (DLRs), advanced power flow control devices, and topology switching/optimization, are generally not considered mitigation options, even though multiple reports[120] and actual projects[121] provide evidence that these solutions can be effective in certain applications. Similarly, stability issues identified in system impact studies are primarily mitigated with additional transmission equipment. Stability improvements through control advancement and control parameter tuning of newly interconnecting and existing IBRs are rarely evaluated, even though they may help avoid costly transmission upgrades.[122] In certain cases, energy storage can be an alternative transmission technology. To allow energy storage to play this role, operations and market rules need to be established for treatment of battery storage as transmission assets rather than a resource, if they have not already been developed.

There is also a lack of transparency around mitigation solutions that are being evaluated and proposed, the assumptions related to costs of these solutions, and ultimate timing of construction, which adds to overall uncertainty for resource developers (see, for example, Solution 1.2 for related recommendations on data transparency). All mitigation options should be evaluated for the same set of future cases/scenarios and same time horizon to allow for fair comparison and informed selection of the most effective solution.

FERC Order 2023 requires that transmission providers evaluate a list of potential alternative technologies during interconnection studies and report the cost, feasibility, and time savings for these alternatives relative to network upgrades in cluster study reports.[123] The list of alternative technologies enumerated in the order does not, however, include enhanced controls and control parameter tuning for IBRs. To assess both alternative transmission technologies and control options for IBRs, transmission providers will need to develop, document, and regularly update

[120] A 2022 DOE report, "Grid-Enhancing Technologies: A Case Study on Ratepayer Impact," details the results of a case study focusing on the effect of power flow control and DLRs on the NYISO service area. The report concludes that these technologies "can be cost-effective in the NYISO region, ultimately saving ratepayers money while integrating more renewable generation." But the report also notes that "additional studies should be completed to assess [their] impact in other regions of interest." This DOE report built on earlier findings from a December 2020 DOE report, "Advanced Transmission Technologies," which provided an overview of these technologies and emphasized their importance in increasing the resilience and reliability of the grid. The report also noted that these technologies can help solve challenges related to the interconnection of intermittent renewable resources to the grid. A 2021 Brattle report explains the potential transformative impact of applying GETs to the electrical grid. Brattle shows that by applying the three listed GETs onto the Kansas and Oklahoma grids, the amount of renewable energy that could interconnect without any transmission upgrades would double and the investment would pay for itself in only 6 months and deliver additional community benefits.

[121] For example, in 2022, PPL Electric Utilities completed a project integrating DLR technology into real-time and market operations. One line with DLR saved around $23 million in 1 year on congestion costs (news.pplweb.com/2023-07-11-PPL-Electric-Utilities-first-of-its-kind-innovation-improves-reliability,-reduces-costs).

[122] More information on control tuning can be found in Shattuck, A., "Control Tuning as Alternative to Transmission Reinforcement," www.esig.energy/event/joint-generator-interconnection-workshop/. More information on control enhances can be found in Wilson, A., et al., "Xcel Energy's Colorado Wind Farm Integration with the Grid," *T&D World*, www.tdworld.com/renewables/article/21246231/xcel-energys-colorado-wind-farm-integration-with-the-grid.

[123] Technologies include static synchronous compensators, static volt-ampere reactive compensators, advanced power flow control devices, transmission switching, synchronous condensers, voltage source converters, advanced conductors, and tower lifting.

models with which these solutions can be tested (Solution 4.2) to have them readily available for interconnection studies. Where grid-forming controls are deemed to be beneficial to improving stability margins, transmission providers can work with resource developers to agree on an alternative site-specific grid-forming plant model to be evaluated.

While evaluation of additional alternative technologies and mitigation options may extend the interconnection study timeline, finding more cost-effective solutions, in turn, may reduce back-and-forth between transmission providers and interconnection customers, the number of withdrawals, and, ultimately, the need for restudies. With accumulation of experience with new technologies, automation advancements (as discussed in Solution 2.3), and workforce development (as discussed in Solution 2.13), the time required for assessment of various mitigation options should be reduced.

Table 26: Solution 3.5 Actors and Actions – Evaluate all effective mitigation options that should be tested during interconnection studies, incorporating alternative transmission technologies as well as control options for IBRs

Actor	Engineering and Technical	Market and Regulatory	Administrative and Organizational
FERC	- Evaluate other emerging solutions beyond those included in Order 2023	- Consider periodically updating list of enumerated alternative technologies - Develop incentive models to encourage alternative technologies	
Transmission providers, transmission owners	- Evaluate all effective mitigation options during interconnection studies - Identify combinations of alternative technologies that accelerate interconnection processes - Keep up-to-date models for existing and emerging solutions	- Engage with market participants and vendors to ensure accurate technology and cost information for all mitigation solutions	- Engage stakeholders to develop and publish a comprehensive set of mitigation solutions
Interconnection customers	- Evaluate viability of grid-forming controls and provide an alternative site-specific grid-forming plant model to the transmission provider		- Provide necessary data and modeling information in a timely manner to enable assessment of advanced IBR controls and control parameter tuning as mitigation options
Consumer groups			- Participate in discussions around leveraging other, potentially lower-cost, mitigation options
Research community (including DOE)	- Evaluate emerging mitigation solutions and their effectiveness - Develop effective screening methods for evaluating and comparing mitigation solutions		- Inform FERC and other stakeholders on new technology mitigation options

Actor	Engineering and Technical	Market and Regulatory	Administrative and Organizational
	- In collaboration with OEMs, develop models for emerging technologies		
Software vendors	- Develop and adapt software to be able to capture and incorporate GETs		

Solution 3.6: Continue to develop and harmonize new, transparent best-practice study methods to adapt to a changing generation mix and changes in load and to facilitate consistent outcomes across transmission providers. (medium-term)

Higher levels of solar generation, wind generation, and electricity storage and changes in load (e.g., via transportation and building electrification, data centers, and hydrogen production) will affect the timing and character of reliability issues studied in system impact studies. For instance, in summer peaking systems with higher levels of solar generation, loss-of-load probabilities shift from summer afternoons to summer evenings. Building electrification may create new reliability concerns in winter. Ensuring that interconnection studies support reliable real-time operations will mean continuing to adapt them to changes in generation mix and loads.

Rightsizing network upgrades in interconnection also requires using realistic assumptions in interconnection studies. In principle, for instance, system impact studies should focus on realistic load and resource conditions in which the transmission system is under stress and should incorporate the tools that system operators have to mitigate stress in real time, including the use of security and transmission constraints in economic dispatch. The conventional "worst-case scenario" approach to impact studies does not meet either of these conditions, which can result in an overbuilding of transmission infrastructure relative to need.[124] Realistic generation and storage dispatch (MW output or charging) and transmission technology (Solution 3.5) assumptions in power flow studies, as well as re-dispatch of generation to solve reliability issues in those studies (Solution 3.2), may better align interconnection studies with operating practices and reduce the need for upgrades.[125] Conventional approaches to impact studies can also lead to manual setup of study cases and leave little room for automation and streamlining (see more in Solution 2.3).

Some transmission providers have developed new study methods that address the above changes in resource mix and the need for more grounded assumptions in interconnection studies, but there are still significant methodological differences among them. Key areas of divergence

[124] PacifiCorp, for instance, argued that using "more realistic study assumptions from existing resources rather than assum[ing] worst case scenario assumptions … in some circumstances should alleviate the need for additional network upgrades to interconnect new resources." (PacifiCorp. 2023. *2023 Integrated Resource Plan, Volume I*. www.pacificorp.com/content/dam/pcorp/documents/en/pacificorp/energy/integrated-resource-plan/2023-irp/2023_IRP_Volume_I.pdf.)

[125] Dispatch assumptions are particularly important for energy storage, which has fewer operational constraints than thermal generation and can thus be turned on or off and ramped quickly to respond to reliability issues.

include study years and time horizons used, generator and energy storage dispatch assumptions, mitigation options, and, for deliverability studies, capacity crediting. Developing rigorous, consistent approaches to modeling HVDC transmission in interconnection studies is also an important consideration. New tools may enable studies to examine more time slices and eventually do chronological simulation over longer time horizons.[126] In studies that focus only on a few time periods, there is often limited understanding in how an upgrade would be used and whether re-dispatch could be used as a strategy to mitigate reliability issues (see more discussion on re-dispatch in Solution 3.2).[127] Coordination with transmission planning (Solution 3.4), including the scenario-based approach proposed in FERC's 2022 transmission NOPR, will also be important.

Order 2023 requires a cluster approach to interconnection studies, though there are still questions about best practices in cluster studies. For instance, FERC declined to require that transmission providers use subgroups in cluster studies, allowing instead for local discretion.[128] However, there are not yet clear best practices for cluster studies. Some transmission providers, such as CAISO, MISO, and SPP, have conducted cluster studies for several years, though the issues they face in designing studies are changing with changes in the generation mix. Other transmission providers have less or even no experience with cluster studies. Developing best practices in cluster studies could benefit the whole industry.

Transmission providers often apply different methods and assumptions in interconnection studies: cases being studied (peak load vs. low load case, high vs. low variable renewable energy), case years, inclusion of planned generation and transmission from the prior study cycle, generation and energy storage dispatch (both for studied and existing generations), generator rebalancing, the list of contingencies to study, study criteria, mitigation options (including, for example, re-dispatch of a generator or battery), and transfer distribution factors considered for cost allocation. Lack of harmonization leads to uncertainty for resource developers and project withdrawals. Harmonization of interconnection study methods and assumptions across transmission providers could reduce ambiguity and uncertainty (see more on this in Solution 2.7 on affected systems).

The assumptions used in interconnection studies, such as re-dispatch assumptions, are often not well-documented either in transmission provider tariffs and business practice manuals or in the interconnection facilities' study reports provided to interconnection customers. In principle, transmission providers should at a minimum enable interconnection customers to be able to approximately recreate the analysis in the interconnection study and understand why network upgrade costs are being assigned to customers (improving this mitigates some concerns

[126] See, for instance, Vyakaranam, B., et al., 2021, "Automated Tool to Create Chronological AC Power Flow Cases for Large Interconnected Systems," *IEEE Open Access Journal of Power and Energy*, 8.
[127] For infrequent, short-duration violations, it may be more economic to re-dispatch generation than to build upgrades.
[128] Order 2023, pp. 244-253. Subgroups are employed today in some regions and are geographically dependent, often related to a specific transmission provider's transmission network.

identified in Solution 3.7). Greater transparency could also benefit harmonization of interconnection study methods and assumptions. Solutions provided in Chapter 1 of this report elaborate on data transparency issues.

Table 27: Solution 3.6 Actors and Actions – Continue to develop and harmonize new, transparent best-practice study methods to adapt to a changing generation mix and changes in load and to facilitate consistent outcomes across transmission providers

Actor	Engineering and Technical	Market and Regulatory	Administrative and Organizational
FERC		- Encourage transparent, harmonized study methods	- Consider technical conference on interconnection study methods and assumptions
Transmission providers, transmission owners	- Develop new study methods and study assumptions representative of system stress scenarios - Develop new study methods to better understand frequency and duration of perceived impacts - Clarify study methods for HVDC transmission interconnection	- Review documentation of interconnection studies and improve transparency	- Engage with stakeholders to communicate new methods - Participate in efforts to develop best practices for cluster studies and generation and storage dispatch assumptions
Interconnection customers	- Propose changes to energy-only modeling, mitigation options, and impact thresholds		- Work with regions and transmission providers, software vendors, and resource community on appropriate study methods and more transparent documentation of methods
Software vendors	- Integrate new methods into modeling software		
Research community (including DOE)	- Study and propose generic changes in study methods and dispatch assumptions - Develop best practices for cluster studies		- Work with software vendors to promote model integration

Solution 3.7: Explore options to allow interconnection customers to self-fund and provide their own interconnection studies, subject to transmission provider oversight, rules, and requirements (long-term)

Transmission providers differ in the extent to which they conduct interconnection studies themselves or outsource them to transmission owners or third-party providers. Regardless of approach, study provider incentives have historically not always been aligned with the societal goals of timely study completion and low-cost solutions to mitigate impacts identified in interconnection studies.[129] Limited regulatory oversight over network upgrade investments in

[129] Transmission owners, for instance, have an incentive to increase the costs of network upgrades to expand rate base, and transmission owners that are generation-owning utilities have an incentive to limit entry.

interconnection contributes to this problem.[130] Penalties for study delays (Solution 2.2) and requirements to consider alternative transmission solutions (Solution 3.5) should help better align incentives. Adoption of better interconnection study data transparency or automation initiatives, as documented in Solutions 1.2, 1.3,[131] 2.3, and 3.6, could also help mitigate concerns over current interconnection study processes.

