Transmission Panel:
The State of Electric Transmission: Engineering, Planning, Logistics, & Policy

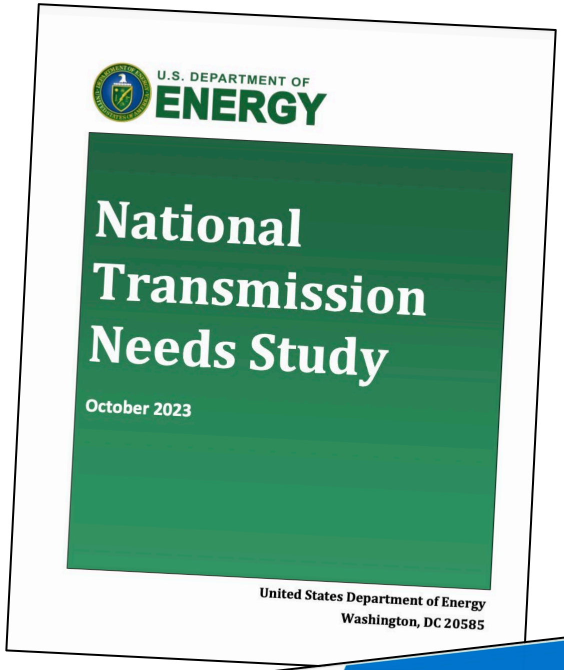
Granger Morgan (NAS), Moderator

Before we turn to our panel, I want to take a moment to frame the discussion in terms of the large and growing need for expanded transmission capacity.

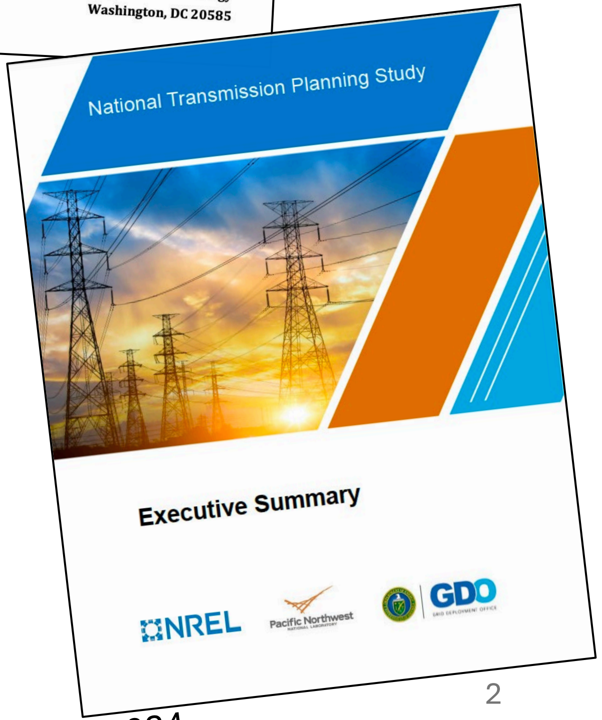
In two recent studies…

…DOE has argued that if the economy is going to stay strong, and the nation is going to make good progress in reducing CO_2 emissions, by 2050 the U.S. will need to ***more than double*** the capacity of our high-voltage transmission system. DOE has also laid out a set of optimal ways in which to expand the transmission system.

However, what neither of these DOE studies does is address the issue of *how to actually get this new transmission built.*