An additional solution may be to introduce choice and competition in interconnection studies themselves, by allowing interconnection customers to self-fund and provide their own studies or collaborate on providing cluster studies across customers. Creating the rules and regulations to enable this solution could be challenging, would take time, and should take equity concerns into account if the opportunity seems to only benefit well-resourced interconnection customers. Authorizing such an approach may require sharing of CEII and data subject to CIP.[132]

Transmission providers would need to certify study providers and set clear rules and requirements for these studies to ensure that all interconnection studies are rigorous and consistent. Transmission providers would also need to provide data for studies and review the studies upon completion. FERC would also likely need to set and harmonize rules and requirements across transmission providers, for example, to specify the conditions under which interconnection customers would be able to choose their own study providers.

Table 28: Solution 3.7 Actors and Actions – Explore options to allow interconnection customers to self-fund and provide their own interconnection studies, subject to transmission provider oversight, rules, and requirements

Actor	Engineering and Technical	Market and Regulatory	Administrative and Organizational
FERC		- Explore regulations for self-funded studies	
Transmission providers, research community (including DOE)	- Explore reliability implications for interconnection customer-funded studies	- Explore rules and regulations for self-funded studies	- Explore organization structure needed to facilitate other entities performing studies
Interconnection customers		- Determine benefit to taking responsibility to undertake studies	- Evaluate internal capabilities to support self-funded studies

[130] It does not appear, for instance, that regulators or transmission providers regularly benchmark interconnection facilities or network upgrade costs.
[131] Platforms such as AEMO's Connections Simulation Tool, which allows developers to run EMT studies on AEMO's PSCAD model, could help give interconnection customers better access and understanding of interconnection study results and enhance transparency and collaboration within the study process. It is unclear if this approach makes sense for less detailed studies.
[132] ERCOT makes some of this information sharing possible through its Market Information System Secure Area. To gain access, stakeholders must fulfill specific requirements defined by ERCOT.

4. Maintain a Reliable, Resilient, and Secure Grid

Wind, solar, and battery storage technologies use power electronics when interfacing with the grid and are known as inverter-based resources (IBRs). IBR technologies are distinct from the thermal and hydro generation sources that have been used for over a century. While performance of thermal and hydro generation is primarily based on the physical design of a generator (i.e., large rotating mass), behavior of IBRs is primarily driven by power electronic controls, which provide a higher degree of flexibility but also higher electrical complexity. Understanding the inverter interactions among other inverters and with other grid components is important to maintaining a reliable grid.

Historically, the goal for connecting wind and solar with inverters was primarily delivering power to the grid. Consequently, grid operators have generally allowed or even required IBR disconnection during times of grid disturbance and reconnection once disturbances had been cleared. This approach minimized IBR interactions with the grid and maintained system reliability when IBR capacities were low. Given the growing capacity of IBRs on the grid, these generation sources increasingly need to ride through disturbances (i.e., stay connected) and support grid recovery. Requirements for ride-through today, however, are not always defined (e.g., performance expectations regarding active and reactive power output during and after the disturbance) and do not include performance specifications during other accompanying phenomena on the grid (e.g., voltage phase angle jump, high rate of change of frequency, transient overvoltage, transient overcurrent). Many areas still have limited interconnection requirements for IBRs, apart from high level requirements introduced by FERC and NERC. [133]

Furthermore, simulation models used to verify the reliability impacts of IBRs operating on the grid remain a work in progress. Current modeling approaches involve positive sequence phasor-domain transient models, also called root-mean-square (RMS) models.[134] However, as IBR capacity grows and greater capability is needed from inverters, additional details of IBR control and protective functions may have a reliability impact on the grid and need to be included in the models. Due to the speed of some controls and faster phenomena on the grid, more detailed EMT models are becoming necessary to capture IBR performance and grid impacts as well as interactions between IBRs connected in close proximity to each other. The more detailed models take additional computing power to run and add to the overall processing time of technical interconnection studies.

[133] Major relevant FERC orders are Order 2003/2006 (standardized GIP/generator interconnection agreements), Order 661 (connection requirements for wind), Order 827 (power factor requirements), and Order 842 (primary frequency response requirement). Order 2023 expands the voltage ride-through rules (see more in Appendix C). Two NERC standards relevant at interconnection phase are FAC-001 Facility Interconnection Requirements and FAC-002 Facility Interconnection Studies, as well as other relevant NERC standards for generators once in service, such as PRC-024-3 Frequency and Voltage Protection Settings. Order 901, issued on October 19, 2023, directs NERC to submit a detailed standards development plan to address IBR reliability. See Solution 4.5 for more discussion of this order.

[134] FERC Order 2023 adopted the term RMS model.

In recent years, there has been a series of disturbance events involving IBR disconnections.[135] These performance issues were not identified during interconnection studies of the involved plants. NERC's event analysis[136] identified several gaps related to IBR interconnection standards, conformity assessments, and modeling capabilities, validation, and verification. In this section of the roadmap, DOE addresses specific solutions that reduce these gaps and enhance the reliability of the grid.

4.1. Interconnection Reliability Assessment Models and Tools

Key Takeaways

Improvements to the models and tools used in interconnection studies are needed to avoid large disturbance events. These improvements need to avoid adding significant time to the overall interconnection process. Recommended solutions primarily involve collection, quality testing, and validation of generation plant electrical models in both the RMS and EMT domains. Collection and assessment of EMT models are needed today, while screening tools should be developed to determine when EMT studies become necessary in a specific region in the future. Aligning the interconnection study process flow with generation project development timelines will ensure that the appropriate, site-specific models of the generation plants are used in system impact studies. Leveraging modern computing technologies should increase modeling capabilities and improve the timeliness of study results.

Solutions Synopsis

Solution 4.1: Require **submission of validated EMT models** for all IBRs during the interconnection process and **develop screening criteria** to determine when EMT studies are necessary within a region. (short-term)

Solution 4.2: Develop rules for **dynamic model quality testing and validation** for both RMS and EMT simulations, ensuring that plant performance conforms with applicable interconnection requirements. (short-term)

Solution 4.3: Develop a **study process flow** that is better aligned with project development timelines. (medium-term)

Solution 4.4: Advance the **computational speed** of interconnection reliability assessments. (medium-term)

[135] The largest event, in Odessa, Texas, led to disconnection of over 1,700 MW of solar power production, larger than the single largest contingency in ERCOT (a trip on 1 nuclear unit), highlighting concerns for grid reliability. NERC. December 2022. *2022 Odessa Disturbance: Texas Event: June 4, 2022; Joint NERC and Texas RE Staff Report*. www.nerc.com/comm/RSTC_Reliability_Guidelines/NERC_2022_Odessa_Disturbance_Report%20(1).pdf.

[136] Between 2016 and 2023, 14 events were reported, primarily involving solar plants (but a few involving wind and battery storage), with the largest events resulting in more than 1,700 MW of nonconsequential tripping or active power reduction. NERC. Event Reports. www.nerc.com/pa/rrm/ea/Pages/Major-Event-Reports.aspx.

Solution 4.1: Require submission of validated EMT models for all IBRs during the interconnection process and develop screening criteria to determine when EMT studies are necessary within a region. (short-term)

Previously, EMT analysis was used for specific local phenomena, such as insulation coordination, harmonic analysis, and high-voltage direct current and flexible alternating current transmission systems (FACTS)[137] control designs. With growing shares of power electronic devices, application of EMT analysis is becoming necessary[138, 139, 140] for subsynchronous resonance studies, IBR control interactions in weak grid conditions, and fault ride-through performance evaluation. Increasingly larger parts of the grid may need to be included in these models.

FERC [Order 2023](#) states that EMT model collection is required in areas where transmission providers are carrying out EMT studies. However, there are very few areas in the United States where EMT studies are being done today. In areas where EMT studies are not yet required, it is becoming increasingly important to collect and quality test site-specific, validated EMT models for all new IBR plants during the interconnection process, for two main reasons:

Models of legacy equipment are difficult to obtain retroactively, once EMT studies ultimately become necessary for a given region. Manufacturers may have gone out of business or may be reluctant to develop EMT models for discontinued products.[141]

Detailed EMT models are needed to assess plant performance conformity with applicable interconnection requirements during phenomena such as transient overvoltage or unbalanced conditions that are not captured in RMS simulations.

The EMT model collection process will involve transmission providers communicating requirements to new IBR applicants, selecting an EMT simulation tool to use, defining model validation criteria, ensuring EMT training is provided to their staff (Solution 2.13), and checking EMT model quality. Furthermore, there will be a significant onus on the interconnection

[137] The "FACTS" definition includes various power electronic-controlled devices for reactive power compensation and power flow control.

[138] NERC Project 2022-04 EMT Modeling has started to address lack of accurate modeling data and the need to perform EMT studies during the interconnection process and long-term planning. Affected NERC Standards: FAC-002, MOD-032, and TPL-001.

[139] NERC also has recently published Reliability Guideline "Electromagnetic Transient Modeling for BPS Connected Inverter-Based Resources – Recommended Model Requirements and Verification Practices"[139], the first in a series of planned Reliability Guidelines on EMT modeling and studies.

[140] The EPRI white paper "Differentiating between Applicability of Simulation Domains and Inverter Mathematical Models in these Domains", provides reference on the capabilities and limitations of IBR models and simulation domains using the recent NERC disturbance events, https://www.epri.com/research/products/000000003002025063.

[141] Isaacs, A. "PSCAD Model Development When OEM Is Out of Business?" ERCOT. www.ercot.com/calendar/01122024-IBRWG-Meeting-_-Webex.

customers to develop and verify the aggregate EMT model for their proposed plant (see Solution 4.2).[142]

While collection of EMT models is important for ensuring reliability, requiring EMT models at the interconnection request stage, as stated in FERC Order 2023, may reduce model usefulness and have detrimental impacts on system reliability. EMT models are sensitive to the specific equipment and control settings used at a plant, and the state-of-the-art technology at the time of an interconnection request could bear little resemblance to what is ultimately installed, posing concerns for accurate equipment representation within a model. Furthermore, at early stages of project development, the equipment itself could still be in a developmental stage,[143] and models of such equipment could still be in the validation process by the respective OEM. More flexibility is needed in determining when during the interconnection process EMT models should be submitted (see more details about study process flow in Solution 4.3) and how these models should be updated as more information becomes available. The development of EMT models for IBR plants is a time-consuming task. To avoid additional delays in the interconnection process, interconnection customers should start model development work early in the interconnection process, updating the model along the way to reflect any changes to the plant design.

The EMT model collection process outlined above will only apply to new IBR plants; however, for meaningful EMT studies, all equipment in the study area should be modelled as accurately as possible. While not necessarily related to the interconnection process, a procedure for collection of EMT models for legacy equipment also needs to be developed. The most effective approach might be to first target IBR plants involved in prior NERC disturbance events, as well as IBR plants undergoing material modifications/upgrades. For these plants, EMT models can also be requested and collected following the above process.

EMT studies are time-consuming and complex (see Solution 2.13 on workforce training and Solution 4.4 on improving modeling capabilities); therefore, beyond EMT model collection, transmission providers, working with the research community, should develop and adopt screening tools and metrics to understand when RMS simulation results are no longer valid or sufficient for interconnection studies and, therefore, EMT studies are needed. [144] This screening analysis is still an active area of research and might be more achievable in the medium term rather than the short term. At the same time, transmission providers should investigate if the

[142] NERC. March 2023. "Model Quality Verification and Attestations," *Reliability Guideline: Electromagnetic Transient Modeling for BPS-Connected Inverter-Based Resources—Recommended Model Requirements for Verification Practices*, p. 16. www.nerc.com/comm/RSTC_Reliability_Guidelines/Reliability_Guideline-EMT_Modeling_and_Simulations.pdf.
[143] Project developers often prefer installing the latest state-of-the-art equipment and, therefore, may order equipment that is still under development and in testing stage.
[144] Recently published CIGRE Technical Brochure 881, *Electromagnetic Transient Simulation Models for Large-Scale System Impact Studies in Power Systems Having a High Penetration of Inverter-Connected Generation,* provides an excellent review of available screening methods. Note that the brochure is only available for free to CIGRE members and otherwise is only for purchase; more work in the public domain could be useful.

validity of RMS studies can be extended with the use of manufacturer-specific, user-defined models in interconnection studies.[145]

Today, EMT studies are needed in areas where the risk of control interactions between IBRs and series-compensated transmission lines exist[146] and in areas on the edges of the grid, far away from load centers and conventional synchronous generation, known as "weak-grid" areas. In the future, as synchronous generators retire and the number of IBRs concentrated in the pockets of the grid with good wind and solar resource increases, EMT studies will be needed in more regions.

Note that even when EMT studies are determined to be necessary during the interconnection process, a better use of transmission provider resources may be to run occasional larger weak-grid area studies in EMT (e.g., Panhandle region in ERCOT) rather than running individualized EMT interconnection studies.

Table 29: Solution 4.1 Actors and Actions – Require submission of validated EMT models for all IBRs during the interconnection process and develop screening criteria to determine when EMT studies are necessary within a region

Actor	Engineering and Technical	Market and Regulatory	Administrative and Organizational
FERC		- Consider requiring collection of EMT models	
NERC	- Continue to provide guidance on EMT modeling/studies - Include EMT modeling and study requirements in NERC standards[147]		
Transmission providers	- Investigate when RMS tools/models can be extended - Develop screening tools to understand when EMT studies are needed		- Collect EMT models for new and certain legacy IBRs
Interconnection customers and their equipment manufacturers	- Develop validated site-specific plant EMT models for new and certain legacy IBRs - Conduct EMT model assessments before submission		

[145] The use of generic RMS models may create unnecessary simplifications, particularly in weak-grid areas, and render RMS simulation results unreliable, calling for complex and time-consuming EMT studies.
[146] The risk of such control interactions between IBRs and series-compensated transmission lines was first identified in a 2009 event in South Texas (ERCOT. "Series Compensation and SSR – Concepts." view.officeapps.live.com/op/view.aspx?src=https%3A%2F%2Fwww.ercot.com%2Ffiles%2Fdocs%2F2014%2F06%2F02%2Fseries_compensation_and_ssr_concepts_2014_ots.ppt&wdOrigin=BROWSELINK.)
[147] Standards development is already ongoing in NERC Projects 2020-06 Verifications of Models and Data for Generators, 2022-02 Modifications to MOD-032 and TPL-001, and 2022-04 EMT Modeling. These projects are all given high priority in NERC's Comprehensive Work Plan Addressing FERC Order 901 Directives. The date for filing these standards with FERC per NERC's Work Plan is 11/04/2025.

Actor	Engineering and Technical	Market and Regulatory	Administrative and Organizational
	- Develop and validate equipment models in EMT - Produce site-specific EMT models for IBR plants - Enhance RMS plant models to extend validity of RMS study results		
Research community (including DOE)	- Develop screening methods and metrics to understand when an EMT study is needed - Develop further enhancements of RMS and EMT models		

Solution 4.2: Develop rules for dynamic model quality testing and validation for both RMS and EMT simulations, ensuring that plant performance conforms with applicable interconnection requirements. (short-term)

Study engineers rely on plant models to carry out interconnection studies, particularly stability studies. FERC Order 2023 requires both manufacturer-specific (user-defined) and generic (standard library) RMS models, which are appropriately parametrized to represent IBR plants, to be submitted by a developer during interconnection process. Furthermore, as discussed in Solution 4.1, provision of EMT models representative of IBR plants is also required in certain circumstances.[148] Timeliness and efficiency of the stability studies, as well as their applicability, strongly depend on the interconnecting plant model's usability and accuracy.[149] "Model usability" refers to the ability of the model to be easily integrated into the simulation tool used for the study and run seamlessly during performed simulations. Model accuracy refers to the ability of the model to replicate equipment and settings of the interconnecting plant as built in the field.

The first stage of model validation should only include a single unit (inverter or a wind turbine) EMT model, benchmarked with hardware tests. Such tests are generally performed once for a certain model or a family of inverters in a manufacturer's laboratory with default settings. A benchmarking report comparing non-site-specific hardware performance to the model should then be submitted to the transmission provider.

[148] FERC Order 2023 states that EMT model collection is required in areas where transmission providers are carrying out EMT studies; however, as outlined in the Solution 4.1, it is recommended that EMT models of IBR plants are collected, quality tested, and validated, even in areas where EMT studies are not yet being carried out.
[149] For example, the PSS/e Dynamic Model reView (DMView) webpage, which hosts ERCOT's Model Quality Testing tool, states that a streamlined process that uses model quality testing would minimize the need for extensive communication and corrections of stability studies. Cheng, Y. PSS/e Dynamic Model review (DMView). sites.google.com/view/dmview/home.

Next, the entire aggregated plant model, including the plant controller and any supplemental equipment, needs to be built and validated. Large-signal disturbance tests are normally not performed on a physical plant to avoid equipment damage. So, until actual disturbance happens in the field during plant operation, there is no plant performance data to validate the entire plant model against. Therefore, two steps are necessary to perform a plant model validation during interconnection process: (1) model verification to make sure that the plant model matches hardware and control settings of the actual plant and (2) benchmarking the EMT and RMS plant models (both user defined and generic).[150]

Once model quality testing and validation are done, a plant model conformity with applicable interconnection requirements needs to be assessed. Again, the assessment of plant performance using accurate RMS and EMT models is done in lieu of physical large-signal disturbance tests. Note that a plant model performance evaluation is different and separate from interconnection studies. The former assesses a plant's capability to conform with applicable interconnection requirements (as discussed in Solutions 4.5 and 4.6), while the latter assesses a plant's impact on the grid along with other interconnecting plants. Both assessments are needed during the interconnection process to ensure reliable plant operation after commissioning. Today, some areas only perform the latter and may only capture some aspects of the former.

Furthermore, recognizing that user-defined RMS models are manufacturer specific and generally have a greater degree of modelling accuracy compared to generic ones, it is recommended that transmission providers use these more accurate models during the interconnection studies for determining needed network upgrades. Project-specific, quality-tested, and validated RMS generic models are more suitable with wide-area transmission planning studies for improved computational efficiency.

Finally, once a plant is constructed, verification should be done to ensure that the physical plant and its control settings correspond to the plant design and settings in respective RMS and EMT models. This verification step is commonplace in Australia[151] and Europe (modelling requirements are scattered in each country's documents),[152] and while it was recently introduced

[150] DOE-funded project PV-MOD, led by EPRI, provides additional guidance and education on model development and model validation. EPRI. Adaptive Protection and Validated Models to Enable Deployment of High Penetrations of Solar PV (PV-MOD). www.epri.com/pvmod.

[151] AEMO. 2021. *Dynamic Model Acceptance Test Guideline*. aemo.com.au/-/media/files/electricity/nem/network_connections/model-acceptance-test-guideline-nov-2021.pdf?la=en&hash=3287CA490B21CE0634D954440940232E.

[152] Fingrid (Finnish System Operator). 2024. "Modelling Instruction for PSS/E and PSCAD models." www.fingrid.fi/globalassets/dokumentit/fi/palvelut/kulutuksen-ja-tuotannon-liittaminen-kantaverkkoon/fingrid-modelling-instruction-for-psse-and-pscad-models-2024_01_12-002.pdf#page14. EirGird (Irish System Operator). EirGird's (Irish System Operator). *EirGrid Grid Code*; *Simulation Studies and Modelling Requirements for Compliance Determination*. cms.eirgrid.ie/sites/default/files/publications/GridCode.pdf; cms.eirgrid.ie/sites/default/files/publications/EirGrid-Simulation-Requirements.pdf. EirGrid captures high-level modelling requirements in its grid code (clause PC.A8); its *Simulation Studies and Modelling Requirements* document is linked to the grid code and provides more details about the types of models and studies that are required for each type of a power plant. EirGrid is starting a new project to review and update those.

in ERCOT,[153] it is still rare among other transmission providers in the Unites States. The models should be validated against commissioning tests and after large disturbances once an IBR plant is in operation (as discussed in Solution 4.6). The latter model validation is extremely important, since this provides the first opportunity to validate IBR plant models based on actual large-signal disturbance.

Table 30: Solution 4.2 Actors and Actions – Develop rules for dynamic model quality testing and validation for both RMS and EMT simulations, ensuring that plant performance conforms with applicable interconnection requirements

Actor	Engineering and Technical	Market and Regulatory	Administrative and Organizational
FERC	- Consider implementing model quality testing validation in LGIAs/Small Generator Interconnection Agreements		
Transmission providers	- Include model quality testing and model validation in interconnection processes - Establish modelling and validation requirements - Identify automation tools/methods for model assessment		- Consider outsourcing model assessment - Review and verify the assessment reports - Collaborate with peers to establish automation tools and share solutions
Interconnection customers	- Ensure that models provided to transmission providers are properly assessed		- Provide model assessment reports to transmission providers - Monitor plant performance - Provide model validation reports after large disturbance events
Research community (including DOE)	- Continue development and improvement of dynamic model validation and screening		

National Grid Electricity System Operator (ESO) (System Operator in Great Britain). Grid Code. www.nationalgrideso.com/industry-information/codes/grid-code-gc. National Grid ESO specifies high-level modelling requirements in their grid code, requiring all generators to provide RMS models; IBRs should also provide EMT models.

[153] ERCOT. Current Planning Guide, sections 5.7.1 and 6. www.ercot.com/mktrules/guides/planning/current; ERCOT. Dynamics Working Group. *DWG Procedure Manual section 3.1*. www.ercot.com/committees/ros/dwg/; ERCOT. Resource Integration. *Model Quality Guide* and Dynamic Model Templates. www.ercot.com/services/rq/integration/.

ERCOT CASE STUDY: The process developed and implemented in ERCOT serves as a good example of streamlined model quality testing, model validation, and conformity assessment (see *Model Quality Guide*, available at www.ercot.com/services/rq/integration/). ERCOT has developed two open-source tools (DMVIEW for RMS models and PMVIEW for EMT models) that allow a generator developer to plug in an RMS or EMT model and run a series of tests for a variety of customizable profiles (e.g., voltage, angle, frequency, system strength) on a single machine equivalent system. The runs are automated and require minimum interference from the user. Simultaneously with model quality testing, the tools allow benchmarking of EMT and RMS model results and assess if the plant performance is in conformity with applicable interconnection requirements, such as low- and high-voltage ride-through and dynamic voltage support. Guidance on expected performance of the model is provided by ERCOT. The developer is not required to use these tools but is required to submit a model quality test report adhering to ERCOT's requirements together with their plant model to ERCOT. ERCOT's DMView (sites.google.com/view/dmview/home) and PMView (sites.google.com/view/pmview/home) are open-source tools and could be adopted by other ISOs/RTOs and utilities. Consistent with recommendations provided in this roadmap, ERCOT requires submission of EMT plant models later in the study process, when decisions about equipment have been made. Additionally, rules and requirements provide detail about the submission of model updates to reflect any modifications.