2023



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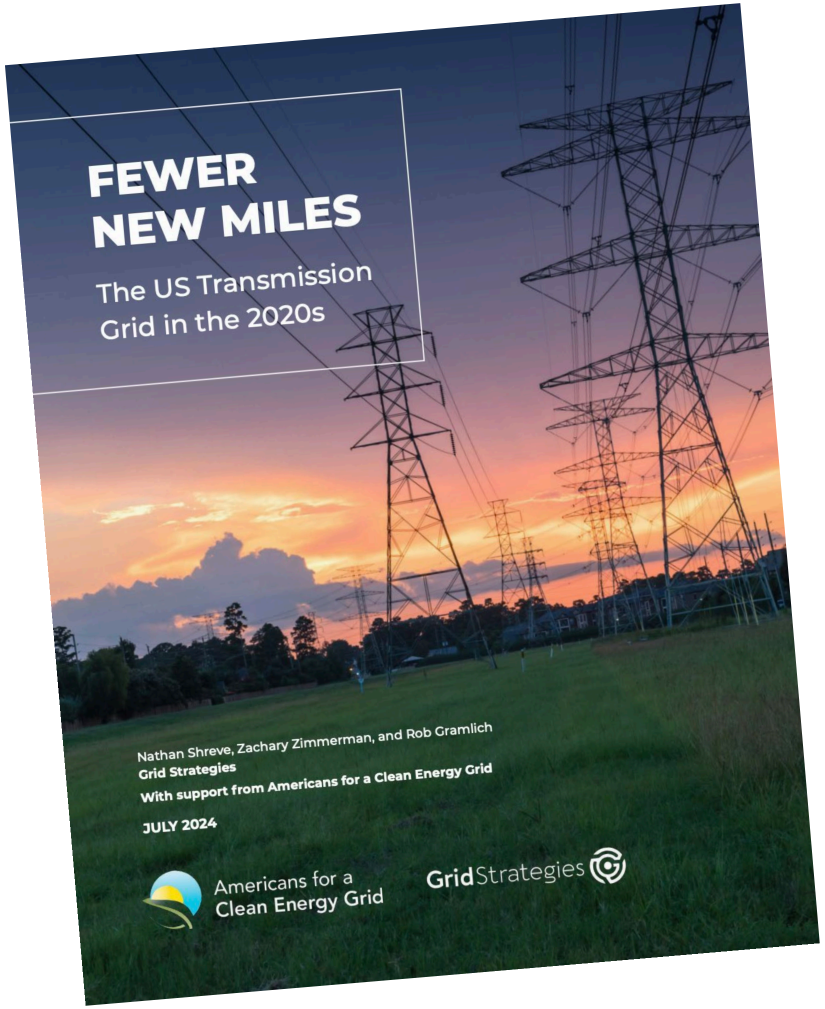
A recent study by two NGOs…



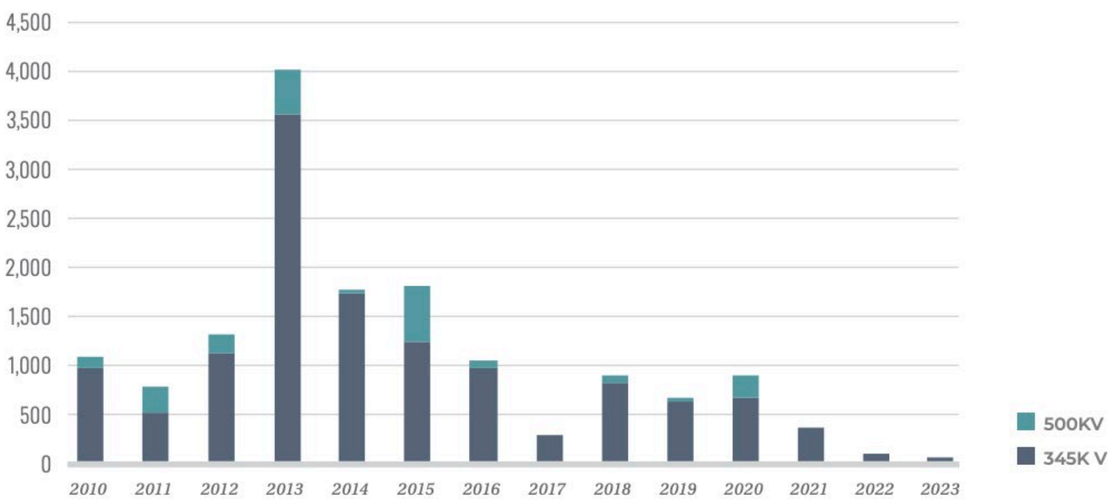
2024

… cites both the DOE study on transmission needs, as well as work by the Net-Zero America study at Princeton to make the case for needed expansion in transmission capacity.