Solution 4.3: Develop a study process flow that is better aligned with project development timelines. (medium-term)

Due to uncertainty of interconnection costs, generation developers typically procure generation plant equipment after the costs of transmission upgrades are known, posing challenges to plant model accuracy in the interconnection process.[154] System impact studies carried out with plant models that are configured with generic parameters render stability studies highly theoretical. Such studies do not guarantee reliability once the generator or generator cluster becomes operational. While a resource developer should inform the transmission provider of any changes to their plant equipment or settings compared to the initially submitted model, they are very disincentivized to do so, due to the risk of restudies and further delays in the interconnection process.

To ensure reliable operation of a new generator or a cluster after commissioning, while also keeping the need for associated restudies to a minimum, the system impact study can be split into the steady-state and stability steps. The steady-state study would identify upgrade needs based on the power flow and short-circuit impacts. The stability study would be carried out later, once the

[154] FERC Order 2023 states that the models are required at the interconnection request stage. However, as outlined in this solution, it is important to make sure that the models provided represent equipment as built in the field and, therefore, are collected at the time when important project design decisions have been made.

relevant design decisions have been made for the plant.[155] With this approach, the resource developers can be informed about thermal upgrade needs and costs after the steady-state and short-circuit study phases. If they choose to proceed with the interconnection, they will procure plant equipment and carry out plant design evaluations to make sure the plant complies with any applicable interconnection standards for expected grid characteristics at the POI. As described in Solution 4.2 above, the transmission provider can then carry out model quality testing, model validation, and conformity assessment with the appropriate site-specific generator parameters and settings.[156] The transmission provider can carry out a meaningful stability study only once accurate, site-specific models demonstrate conformity with applicable interconnection requirements.

It is possible that several iterations will be needed between stability studies and plant design evaluations, with updated models identified in each iteration. While this can potentially lengthen the interconnection process, it ensures that reliability impacts of a new generator or generator cluster are adequately evaluated and addressed. As a part of this iterative process, plant control parameter tuning may effectively be used as an alternative to costly transmission upgrades in case of stability concerns (Solution 3.5). Facility studies should then follow, once the plant design and impact studies have been finalized.

System impact and conformity assessments with applicable requirements and facility studies may need to be repeated if significant changes to the generator, supplemental equipment, or control settings have been made. These changes may happen as the generator owner is updating its plant or an OEM is issuing control software updates. Control parameter changes may also be needed to adapt plant performance to changing system conditions (e.g., declining system strength).

Once a plant is constructed, verification should be done to ensure that the physical plant corresponds to the design that was studied. Post-commissioning monitoring and periodic testing need to continue through the lifetime of the project, especially after large-signal disturbances where simulated results can be compared with actual measurements from the field or if a plant has undergone any upgrades or modifications. Generator owners would be the most appropriate entity for such monitoring, collaborating with transmission providers to provide required evidence of conformity with applicable requirements. Transmission providers can also develop automated monitoring and model validation process (such as already implemented by BPA and ISO-NE).[157]

[155] EPRI. 2022. Presentation at ESIG/NAGF/NERC/EPRI Joint Virtual Generator Interconnection Workshop. www.esig.energy/event/joint-generator-interconnection-workshop/.
[156] Alternatively, as described with ERCOT's example in Solution 4.2, this responsibility can be left with the resource developer/consultant, while the transmission provider is left to review the assessment report and carry out certain spot-checks.
[157] Wu, M., et al. 2017 "Power Plant Model Verification at ISO New England," 2017 IEEE Power & Energy Society General Meeting, Chicago, pp. 1–5. doi: 10.1109/PESGM.2017.8273867.

Additionally, it is recommended to develop a detailed process for how modifications or upgrades during an interconnecting resource's lifetime should be handled, recognizing that some of these changes may substantially affect a plant's performance so that some of the interconnection studies may need to be repeated, while in other cases it may not be necessary. Better screening and differentiation between various upgrades may help reduce the need for time-consuming restudies. For example, swapping degraded battery cells in a battery storage plant with new cells having the same characteristics should not trigger modification requests and time-consuming restudies.[158]

Table 31: Solution 4.3 Actors and Actions – Develop a study process flow that is better aligned with project development timelines

Actor	Engineering and Technical	Market and Regulatory	Administrative and Organizational
FERC	- Align study processes with project development steps	- Allow flexibility to implement additional study steps	
Transmission providers	- Periodically review post-commissioning monitoring results - Develop a detailed process for assessment of plant modifications/augmentation		- Conduct steady-state impact studies first and stability studies after site-specific plant models become available
Interconnection customers	- Provide a site-specific plant model to the transmission provider as soon as practicable		- Inform the transmission providers of any plant design changes that may affect the plant's performance

Solution 4.4: Advance the computational speed of interconnection reliability assessments (medium-term)

Transmission owners and grid operators must conduct a variety of studies before a new resource connects with the grid, in order to ensure the continued reliable operation of the transmission system. These studies primarily include power flow analysis (for steady-state thermal overloads and voltage violations), short-circuit analysis, stability analysis (including EMT analysis), and system protection analysis. Other studies may be included, depending on the circumstances and grid context. EMT studies are required in more instances to evaluate transient behavior in systems with increasing amounts of IBRs.

Solution 4.1 details disturbance event consequences for not performing sufficiently detailed studies. To reduce risk of IBR performance issues and adverse IBR control interactions, NERC has recently recommended the use of detailed EMT studies.[159] However, as discussed in

[158] See Tesla presentation at the 1/12/2024 ERCOT working group, "Tesla BESS Grid Forming and Augmentation_ERCOT".
[159] NERC. March 2023. *Reliability Guideline*. www.nerc.com/comm/RSTC_Reliability_Guidelines/Reliability_Guideline-EMT_Modeling_and_Simulations.pdf.

Solutions 4.1–4.3, the models and tools used to conduct these studies are becoming more complex and computationally intensive, due to high levels of modeling detail, high temporal resolution of these simulations, and also the increasing system size.

Additionally, contingency analyses and protection studies require additional detail and new simulation methods to prevent component misoperation in areas with high quantities of IBRs.[160]

Though these interconnection analyses may be needed to ensure reliability in weak grid areas with a high share of IBRs, the increased computational complexity can result in increased time to prepare the models and to execute and perform studies. Such issues threaten earlier goals of the roadmap to speed up interconnection timelines.

To expedite these more complex studies, Solutions 2.12–2.16 discuss methods to expand and upskill the workforce; however, as innovation continues to occur in computation techniques in general, there is also a need to improve the algorithms applied in the software tools used to conduct interconnection analyses, such as EMT tools. Currently, power systems engineers might not have simulation tools that are designed and optimized for wider-area stability (EMT) studies. Algorithm developers should focus on improved computational efficiency that provides faster interconnection study results, even while the computational complexity of the tools increases.

Some work has been done to survey potential techniques and combine new algorithms with high-performance computing to enhance speed while maintaining accuracy.[161] Developing appropriate system equivalents and incorporating variable time step sizes in the analysis are promising solutions for increasing speed and accuracy. Additional investigation, research, and testing can support successful implementation. Improvements in cloud computing, quantum computing, and artificial intelligence may further improve performance. Continued research efforts by DOE[162] and others are expected to lead to future computational enhancements to perform complex analyses, including those required of the electric grid. Researchers focused solely on either modern computational techniques or electricity system simulations should seek collaborations with each other to contribute to the important interconnection analysis application.

[160] EPRI. July 2019. "Impact of Inverter-Based Resources on Protection Schemes Based on Negative Sequence Components." www.epri.com/research/products/000000003002016197

[161] Subedi, S., et al.. 2021. "Review of Methods to Accelerate Electromagnetic Transient Simulation of Power Systems," IEEE *Access*, vol. 9, pp. 89714–89731. doi: 10.1109/ACCESS.2021.3090320. ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=9459192; Pacific Northwest National Laboratory. GridPack™. www.pnnl.gov/projects/gridpacktm-open-source-framework-developing-high-performance-computing-simulations-power; Guichard, P., et al. January 2024. "An Approach Inspired by Quantum Mechanics for the Modeling of Large Power Systems," *IEEE Transactions on Power Systems*, vol. 39, no. 1, pp. 1360–1369. doi: 10.1109/TPWRS.2023.3243933; Choi *et al*. 2023. "Hardware-based Advanced Electromagnetic Transient Simulation for A Large-Scale PV Plant in Real Time Digital Simulator," 2023 IEEE Energy Conversion Congress and Exposition (ECCE), Nashville, pp. 965–971, doi: 10.1109/ECCE53617.2023.10362673; Debnath, S., et al. 2023. "High-Performance Computing Based EMT Simulation of Large PV or Hybrid PV Plants," 2023 IEEE Power & Energy Society General Meeting (PESGM), Orlando, pp. 1–5. doi: 10.1109/PESGM52003.2023.10252525.

[162] See more about DOE's Office of Science work in Broz, J., et al., *Basic Research Needs in Quantum Computing and Networking*, doi: 10.2172/2001044, OSTI: 2001044, www.osti.gov/biblio/2001044/.

It is recommended to continue efforts toward developing optimized computational algorithms that will improve the ability of power systems engineers to more rapidly and accurately perform detailed interconnection studies with many IBRs and improve the computational efficiency of tools that are used in large power systems simulations. This includes the development of analytical methods for optimal selection of study area size and equivalencing the grid outside the study area while maintaining high accuracy of results. These efforts go hand in hand with efforts to further automate more of the interconnection process (Solution 2.3) and should further facilitate improvements and enhancements to interconnection study assumptions outlined in Solutions 3.5 and 3.6.

Table 32: Solution 4.4 Actors and Actions – Advance the computational speed of interconnection reliability assessments

Actor	Engineering and Technical	Market and Regulatory	Administrative and Organizational
Research community (including DOE)	- Investigate methods to improve computational efficiency of tools used for wider-area EMT studies - Foster collaborations between computational and electricity system experts - Continue developing analytical methods for optimal selection of study area size and equivalencing the grid outside the study area while maintaining high accuracy of results		
Transmission providers	- Collaborate with peers to establish improvement priorities for study tools with regard to computational efficiency		
Software vendors	- Improve computational efficiency of tools used for system studies - Develop and test new tools that can expedite accurate interconnection study results		

4.2. Interconnection Standards

Key Takeaways

To ensure reliable operation of newly interconnecting plants, comprehensive interconnection standards are necessary. Interconnection requirements specifying IBR generator capabilities and expected performance are still limited in the United States beyond high-level FERC and NERC requirements. Furthermore, current requirements lack performance specifications for accompanying phenomena during voltage or frequency disturbances. Finally, compliance with applicable cybersecurity standards is not assessed during the interconnection process.

Solutions Synopsis

Solution 4.5: Adopt and implement a harmonized and comprehensive set of **generation interconnection requirements or standards,** consistent with IEEE Standard 2800-2022. (short-term)
Solution 4.6: Adopt and implement harmonized requirements for **plant conformity assessment** as a part of generator interconnection procedures and consistent with IEEE P2800.2, once approved. (medium-term)
Solution 4.7: Assess the need for new interconnection requirements/standards to cover expected performance from **emerging technologies.** (medium-term)
Solution 4.8: Evaluate **cyber and physical security concerns** during the interconnection process. (medium-term)
Solution 4.9: Investigate the relationship between the **interconnection process and system reliability.** (long-term)

Solutions 4.5: Adopt and implement a harmonized and comprehensive set of generation interconnection requirements or standards, consistent with IEEE Standard 2800-2022. (short-term)

The primary goal of interconnection studies today is to ensure a new generator's ability to produce power without overloading existing infrastructure or causing stability issues. Understanding a generator's ability to ride through disturbances and support the grid, however, is insufficiently addressed. Interconnection requirements specifying IBR generator capabilities and expected performance are still limited in the United States beyond high-level FERC and NERC requirements (see the introduction to this section for a summary of current requirements). Current requirements lack performance specifications for accompanying phenomena during voltage or frequency disturbances. Additionally, the ability of a new generator to comply with those standards is usually not verified during the interconnection process. Some transmission providers have gradually introduced additional interconnection requirements for generators (e.g., ERCOT, ISO-NE). However, these requirements are not sufficiently comprehensive to prevent some of the observed IBR plant performance issues.

These gaps are recognized in the recent FERC Order 901, directing NERC to submit a detailed standards development plan that addresses IBR reliability gaps in four areas:

1. Data sharing
2. Model validation
3. Planning and operational studies
4. Performance requirements

FERC sets a deadline of November 2026 for any new or modified standards to be submitted. On January 17, 2024, NERC filed a work plan to address FERC Order 901, identifying priorities and timelines of required standard development efforts. However, NERC standards are likely to focus on IBR performance, while keeping ease of compliance in mind. Therefore, ISOs/RTOs and utilities will still need to develop their own interconnection requirements and study processes to ensure that performance requirements established by NERC are being met. This will inevitably result in regional differences in requirements, inefficiencies, and the higher cost of equipment, with manufacturers having to address different performance requirements in each area as well as inevitable reliability gaps.

On the other hand, a harmonized and detailed set of requirements nationwide will reduce uncertainty and ambiguity for all stakeholders and ensure that state-of-the-art equipment is installed in the field. A harmonized set of plant performance expectations will also allow streamlining of plant design evaluation studies for resource developers. IEEE 2800 for "Interconnection and Interoperability of Inverter-Based Resources Interconnecting with Associated Transmission Electric Power Systems" was approved in April 2022. The standard has been developed with large industry participation and approved with high acceptance rates. The standard defines interconnection requirements based on grid reliability needs and state-of-the-art capabilities of current IBR technologies. IEEE standards in general are considered voluntary; therefore, enforcement of any requirements specified in IEEE 2800-2022 will also require adoption by the regional/local authority governing interconnection requirements.[163] Several regions in the United States—for example, NYISO, ERCOT, Florida Power & Light (FPL), MISO, SPP, and ISO-NE—are currently in the process of adopting the standard. There are three general paths for adoption of the standard:

General reference – The transmission provider substantially adopts the standard in full and refers to IEEE 2800 as the applicable standard in the area (e.g., FPL,[164] SPP).
Detailed reference – The transmission provider adopts some or all clauses of the standard but provides additional details in the transmission provider's rules, clarifying how each of the clauses applies and detailing exceptions (e.g., NYISO, MISO,[165] and ISO-NE).
Full Specification – The transmission provider explicitly specifies each requirement in its own interconnection rules by leaning on IEEE 2800 specifications. Where existing interconnection requirements in the transmission provider's area are more stringent than IEEE 2800, the former prevails (e.g., ERCOT).
To ensure reliable operation of the grid with the growing shares of IBRs, IEEE 2800 adoption efforts need to continue with all transmission providers using one of the paths outlined above, as applicable. DOE could use its convening powers to gather ideas from industry experts to discuss a path toward wider IEEE 2800 adoption and harmonization of adoption efforts, recognizing

[163] In the case of IEEE Standard 2800-2022, these authorities are primarily Planning Coordinators, Transmission Planners, and/or Transmission Operators. As defined by NERC. For the purpose of this document, the authority governing interconnection is a transmission provider.
[164] FPL. 2023. FPL Facility Interconnection Requirements. www.oasis.oati.com/FPL.
[165] MISO. IBR Performance Requirements Draft GIA. www.misoenergy.org/stakeholder-engagement/stakeholder-feedback/2023/pac-ibr-performance-requirements-draft-gia-20231011/.

regional differences and limitations. Alternatively, adoption of IEEE 2800 by general reference in FERC LGIAs can lead to a harmonized and comprehensive set of generation interconnection requirements being applied across all jurisdictional areas.

New interconnection requirements will only apply to new IBR plants. Improving modeling accuracy of legacy IBR plants to reflect their actual behavior in both RMS and EMT domains will help transmission providers capture and mitigate any potential reliability impacts from legacy IBRs during system studies.

Table 33: Solution 4.5 Actors and Actions – Adopt and implement a harmonized and comprehensive set of generation interconnection requirements or standards

Actor	Engineering and Technical	Market and Regulatory	Administrative and Organizational
FERC		- Consider adoption of IEEE 2800 as a part of LGIAs	
NERC, research community (including DOE)	- Participate in outreach and education regarding the standards	- Work on Order 901 compliance	- Convene stakeholders to discuss adoption of IEEE 2800
Transmission providers		- Adopt the IEEE 2800 standard, considering paths outlined above	
Interconnection customers	- Design plants with IEEE 2800 capabilities - Evaluate existing and new equipment for IEEE 2800 capabilities		

Solution 4.6: Adopt and implement harmonized requirements for plant conformity assessment as a part of generator interconnection procedures and consistent with IEEE P2800.2, once approved. (medium-term)

A plant's conformity with applicable interconnection requirements needs to be assessed during the interconnection process and throughout the lifetime of the project. This can be done by resource developers during the plant design evaluation step and verified by transmission providers during various steps of the interconnection process (see Solutions 4.1–4.4). However, procedures for such assessment are insufficient or nonexistent. This may lead to the installation of equipment that is not state of the art or to protective or control settings that result in inadequate performance of the plant during grid disturbances, which would be detrimental to the overall reliability of the grid.

A harmonized set of plant interconnection requirements and performance expectations, as outlined in Solution 4.5, should accompany comprehensive testing and verification procedures, which will set clear expectations for OEMs and resource developers. These procedures will also facilitate streamlining both plant design evaluation studies for resource developers and plant performance conformity assessments for the transmission providers. IEEE P2800.2 "Draft Recommended Practice for Test and Verification Procedures for Inverter-Based Resources Interconnecting with Bulk Power Systems" is currently being developed. The latest draft includes specific recommendations for what type of model (e.g., steady-state, phasor-domain stability, EMT) should be used to assess an IBR plant's conformity with specific requirements of IEEE 2800. It also provides recommendations for the level of detail with which an IBR plant model should represent individual elements (e.g., disaggregated model) or combine elements into equivalents (e.g., aggregated model). Thus, IEEE P2800.2 recommends IBR plant design evaluation procedures include validated IBR unit models and verified IBR plant models for the above-mentioned modeling domains, including EMT.

This recommended practice will provide guidance on conformity assessment with IEEE 2800 requirements at the interconnection phase as well as during the lifetime of a generator. This development is expected to be completed in 2024, filling an important gap in the reliable integration of IBRs.[166] As a short-term stopgap solution, prior to the availability of harmonized plant conformity assessment procedures recommended in IEEE P2800.2, transmission providers could use existing databases for IBR unit capability (e.g., inverters, plant controllers) that already exist in other countries to reduce uncertainty.[167]

Once IEEE P2800.2 is fully developed and approved, transmission providers should adopt the recommended practice using one of the adoption paths outlined in Solution 4.5 for IEEE 2800. Alternatively, adoption of IEEE P2800.2 by general reference in FERC LGIPs can lead to a harmonized set of testing and verification procedures being applied across all jurisdictional areas. A plant-level conformity assessment training and evaluation program could help with dissemination of information and the development of a qualified workforce (as discussed in Solution 2.13).

Table 34: Solution 4.6 Actors and Actions – Adopt and implement harmonized requirements for plant conformity assessment as a part of generator interconnection procedures

Actor	Engineering and Technical	Market and Regulatory	Administrative and Organizational
FERC		- Consider adoption of IEEE P2800.2 as a part of LGIPs	
NERC, research community (including DOE)	- Participate in outreach and education regarding the standards	- Work on Order 901 compliance	- Convene stakeholders to discuss adoption of IEEE P2800.2
Transmission providers	- Implement recommended practices of IEEE P2800.2 upon approval - Include assessment of conformity with the new standard during the interconnection process		
Interconnection customer	- Transmission providers could use existing databases for IBR units' capability in short-term		- Provide evidence of plant conformity with the new standard

[166] Note that adoption of IEEE 2800 is not contingent upon approval of IEEE P2800.2, and transmission providers can develop their own conformity assessment process in the interim.
[167] One example is a database of the German FGW, providing information about equipment reliability and conformity with German VDE guidelines (wind-fgw.de/database/?lang=en).

Actor	Engineering and Technical	Market and Regulatory	Administrative and Organizational
	- Implement recommended design evaluation and equipment testing of IEEE P2800.2 upon approval		

Solution 4.7: Assess the need for new interconnection requirements and standards to cover expected performance from emerging technologies. (medium-term)

New power electronic equipment is constantly emerging. Therefore, the interconnection process must maintain awareness of important changes and provide assessments of when new performance standards will be needed. For example, grid-forming inverters and controls are actively being developed. These controls can be implemented both on IBRs and on power-electronic-based transmission assets, such as static synchronous compensators or high-voltage direct current converter stations. Similarly, large fleet depots of heavy-duty electric vehicle charging and discharging (e.g., long-haul truck stops and potential vehicle-to-grid [V2G] capabilities) as well as proliferation of distributed energy resources may impose new dynamics, controls, and interactions with the transmission system. Furthermore, work is needed to establish more uniform technical standards for the interconnection of HVDC transmission.

Determining the need for new requirements and standards for these new devices and use cases is important for ensuring continued grid reliability.[168, 169] The electric power industry needs to continue to support discussions on the need to integrate emerging technologies. As IBR control strategies continue developing and new control advancements are introduced, the research community, in collaboration with OEMs, will need to ensure that such enhancements are included in RMS and EMT models of IBRs collected, quality tested, and validated during the interconnection process (see more in Solutions 4.1 and 4.2 above). It is important to understand what aspects of the new equipment are necessary to include in models for grid reliability assessments, including how the temporal profiles of many of the resources can vary (e.g., electric vehicle presence for V2G).

Table 35: Solution 4.7 Actors and Actions – Assess the need for new interconnection requirements and standards to cover expected performance from emerging technologies

Actor	Engineering and Technical	Market and Regulatory	Administrative and Organizational
NERC	- Develop new standards as applicable		- Consider convening technical conferences supporting emerging standard discussions

[168] The NERC Inverter Based Resource Performance Subcommittee has developed the white paper *Grid Forming Functional Specifications for BPS-Connected Battery Energy Storage Systems: Functional Specifications, Verification, and Modeling*, which is a first step in that direction and provides some guidance to the transmission providers that are looking to deploy grid-forming capability on new battery storage projects.
[169] The DOE-funded project UNIFI has a workstream that focuses on standards, specifications, and testing of grid-forming inverters (sites.google.com/view/unifi-consortium/home).

Actor	Engineering and Technical	Market and Regulatory	Administrative and Organizational
Transmission providers	- Contribute to language choices within the standard development process		- Participate in future discussions about emerging standards
Interconnection customers	- Design plants with new capabilities at the POI - Contribute to language choices within the standard development process		- Participate in future discussions about emerging standards
Research community (including DOE)	- Develop new grid-supporting capabilities - Inform need for future standards - Develop RMS and EMT models that incorporate new technologies		

Solution 4.8: Evaluate cyber and physical security concerns during the interconnection process. (medium-term)

Recent cyber and physical security attacks on the electric grid highlight the critical nature of grid security. The risk of these attacks is not limited to power generators connected to the grid, but it can also be posed by large loads. There is an urgent need for federal agencies and regulators to collaborate with the industry through public-private partnerships to develop processes, procedures, and recommendations to safeguard our nation's critical infrastructure.