The report argues that because of the priorities of state PUCs and other factors, utilities are "…incentivized to prioritize low- voltage upgrades focused on reliability and asset replacement."

FIGURE 1 Investment in new high-voltage lines peaked in 2013 and has steadily fallen over the last 10 years.[3]

MILES OF 345 KV+ TRANSMISSION LINES ADDED EACH YEAR



Another major problem involves interconnection

When new generators (wind, solar, gas, etc.) get built, they need to connect to the high voltage transmission systems. The system to deal with that is seriously broken. While FERC has been working to address this problem, there is still a long way to go.

POLICY FORUM

POLICY FORUM

Can federal grid reforms solve the interconnection problem?

Coordinated, comprehensive planning is sorely needed

By Les Armstrong[1], Alexa Canaan[2], Christopher Knittel[3,4], Gilbert Metcalf[3,4], Tim Schittekatte[3,5]

Although fossil fuel–generated electricity production has historically vastly outweighed production from wind and solar, that is changing. However, in many countries, there is a substantial and growing waiting list for connecting new generation projects to the electrical grid. In the United States, for example, the number of applications has increased rapidly since 2010 to more than 3000 projects in the various interconnection queues as of 2021 (see the figure). The median time from interconnection request to interconnection agreement was 35 months in 2022, with wait times even longer for wind and solar (*1*). In response to this growing bottleneck, the US Federal Energy Regulatory Commission (FERC) issued two recent orders aimed at improving the generation interconnection process and long-term transmission grid planning. We argue that these are good first steps toward addressing the problems that have arisen over the past two decades, but crucial issues remain unaddressed.

In the United States, electricity production from wind and utility-scale solar exceeded that from coal for the first time in April 2022 and again during February through May 2023 (*2*). One study estimates that average annual low-carbon capacity additions in the United States will increase from 27 GW/year to 51 GW/year as a result of the Inflation Reduction Act. Other studies estimate additions will be even larger (*3*).

The interconnection bottleneck problem facing new generation projects is not specific to the United States. The interconnection queue in Great Britain totaled nearly 400 GW in 2023—well in excess of what is needed to power the entire British energy system at peak demand (*4*). Several continental European countries show similar statistics (e.g., Spain and Italy) (*5*).

ROOTS OF THE PROBLEM

In 2003, FERC issued its initial interconnection policy, Order 2003, establishing procedures for connecting large generation facilities (20 MW and larger) to the transmission grid. The purpose of the order was to standardize the interconnection process, reduce planning uncertainty, and reduce delays for new projects. Owing to congestion, the introduction of a new generating facility to the grid can have unforeseen consequences for the existing system. As a result, transmission providers require a series of studies before allowing a new facility to interconnect to the grid to ensure stability.

The proposed facility might require network upgrades, defined as modifications or additions to existing transmission and distribution infrastructure. FERC Order 2003 assigned all costs of network upgrades arising from the proposed project to the first project that triggered required network upgrades. The required upgrades and consequent costs were based on both the existing transmission grid and set of grid-connected facilities as well as the anticipated grid-connected facilities earlier in the queue than the proposed project. Departures from the queue of those earlier projects could trigger changes to the assigned network upgrade costs. As projects proceed through the various study processes, costs can change drastically.

A complicating factor for predicting the ultimate network upgrade costs that will be borne by a project is the presence of other speculative projects in the queue. Modest adjustments in position in the queue or geographic location of the project can lead to substantial changes in the assigned network upgrade costs that are difficult to predict for developers. Geographic location can matter given the distance of a project from the grid and the potential congestion the project could create when added to the grid in a particular site. Entering multiple projects in the queue, even when the developer only plans to construct one of them, creates option value as the project with the lowest assigned costs can be kept whereas others are eventually withdrawn from the queue at low cost. Placing multiple project requests in the queue is a way to insure against unexpectedly high network upgrade costs but leads to the need for more restudies, longer queues, and greater uncertainty for all other projects around their ultimate assigned costs.

The first-come, first-served approach with generators paying most (if not all) network upgrade costs has been especially problematic for renewable projects, which, among other things, are more geographically constrained than fossil fuel projects (*1*, *6*). Researchers have found that interconnection costs, on average, are higher for renewable projects and that important externalities, both positive and negative, exist across projects (*7*). As the queue size increases, study times increase. Project developers do not account for the delay cost they impose on others when they make an interconnection request. Ignoring this cost leads to excessive entry from society's point of view (a classic negative congestion externality). In addition, interconnection costs tend to be lower when locating near projects that recently connected and incurred substantial network upgrade costs. This suggests a positive timing externality as later entrants benefit from investments made by such earlier entrants (a positive spillover that leads to less than efficient investments from a societal perspective).

The existing literature indicates clear problems with queuing from the first-come, first-served approach taken by FERC Order 2003, along with the approach of allocating all network upgrade costs to the specific project triggering upgrades. The latter is particularly problematic because added upgrade costs to the project, which typically were less than 10% of what the project cost initially before accounting for any upgrade costs, have risen to as much as 50 to 100% of project costs. It is also argued that network upgrades contribute to a more resilient grid; in that case, spreading the costs more broadly among grid users would be more consistent with FERC's "beneficiary pays" principle (*8*).

The interconnection bottleneck highlights another problem: Proposed transmission grid expansions often are driven by specific, localized generation project proposals that do not take into account broader, regional supply and demand considerations. At its core, the interconnection

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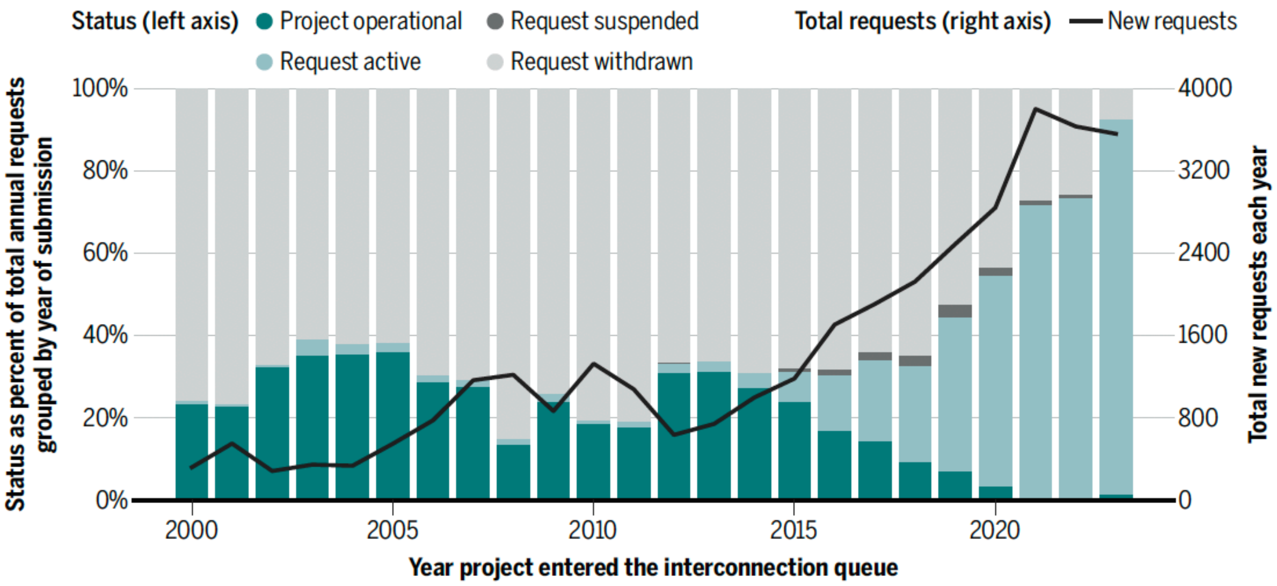
Downloaded from https://www.science.org at Carnegie Mellon University on March 25, 2025