Both FERC and NERC already acknowledge and address these risks through a series of cybersecurity standards that fall into the category of CIP standards, which have been developed by industry through the NERC reliability standards development process.[170] Federal entities, including NERC and FERC, should continue developing standardized cybersecurity requirements and protocols for interconnection customers to meet. Standardization of requirements would eliminate the need for transmission providers to perform a bespoke analysis for each project entering the queue. It would also provide transparency and certainty for interconnection customers in the interconnection process. Such standards help ensure a comprehensive regime of cybersecurity processes, measures, and protections to avoid cyberattacks, manage reliability risks, and create suitable recovery plans in the event of a cyberattack. Compliance with these requirements is ongoing throughout the life cycle of all electrical assets and should be incorporated in IAs by reference of maintaining cybersecurity plans and adhering to the evolving security protocols and standards.

[170] Key NERC CIP standards applying to generators are CIP-002-5.1a: BES Cyber System Categorization, CIP-003-8: Security Management Controls, CIP-004-6: Personnel & Training, CIP-005-7: Electronic Security Perimeter(s), CIP-006-6: Physical Security of BES Cyber Systems, CIP-007-6: System Security Management, CIP-008-6: Incident Reporting and Response Planning, CIP-009-6: Recovery Plans for BES Cyber Systems, CIP-010-4: Configuration Change Management and Vulnerability, CIP-011-2: Information Protection, CIP-012-1: Communications between Control Centers, and CIP-013-2: Supply Chain Risk Management.

However, the NERC standards, in particular, apply only after a generation plant has been commissioned and connected to the grid. There is no mandate so far[171] that any requirements be assessed during the interconnection process prior to commercial operation. Including security evaluation as part of the design evaluation of a power plant as it is being designed and built would better ensure that processes, plant design, and communication systems directly address security threats. Accounting for security threats during the interconnection and planning evaluations would also allow common-mode outages and failures caused by cyber and physical attacks to be more proactively addressed. FERC and other federal agency partners could investigate innovative incentives that encourage utilities to adopt a robust, holistic, and long-term cyber-resilience program and risk management plans to address grid security challenges. The federal government should incentivize new holistic models for both physical and cybersecurity investments that could be instituted to reflect the risks posed and drive progress within the industry. Additionally, FERC could incentivize industry participation in a centralized repository of vendor and supplier assessments and facilitate the development of a national vendor and supplier accreditation program.

Finally, it is recommended that FERC collaborate with other government agencies, such as DOE, the Department of Defense, and the Federal Trade Commission—and industry—to design a bill of materials standards for equipment components used for critical infrastructure. Such standards could be flexible to incorporate new technologies, practices, and procedures.

While addressing cybersecurity concerns is of paramount importance, sharing of data and information between stakeholders involved in the interconnection process (as discussed in Solution 1.3) is extremely important for the efficiency and timeliness of the interconnection process. Therefore, it is important to develop requirements and processes for secure sharing of such information (see Solutions 1.2 and 3.7).

Table 36: Solution 4.8 Actors and Actions – Evaluate cyber and physical security concerns during the interconnection process

Actor	Engineering and Technical	Market and Regulatory	Administrative and Organizational
FERC	- Incentivize holistic cyber and physical security programs - Facilitate the development of a national vendor and supplier accreditation program - Design a bill of materials standards for equipment components used for critical infrastructure	- Consider requiring conformity with relevant CIP standards as a part of GIPs - Incentivize industry participation in a centralized repository of vendor and supplier assessments	

[171] This may change with the implementation of NERC's standards development work plan filed in response to FERC Order 901.

Actor	Engineering and Technical	Market and Regulatory	Administrative and Organizational
NERC	- Consider extending CIP standard applicability prior to commissioning	- Inform industry on standardized language for IAs	
Research community (including DOE)	- Inform industry on security concerns and mitigation options - Develop cyber-informed engineering strategies to incorporate with the CISA Cyber Security Evaluation Tool to serve as a cybersecurity hardening guide for interconnection customers	- Inform industry on standardized language for IAs	
Transmission providers	- Evaluate conformity with relevant CIP standards prior to commissioning	- Include cybersecurity expectations in IAs	
Interconnection customers	- Design plants in conformity with relevant CIP standards - Incorporate the cyber-informed engineering best practices into plant design - Maintain cybersecurity plans		
Insurance providers		- Incorporate cybersecurity best practices into customer policies	

Solution 4.9: Investigate the relationship between the interconnection process and system reliability issues. (long-term)

There has always been a balance between interconnection standards, which set minimum performance requirements on resources and loads connecting to the transmission system, and using system impact studies to preemptively ensure that system operators can reliably operate the transmission system in real time as new resources interconnect. Stringent performance requirements on interconnecting resources can reduce the burden on system operators to mitigate real-time reliability violations and potentially reduce the number of study iterations within the interconnection study process.

In today's interconnection process, for example, changes made to a project during the interconnection process can trigger a restudy.[172] Such an outcome causes processes delays and could lead to inefficient management of the interconnection queue. Alternatively, a future paradigm that enforces more stringent interconnection requirements could limit such restudies,

[172] Such changes might include updating a model of inverter or wind turbine or updates to specific equipment such as hardware and control systems. Under FERC Order 2023, the project may need to withdraw and ultimately reapply into the next cluster because of such changes. This could happen even if the plant MW rating remains the same.

because an interconnection customer would conform to a higher standard that mitigates certain system reliability concerns.[173] Evaluating such opportunities should remain a priority for the research community.

Technology improvements and lower-cost electricity storage may enable even further improvements. For example, co-locating a small grid-forming energy storage device with a newly interconnecting plant could enhance a generator's stability margins,[174] potentially resulting in the reduction or elimination of stability-related concerns and the corresponding necessity for studying such issues in detail during the interconnection process.

Expanding the scope and requirements in interconnection standards as well as incorporating battery additions as proposed above may raise costs for resource developers, but it could also significantly simplify and expedite the interconnection process.

Table 37: Solution 4.9 Actors and Actions – Investigate the relationship between the interconnection process and system reliability issues

Actor	Engineering and Technical	Market and Regulatory	Administrative and Organizational
Research community (including DOE)	- Explore potential for expanding the scope and requirements of interconnection standards - Evaluate whether better equipment that conforms to stricter standards will perform consistently, eliminating need for restudies - Model the reliability benefits of equipping plants with an incremental amount of storage	- Investigate the benefits and costs of stricter interconnection standards and/or co-location with storage	

[173] Note that even in this case, an updated plant model reflecting the change will need to be resubmitted. Such equipment improvements could involve hardware, controls, and device settings.
[174] If voltage is an issue, for instance, it may make sense to widen the reactive power capability of the generator (either through changes to current equipment or by adding additional equipment to supplement the generator).

Conclusions

Over the past 5 years, transmission providers have seen a dramatic increase in the number of interconnection requests. While the number of projects currently active in interconnection queues is unprecedented, queues are likely to remain large and volatile for the foreseeable future. Ongoing interconnection reforms, including but going beyond FERC's Order 2023, will be necessary to ensure that interconnection processes are transparent, timely, and efficient, while continuing to support reliable real-time transmission operations.

This roadmap identifies solutions for interconnection challenges that support nearer-term opportunities, such as addressing cost allocation issues for network upgrades, as well as longer-term ideas that need further exploration, such as removing network upgrades from the interconnection process altogether. Interconnection reforms are complex. They involve a multitude of trade-offs: for instance, between open access and queue rationing, between choice and certainty for interconnection customers, between bottom-up tailored solutions and standardization across markets. The roadmap solutions aim to identify priority areas for reform and where trade-offs may exist, but they do not provide detailed prescriptions for how trade-offs should be resolved. This document can serve as a starting point for those future discussions and conversations.

For most transmission providers, interconnection reform often occurs through stakeholder processes. In addition to those efforts, FERC technical conferences, electric industry events, advocacy work, and research studies all contribute to the generation and dissemination of new ideas that eventually converge across different regions. Reform is thus a group effort. In keeping with this reality, the solutions in this roadmap describe actions for a range of different actors and different professional fields: engineering and technical, market and regulatory, and administrative and organizational.

The focus of roadmap solutions changes over time. In the short term (1–3 years), solutions build on existing policy or initiatives that are currently underway, including a focus on continued improvements in data access, queue management, automation, and cost allocation for proactive transmission investments, as well as implementation of already-developed reliability standards. In the medium term (3–5 years), solutions focus on areas that require discussion or more effort but are still within the existing regulatory framework for interconnection. They include improving access to interconnection study models and modeling assumptions, creating tools for better visualizing interconnection data, expanding fast-track options, developing new study methods and reliability standards, and ensuring that generators have the option to be re-dispatched rather than paying for network upgrades. Longer-term solutions (more than 5 years) would require large changes in regulation and policy and are contingent on the effectiveness of nearer- and medium-term solutions in addressing challenges. They include enabling competition and choice for interconnection studies and exploring options for delinking deliverability and resource adequacy from the interconnection process.

Across solutions, several themes emerge, each relating to roadmap goals to improve the transparency, timeliness, economic efficiency, and reliability of the interconnection process. Ensuring equity permeates almost every theme.

Improvements in information technologies create opportunities for automation in interconnection, particularly for collecting, managing, and reporting data. Better data management and visualization could help improve data access and transparency, which would in turn enhance efficiency and enable more equitable access to information (Solutions 1.1–1.3). Interconnection processes must continue to adapt to a changing generation mix, and changing transmission technologies must adapt to right-size network upgrades. The energy-limited resources that dominate interconnection queues may require new interconnection study methods (Solution 3.6) and new approaches to how congestion-related network upgrades are considered in interconnection (Solution 3.2). New transmission technologies may be able to mitigate system impacts identified in interconnection at a lower cost than traditional transmission infrastructure (Solution 3.5).

With a constrained transmission system, making use of available capacity will be critical for timely connection of new resources at a low cost. Transmission providers can encourage use of scarce transmission capacity through interconnection fast tracks for resources that use existing capacity (Solution 2.5) and by providing interconnection customers with the information necessary for efficient siting (Solutions 1.2–1.3).

Interconnection and transmission planning require coordination and balance. Coordination in process timing, inputs, and model assumptions will lead to more efficient, equitable, and consistent outcomes (Solution 3.4). Additionally, centering equity goals in transmission planning may lead to proactive infrastructure upgrades in regions where Tribal and EEJ projects seek to interconnect (Solution 2.10).

Interconnection reforms must address outstanding issues in market design, regulation, and transmission planning. These include ensuring that affected system studies are consistent with open-access principles (Solutions 2.7–2.9), determining whether generators should have the option to be re-dispatched rather than paying for congestion-related upgrades (Solution 3.2), implementing Order 1000's requirements for policy-driven transmission (Solution 3.1), and centering equity in transmission planning and valuation efforts (Solution 2.10).

Workforce development is integral to interconnection reforms. Creative, dedicated professionals are critical to the development and implementation of interconnection solutions (Solutions 2.12–2.16). Efforts can and should also be tailored toward developing and retaining a more diverse interconnection workforce and expanding technical assistance and education opportunities in interconnection, especially for EEJ communities (Solutions 2.11 and 2.16).

Maintaining reliability must be assured. New models and screening tools need to be developed to better consider dynamic characteristics of IBRs (Solutions 4.1–4.4). Furthermore, developing interconnection standards to cover expected performance from emerging technologies is needed (Solution 4.7).

DOE will continue to support innovation in activities within the roadmap through individual program office missions and cross-office collaborations. These include the offices and activities detailed in Table 36.

Focused and targeted interconnection reforms can help create future interconnection processes that are open and transparent and able to efficiently process large volumes of interconnection requests, lead to right-sized transmission investments while providing incentives for efficient generator siting, and maintain the real-time operational reliability of the transmission system.

Appendix A: DOE Roles Supporting Interconnection

Table 38: DOE Roles in Supporting Transmission System Interconnection

DOE Office	Role in Supporting Transmission System Interconnection
Solar Energy Technologies Office (SETO)	SETO supports interconnection queue and cost data collection and analysis, convenes stakeholders to develop and share interconnection best practices, and provides technical assistance through i2X. SETO funds national labs to analyze timelines of transmission interconnection queues and associated costs and provide publicly accessible datasets and data visualizations. SETO funds new modeling and host capacity analysis methods to improve interconnection study processes and timelines, including improved steady-state, dynamic, and EMT models of large solar generation plants and the aggregated response of many distributed solar resources. SETO's work also includes funding the UNIFI Consortium, led by NREL, which brings together researchers and industry to define the next generation of grid-forming inverters. SETO also funds several national labs to support the development of industry standards related to interconnection requirements and guidelines for IBRs, including development of IEEE 1547-2018 and IEEE 2800-2022.
Wind Energy Technologies Office (WETO)	WETO supports interconnection queue and cost data collection and analysis, convenes stakeholders to develop and share interconnection best practices, and provides technical assistance through i2X. WETO funds R&D to improve data, tools, models, and analyses that are relevant to bulk transmission interconnection. These include an open-source data portal for wind power production data, open-source wind EMT models and dynamic simulation tools, enhanced wind short-circuit models, an impedance-based tool that identifies root causes of system oscillation, and a suite of wind cybersecurity efforts. WETO acknowledges the importance of transmission adequacy to interconnection through conducting transmission planning studies, demonstrating grid enhancement technologies, and analyzing transmission siting barriers. WETO leads the grid-forming research of wind and is co-sponsoring the UNIFI consortium to promote the interoperability among grid-forming inverters, along with supporting IEEE 2800 standards development and adoption.
Energy Justice and Equity (EJE)	EJE plays a convening role to support meaningful stakeholder engagement between program offices and small and disadvantaged businesses, minority educational institutions, and historically underrepresented communities. EJE works closely with DOE program offices, such as GDO, the Office of Indian Energy, and the Office of Clean Energy Demonstrations, as well as technology offices within EERE, to ensure energy equity considerations are incorporated into relevant interconnection funding opportunities. EJE also helps manage two research projects on equitable grid planning and operations as part of the Grid Modernization Initiative. EJE maintains an Energy Justice

DOE Office	Role in Supporting Transmission System Interconnection
	Mapping Tool that allows users to explore census tracts identified as disadvantaged communities as defined by the Justice40 Initiative. EJE also provides guidance on best practices for community engagement centered on improving transparency and coordination among energy developers, governments, utilities, and local communities.
Office of Cybersecurity, Energy Security, and Emergency Response (CESER)	CESER advances research, development, and deployment of technologies, tools, and techniques to reduce risks to the nation's critical energy infrastructure posed by cyber and other emerging threats. Continuing to increase the security, reliability, and resiliency of our energy infrastructure will help ensure the success of grid modernization and transformation of the nation's energy systems. CESER activities include the ongoing support of RD&D of advanced cybersecurity solutions, acceleration of information sharing to enhance situational awareness, and technical assistance in the development and adoption of best practices. The office is also investing in RD&D of cross-cutting tools and technologies to help make the U.S. energy infrastructure more cyber resilient and secure.
Grid Deployment Office (GDO)	GDO supports interconnection primarily through coordinated transmission planning and deploying proactive grid enhancements needed to accommodate future interconnection levels. GDO fosters efficient and coordinated transmission planning through several avenues, including the National Transmission Needs Study, National Transmission Planning Study, and Offshore Wind Transmission federal planning and support. GDO also funds the GRIP Program to enhance grid flexibility and improve the resilience of the power system against threats of extreme weather and climate change. Smart Grid Grants are a $3 billion topic area within this program. One focus of Smart Grid Grants is integrating renewable energy at the transmission and distribution levels, and the program seeks proposals that lead to more rapid processing of interconnection applications and minimize queue-related delays for clean energy. Additionally, the Grid Innovation Program topic area of GRIP is a $5 billion program that seeks to deploy projects that use innovative approaches to transmission, storage, and distribution infrastructure to enhance grid resilience and reliability. This may include projects with innovative approaches to interconnection.
Loan Program Office (LPO)	LPO provides debt financing for high-impact, large-scale energy infrastructure and manufacturing projects in the United States. LPO has issued tens of billions of dollars in strategic debt financing to transform the energy and transportation economy to benefit Americans. LPO loans helped launched the utility-scale solar and wind industries, have expanded domestic manufacturing of electric vehicles, and are reviving nuclear energy in the United States. LPO financing programs support projects across the energy sector, including the Title 17 Clean Energy Financing Program, developed to stand up financing to support clean energy deployment and energy infrastructure reinvestment. Through the Energy Infrastructure Reinvestment category of the Title 17 Clean

DOE Office	Role in Supporting Transmission System Interconnection
	Energy Financing Program, LPO is seeking to finance projects that retool, repower, repurpose, or replace energy infrastructure that has ceased operations or enable operating energy infrastructure to avoid, reduce, utilize, or sequester air pollutants or greenhouse gas emissions, including transmission infrastructure investments to support transmission interconnection, reconductoring transmission lines, and upgrading voltage.
Vehicle Technologies Office (VTO)	VTO's work on interconnection focuses on stakeholder engagement and coordination to develop and distribute best practices for interconnection, provide technical assistance to accelerate electric vehicle charging infrastructure deployment, and support solutions to maintain a reliable and resilient grid. VTO funds multiple efforts dedicated to developing innovative interconnection and load service request, streamlining processes to reduce the soft costs for building out a national EV charging infrastructure. VTO also maintains a strong dialogue with utilities, regulators, and industry to address the current gaps and bottlenecks in interconnection to enable greater vehicle grid integration.
Industrial Efficiency and Decarbonization Office (IEDO)	IEDO's work on interconnection primarily involves research into distribution-level interconnection issues impacting combined heat and power (CHP) and waste heat to power (WHP) projects in the United States. IEDO conducts these activities through technical assistance and stakeholder engagement, funding cooperative agreements, and national lab research. In response to Section 40556 of the BIL, IEDO initiated a review of CHP and WHP interconnection rules to identify barriers and develop model guidance to integrate CHP and WHP into the electric power grid. IEDO funds research and stakeholder engagement to identify opportunities for CHP and other onsite energy resources to deliver ancillary services to the electric grid. This includes exploring RD&D needs and developing an RD&D portfolio that supports industrial sector interaction with the grid through flexible core processes, onsite generation, energy storage, control systems, and power electronics. Additionally, IEDO provides technical assistance through its Onsite Energy Program and Better Plants Program to help industrial and other large energy issues integrate distributed generation at their facilities, including support related to navigating interconnection procedures and net metering policies.

DOE Office	Role in Supporting Transmission System Interconnection
Office of Electricity (OE)	OE accelerates the advancement and deployment of technologies that improve the reliability, resilience, security, and affordability of the grid. Multiple programs within OE do work relevant to transmission interconnection through modeling, standards development, grid controls, and data interoperability. The OE Storage Division propels U.S. leadership in the development, deployment, and utilization of energy storage technologies by advancing high-potential storage technologies that incorporate safe, low-cost, and earth-abundant elements, validating next-generation storage technologies to be grid- and end-user ready, and enhancing the energy community's ability to analyze and adopt storage. Current OE storage division interconnection-related work includes supporting continued development of IBR-related standards as well as demonstrations of new use cases for storage as a flexibility solution for increasing interconnection or renewable integration capacity. The OE Grid Controls and Communications Division drives RD&D of new controls that allow system operators and planners to maintain and improve system reliability and resilience. This includes advancing the development of coordinated transmission and distribution controls, protection planning, and operator tools and data integration. Current Grid Controls and Communications Division interconnection-related work includes development of better power system data standards, sharing frameworks, and governance. The division works to develop advanced grid models, controls, and integrated planning frameworks and demonstrate and validate these technologies with industry partners.
Water Power Technologies Office (WPTO)	The mission of WPTO is to enable research, development, and testing of new technologies to advance marine energy as well as next-generation hydropower and pumped storage systems for a flexible, reliable grid. WPTO's Innovations for Low-Impact Hydropower Growth portfolio has studied and disseminated best practices for small hydropower interconnection, such as at nonpowered dam retrofits or conduit hydropower projects. The HydroWIRES Initiative also touches on interconnection, seeking to understand, enable, and improve hydropower's contributions to reliability, resilience, and integration in the rapidly evolving U.S. electricity system. HydroWIRES includes research, development, demonstration, and deployment, modeling, analysis, and technical assistance activities on various grid aspects of hydropower and pumped storage hydropower, some of which include consideration of transmission and interconnection constraints. WPTO's Marine Energy Program considers interconnection and transmission queue issues through analytical work focused on the grid value proposition of utility-scale marine energy technologies, a focus on microgrids to enable resilience for coastal and island communities, and the development of the PacWave testing site off the Oregon coast.

DOE Office	Role in Supporting Transmission System Interconnection
Geothermal Technologies Office (GTO)	GTO's mission is to increase deployment of geothermal energy through RD&D of innovative technologies that enhance exploration and production. GTO is not currently working on interconnection research; rather, its focus has narrowed to means by which mass deployment of geothermal technology can alleviate grid interconnection queues by lowering peak demand and decreasing overall requirement for grid infrastructure. As analyzed in the recent geothermal heat pump impacts report (ORNL, info.ornl.gov/sites/publications/Files/Pub196793.pdf), grid modeling demonstrates that the mass deployment of deep demand-side efficiency measures such as geothermal heat pumps dramatically slashes peak electricity loads, reduces the need for as much as 185 GW of winter capacity otherwise required for resource adequacy, and eliminates the need for more than 43,000 miles (65.3 TW-mi) of interregional transmission in a highly electrified future. GTO continues to work on a variety of analysis and demonstration initiatives designed to help the United State achieve the mass-deployment levels considered in this impacts report.

Appendix B: Connection of Roadmap Solutions to FERC Order 2023

Table 39: Connection of Roadmap Solutions to FERC Order 2023

FERC Order 2023 Activity	Description	Corresponding Roadmap Solution
Cluster Study Approach	Requirement to adopt a cluster interconnection study method when evaluating generator interconnection requests where individual interconnection requests are grouped into clusters based on timing and location of request. Allocate network upgrade costs based on a proportional impact methodology within those clusters.	Several solutions provide support for this activity. Clustering is a part of the roadmap's discussion around interconnection studies and transmission planning coordination improvements (see **Solution 3.4** on transmission planning and **3.6** on interconnection studies).
First-ready, first-served process	Requirements to add significant application and readiness deposits, withdrawal penalties, and bolstered site control to reduce speculative or duplicative interconnection requests with more stringent requirements for entering and remaining in the queue.	**Solution 2.1** includes additional discussions of implementation trade-offs.
Timeline requirements on interconnection studies	Movement away from "reasonable efforts" to process interconnection requests in a timely manner toward firm deadlines and penalties if transmission providers fail to process interconnection requests on time.	**Solution 2.2** focuses on Order 2023 implementation. **Solution 2.3** includes opportunities to help achieve timeline requirements.
Heatmaps of capacity	Requirement that transmission providers make more information available to help developers make decisions about siting and other aspects of their proposed facility, the centerpiece of which is the maintenance of an interconnection "heatmap" of available interconnection capacity.	**Solution 1.3** includes additional ideas for tools and products to enhance siting decision-making.
Improved affected system studies	Adoption of a pro forma affected system study agreements and facilities construction agreements with firm deadlines to initiate the affected system study process and to conduct affected system studies.	**Solution 2.7** includes additional ideas for coordination between affected systems. **Solution 2.8** focuses on Order 2023 implementation.
Flexibility for storage and hybrids	Requirement to incorporate an interconnection customer's planned operating assumptions for the proposed charging of a battery energy storage resource, including standalone facilities, co-located facilities, or hybrid generating/storage facilities. Generally	**Solution 3.6** includes more expansive discussion on improving interconnection study approaches for all interconnection customers, and **Solution 2.5** discusses corresponding fast-tracking opportunities. **Solution 4.3** discusses issues around battery augmentation.