Growing backlog in the interconnection queue

Data are from seven independent system operators and regional transmission organizations and 26 utilities as of the end of 2023. The completion rate shown is calculated based on number of projects, not capacity. For projects entering queues in recent years, the final outcome may have yet to be determined.



You might ask:

Do we really need more transmission capacity?

Won’t distributed generation (DG) like rooftop solar and moving large loads such as data centers to where electricity is generated make it unnecessary to expand transmission capacity?

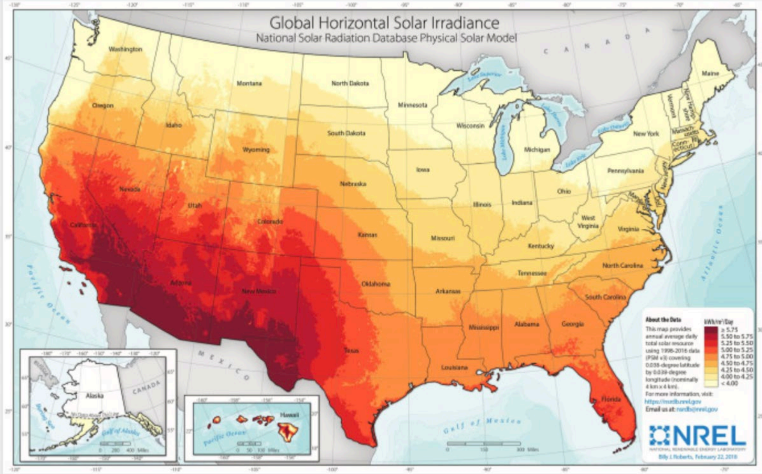
Image sources: Environmentamerica.org ; G. Morgan & J. Apt

The answer is…

…those things will help but we still need to move power to where loads are from:

- wind power in the Midwest and offshore platforms,
- solar in the Southwest
- hydro from Canada and other remote locations

And, as the system has a lower proportion of rotating machines that provide inertia, we also need transmission to help assure continued system resilience.



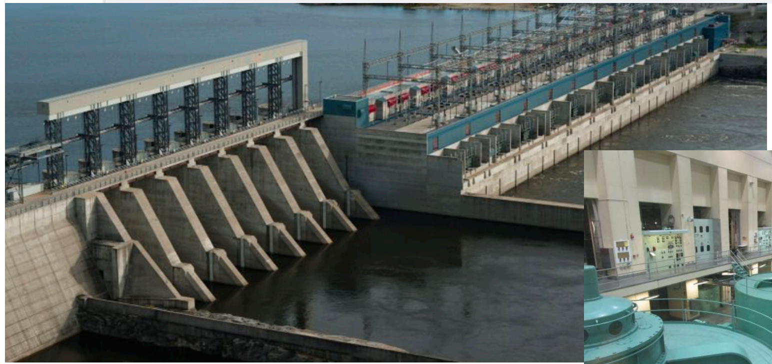


Image sources: NREL; Hydro Quebec; BPA

As our panelists will explain…

…the Federal Energy Regulatory Commission (FERC), State Regulators, several DoE labs, and others are working on the issue of expanding transmission capacity. Much of what they are doing is incremental and typically does not contemplate possible fundamental institutional, legal or regulatory changes, nor does it address public understanding and resistance.

In a public webcast of a plenary session of the NAS annual meeting on the morning of Saturday, April 26 we'll talk about many of these broader issues.

Two strategies to expand transmission capacity…

…beyond the option of acquiring new ROWs and building new overhead lines:

While these strategies are not part of today's workshop, on the next slide I'll summarize a few .

1. Expand the amount of power that can be moved through existing high voltage transmission corridors.

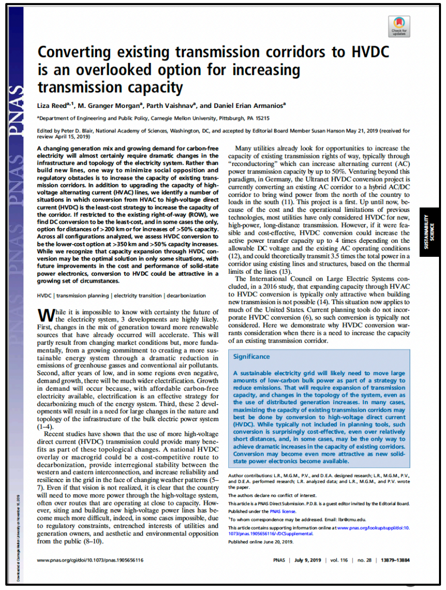
2. Use overhead lines in non-traditional right-of-ways (ROWs) or HVDC cables embedded in both traditional and non-traditional ROWs.

More power through existing ROWs

Three strategies hold potential to move more power through existing transmission ROWs.

1. Make greater and better use of the large amounts of data now being collected on modern transmission systems in order to operate those systems more efficiently.
2. Upgrade the capacity of existing HVAC lines. Because the amount of power that can be moved through a line is proportional to the product of the voltage and the current (P=VI), increasing either or both allows one to move more power. Doing this often requires reconductoring, new insulator strings, and/or wider ROWs.

3. Convert existing HVAC lines to HVDC.



More power through non-traditional ROWs

HVAC Overhead lines

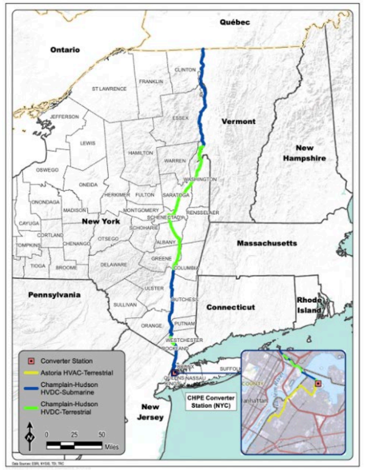
HVDC Cables

Because of induction effects, long HVAC cables are not very feasible.

- Existing lower-voltage transmission corridors
- **Existing state and federal highways**
- **Existing rail corridors**
- Waterways (lakes, rivers, canals)
- Abandoned and repurposed rail corridors
- Existing pipeline corridors

Champlain Hudson Power Express

This >300-mile transmission line now under construction will deliver >1GW of low-carbon power from Quebec to New York City.



Soo Green

Buried HVDC cables are more expensive…

…than overhead lines.

However, if the need to move power is high enough, and the likelihood of successfully building a conventional overhead line is low, the expected value of a buried HVDC cable may exceed that of the overhead line.

A decision like this probably requires regulatory and cost recovery strategies which today we do not have.

Finally, I'll conclude by noting an elephant in the room that we do not have the evidence to talk about.

Public perceptions and opposition, and improving public understanding.

It is widely assumed that building underground transmission systems will be more acceptable to the public. However, while there have been a few recent studies conducted in Europe, there do not appear to be *any* US-focused studies that use good modern social science research methods.

Image source: https://www.storysanctum.org/post/an-elephant-in-the-room

Panel speakers:

- Jeff Dagle, Chief Electrical Engineer,
  Pacific Northwest National Laboratory
- Eric Johnson, External Affairs,
  ISO New England
- Greg Mathe, Director, Electric Transmission
  Engagement, Permitting & Land,
  Dominion Energy