FERC Order 2023 Activity	Description	Corresponding Roadmap Solution
	provides more ability to co-locate resources behind a point of interconnection.	
Interconnection generator models	Requirement that interconnection customers provide generator models needed for accurate interconnection studies.	**Solution 1.2** discusses data transparency from OEMs and interconnection customers to improve generator models and corresponding studies, also including opportunities for increasing transmission provider transparency. **Solution 4.1** discusses details and challenges of collecting generator models. **Solution 4.2** discusses opportunities for improving model validation. **Solution 4.3** provides process approaches to ensure accurate generation models.
Alternative transmission technologies	Requirement for transmission providers to evaluate alternative transmission technologies within cluster studies and whether the specific alternative transmission technologies that must be evaluated were provided in the order.	**Solution 3.5** includes additional alternative transmission technology opportunities.
Outside scope but complementary for Order 2023 implementation	This category is used to bucket solutions the roadmap proposed that are additional and important for the industry to pursue beyond Order 2023 but that align and could complement Order 2023 implementation.	**Solution 1.1** – Data transparency on projects in queue **Solution 2.4** – One-off interventions **Solution 2.5** – Fast-track enhancements **Solution 2.9** – Affected system transmission coordination **Solution 2.10** – Technical assistance for EEJ communities **Solution 2.11** – Incorporating equity in transmission planning **Solution 2.12–2.16** – Activities to bolster workforce development **Solution 3.1** – Proactive transmission planning **Solution 3.2** – Energy-only interconnection service **Solution 3.4** – Transmission planning and interconnection coordination **Solution 4.4** – Improvements to computational capability to facilitate reliability assessments **Solution 4.5** – IEEE 2800 standard adoption **Solution 4.6** – Plant conformity assessments **Solution 4.7** – Consideration of emerging technologies **Solution 4.8** – Cyber and physical security concerns

FERC Order 2023 Activity	Description	Corresponding Roadmap Solution
Outside scope of Order 2023	This category is used to bucket longer-term ideas that are good to pursue, but likely only if nearer-term measures don't work. They would represent a more serious departure from current industry practice, but in the long run, they would help further improve the interconnection process and reliability of the grid.	**Solution 2.6** – Market-based rationing **Solution 3.3** – Delinking interconnection process and network upgrades **Solution 3.7** – Providing interconnection studies by interconnection customers **Solution 4.8** – Investigating the relationship between interconnection process and system reliability

Appendix C: Summary of FERC Interconnection Orders

Table 40: Summary of FERC Interconnection Orders

Note: Yellow-highlighted rows were major interconnection orders.

Interconnection-Related FERC Order	Date	Key Interconnection-Related Provisions	Impact and Takeaways
Order 2003	July 2003	Opened access to and standardized the process for large generators applying for interconnection. Set up "first-come, first-served" queue management policy while giving ISOs/RTOs greater flexibility to comply, given their "independent entity" status.	Increased competition for project development. Led to many interconnection requests across the United States and corresponding challenges with backlogged queues, which ultimately motivated transmission-provider-driven reforms in the late 2000s/early 2010s.
Orders 661 and 661-A	June and December 2005	Required public utilities to add standard procedures and technical requirements (e.g., supervisory control and data acquisition capability, power factor criteria) for interconnection of large wind generators. However, exemption was made available if reactive power capacity was not required to ensure reliability.	Incorporated, for the first time, rules for nonsynchronous generators to enhance reliability outcomes.
Order 2006	May 2005	Established small generator interconnection procedures, agreements, and standards for projects interconnecting at the transmission level.	Developed multiple tracks of interconnection, depending on size and voltage level for small projects. Served as model for state-level standards when small facilities more commonly connect to intrastate distribution grids.
Order 1000	July 2011	Reformed electric transmission planning and cost allocation rules by eliminating federal right of first refusal on certain transmission, incorporating public policy into planning and creating a goal that transmission costs be assigned to those that benefit from the development.	Aimed to increase competition within transmission development, with some limited success. Has been difficult to comprehensively define the benefits of transmission for cost allocation as well as to identify interregional planning opportunities.
Order 792	November 2013	For small generators, created new provisions for an interconnection customer to request a pre-application report, revised rules around fast-tracking, and added energy storage devices as a	Incremental changes, but seen as a small step toward integration of small-scale storage resources.

Interconnection-Related FERC Order	Date	Key Interconnection-Related Provisions	Impact and Takeaways
		category of resources eligible to interconnect.	
Order 807	March 2015	Updated rules for access and procedures governing existing interconnection customers' interconnection facilities.	Aimed to balance open-access principles and regulatory burden for managing existing interconnection facilities.
Order 827	June 2016	Eliminates exemptions for nonsynchronous generators from the requirement to provide reactive power. Did not always apply to existing generators making incremental interconnection requests.	Update to original rules in Order 661, given technological advancements and increased wind capacity. Continued to facilitate increased capabilities for generators to enhance power system reliability.
Order 828	July 2016	Matches ride-through requirements of small generators with already existing rules for large generators to ride through abnormal frequency and voltage events.	Goal was to eliminate the difference in a reliability requirement for small and large generators.
Order 842	February 2018	Required new interconnecting generators to install, maintain, and operate equipment capable of providing primary frequency response.	Applied to both synchronous and nonsynchronous generators and was intended to address reliability concerns from evolving generation resource mix.
Order 845	April 2018	Revised large generator procedures to allow surplus interconnection service, the option to self-build interconnection facilities, and select service below nameplate capacity. Also recognized energy storage as a generating facility and increased transparency requirements on study models/assumptions and study timeline metrics.	Important step toward facilitating the integration of energy storage into the interconnection process. There have been limited applications of surplus service. Queue backlogs only continued to increase after order.
Order 2023	July 2023	Required a first-ready, first-served clustering process for bulk power generator interconnections, deadlines for the cluster process and affected systems studies, and technology advancement, such as GETs.	Too soon to tell. Many stakeholders note that while the order is an important step forward, deeper structural changes with interconnection processes may be needed.
Order 901	October 2023	Directs NERC to submit a detailed standards development plan to address IBR reliability gaps in four areas:	Important step that should lead to further harmonization in performance requirements, model validation, planning studies, and

Interconnection-Related FERC Order	Date	Key Interconnection-Related Provisions	Impact and Takeaways
		• Data sharing • Model validation • Planning and operational studies • Performance requirements. Informational filing by NERC was due January 2024. New or modified standards are to be submitted by NERC by November 2026.	data sharing. However, it is too soon to tell how many details will still be left for regional entities to determine. NERC standards can be relatively high level.

Glossary

Balancing Authority – The responsible entity that integrates resource plans ahead of time, maintains demand and resource balance within a balancing authority area, and supports interconnection frequency in real time.

Balancing Authority Area – The collection of generation, transmission, and loads within the metered boundaries of the balancing authority. The balancing authority maintains load-resource balance within this area.

Base Load – The minimum amount of electric power delivered or required over a given period at a constant rate.

Battery Energy Storage Systems (BESS) – Device comprising series-parallel battery packs to enable storing of excess energy production by renewable energy sources. The energy stored can then be released when the power is required to supplement power demand.

Bulk Electric System (BES) – Generally, but with exceptions, all transmission elements operated at 100 kilovolts or higher and real power and reactive power resources connected at 100 kilovolts or higher. This does not include facilities used in the local distribution of electric energy.[175]

Bulk Power System (BPS) – (1) Facilities and control systems necessary for operating an interconnected electric energy transmission network (or any portion thereof) and (2) electric energy from generation facilities needed to maintain transmission system reliability. The term does not include facilities used in the local distribution of electric energy.

Congestion – Occurs when a portion or line segment of the transmission grid becomes overloaded with electric power and thus the lowest-cost electricity cannot reach some customers due to these transmission constraints.

Critical Electric/Energy Infrastructure Information (CEII) – Defined at FPA section 215(a)(3), with designation criteria codified at 18 CFR 388.113(c). Information related to critical electric infrastructure, or proposed critical electrical infrastructure, generated by or provided to FERC or another federal agency, other than classified national security information, that is designated as CEII by FERC or the Secretary of Energy pursuant to section 215A(d) of the FPA. The term includes information that qualifies as CEII under FERC's regulations.

Curtailment – A reduction in the scheduled capacity or energy delivery of an interchange transaction.

Demand – (1) The rate at which electric energy is delivered to or by a system or part of a system, generally expressed in kilowatts or megawatts, at a given instant or averaged over any designated interval of time. (2) The rate at which energy is being used by the customer.

[175] See Glossary of Terms Used in NERC Reliability Standards for full list of inclusions and exclusions.

Energy Resource Interconnection Service (ERIS) – Interconnection service that allows the interconnection customer to connect its generating facility to the transmission provider's transmission system to be eligible to deliver the generating facility's electric output, using the existing firm or nonfirm capacity of the transmission provider's transmission system on an "as available basis."

Equity and Energy Justice (EEJ) – Sometimes referred to as "energy equity and environmental justice,"[176] DOE efforts to prioritize EEJ work to improve the health, safety, and energy resilience of communities that have been disproportionately affected by fossil fuels, by ensuring all Americans have access to affordable clean energy. This effort is in alignment with the Justice40 Initiative, directing 40% of the overall benefits from federal investments to flow to disadvantaged communities.

Facility – A set of electrical equipment that operates as a single bulk electric system element (e.g., a line, a generator, a shunt compensator, transformer, etc.).

Generator Operator – The entity that operates generating facility(ies) and performs the functions of supplying energy and interconnected operations services.

Generator Owner – Entity that owns and maintains generating facility(ies).

Indian Energy – The development of utility-scale or community-scale energy by Tribes or Tribally designated developers within the external boundaries of one or more Tribal reservations.

Interconnection – A geographic area in which the operation of bulk power system components is synchronized such that the failure of one or more of such components may adversely affect the ability of the operators of other components within the system to maintain reliable operation of the facilities within their control. When capitalized, any one of the four major electric system networks in North America: Eastern, Western, ERCOT, and Quebec.

Network Resource Interconnection Service (NRIS) – Interconnection service that allows the interconnection customer to connect its generating facility to the transmission provider's transmission system and be deliverable during severe grid conditions, such that the generator can be designated as a capacity resource and contribute to resource adequacy requirements.

Reliable Operation – Operating the elements of the bulk power system within equipment and electric system thermal, voltage, and stability limits so that instability, uncontrolled separation, or cascading failures of such system will not occur as a result of a sudden disturbance, including a cybersecurity incident, or unanticipated failure of system elements.

Resource Adequacy – The ability of supply-side and demand-side resources to meet the aggregate electrical demand (including losses).

[176] Office of Energy Efficiency & Renewable Energy. Energy Equity and Environmental Justice. www.energy.gov/eere/energy-equity-and-environmental-justice.

System Operator – An individual at a control center of a balancing authority, transmission operator, or reliability coordinator who operates or directs the operation of the bulk electric system in real time.

Transmission – An interconnected group of lines and associated equipment for the movement or transfer of electric energy between points of supply and points at which it is transformed for delivery to customers or is delivered to other electric systems.

Transmission Operator – The entity responsible for the reliability of its "local" transmission system and that operates or directs the operations of the transmission facilities.

Transmission Owner – The entity that owns and maintains transmission facilities.

Transmission Planner – The entity that develops a long-term (generally one year and beyond) plan for the reliability of the interconnected bulk electric transmission systems within its portion of the planning authority area.

Transmission Provider – The entity that administers the transmission network, referencing both ISOs/RTOs and non-ISO/RTO balancing authorities in this document. Could encompass system operator, transmission operator, and transmission planning roles.

Vehicle to Grid (V2G) – The general operating case where electric vehicles not only charge their onboard batteries but also can supply energy back to the power grid by discharging them.

U.S. DEPARTMENT OF ENERGY

For more information, visit: energy.gov/i2X

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