Transmission Investment Needs and Challenges

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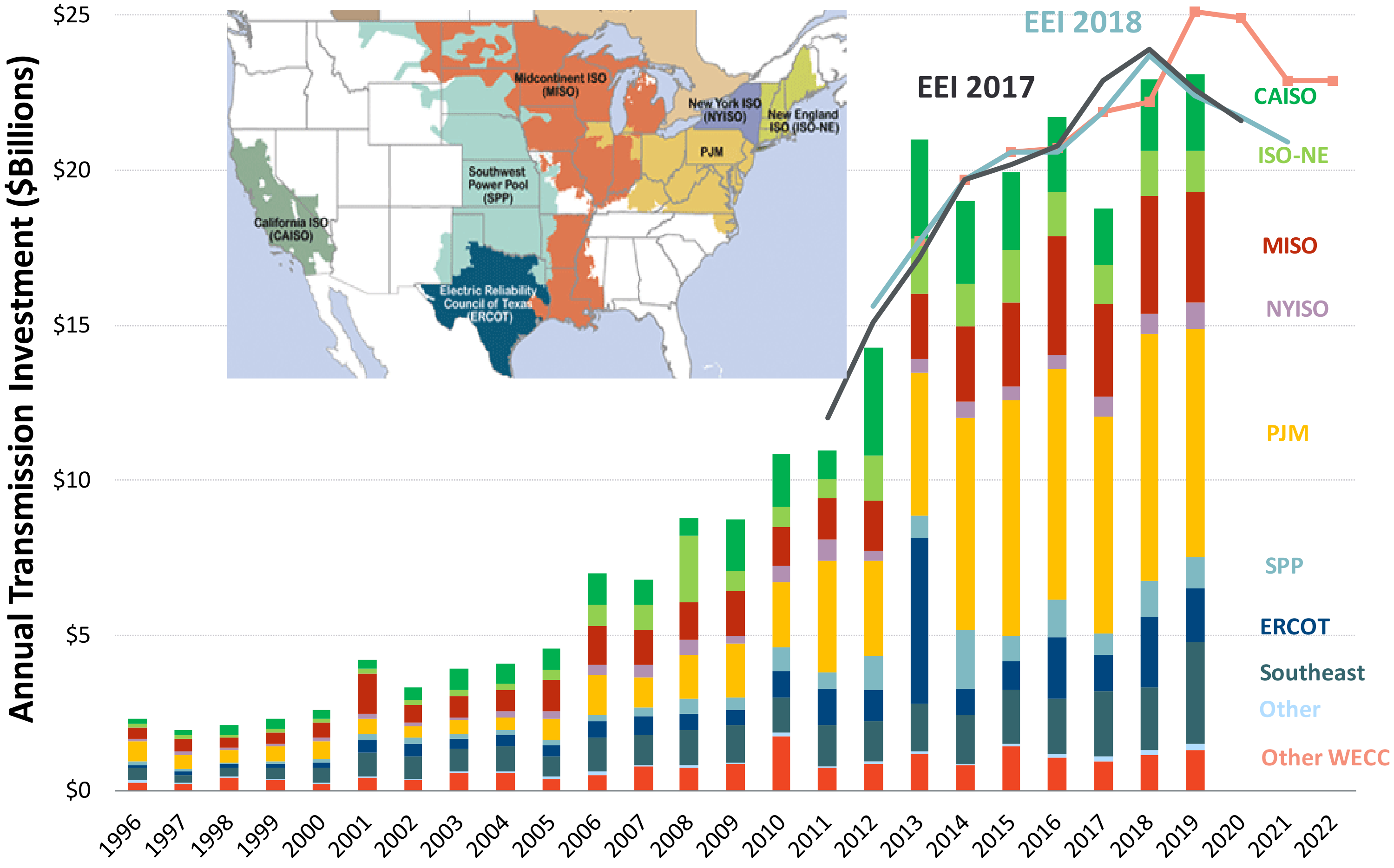
Contents

1. Level of transmission investments and future needs
2. The benefits of a more robust national grid
3. Barriers to transmission development
   - For renewable resources, including offshore wind
   - To lower total costs, nation wide
4. How to improve transmission planning

Additional Reading

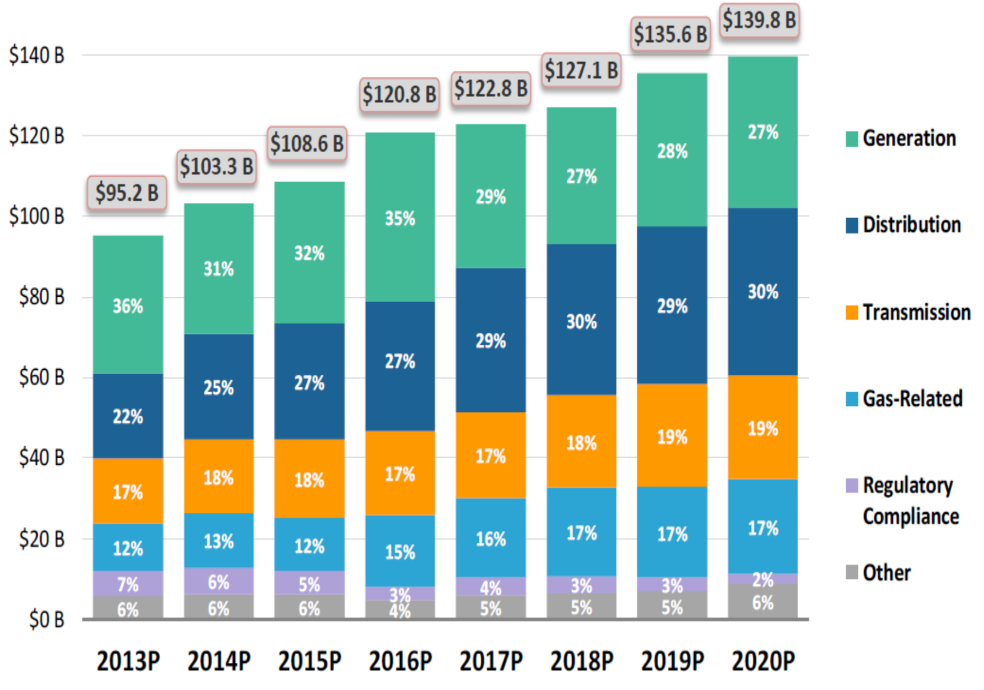
Transmission Investment is at Historically High Levels

Annual Transmission Investment
As reported to FERC by Region (1996 – 2019)



Source: FERC Form 1 Data, EEI "Historical and Projected Transmission Investment" most recent accessed here: https://www.eei.org/resourcesandmedia/Documents/Historical%20and%20Projected%20Transmission%20Investment.pdf

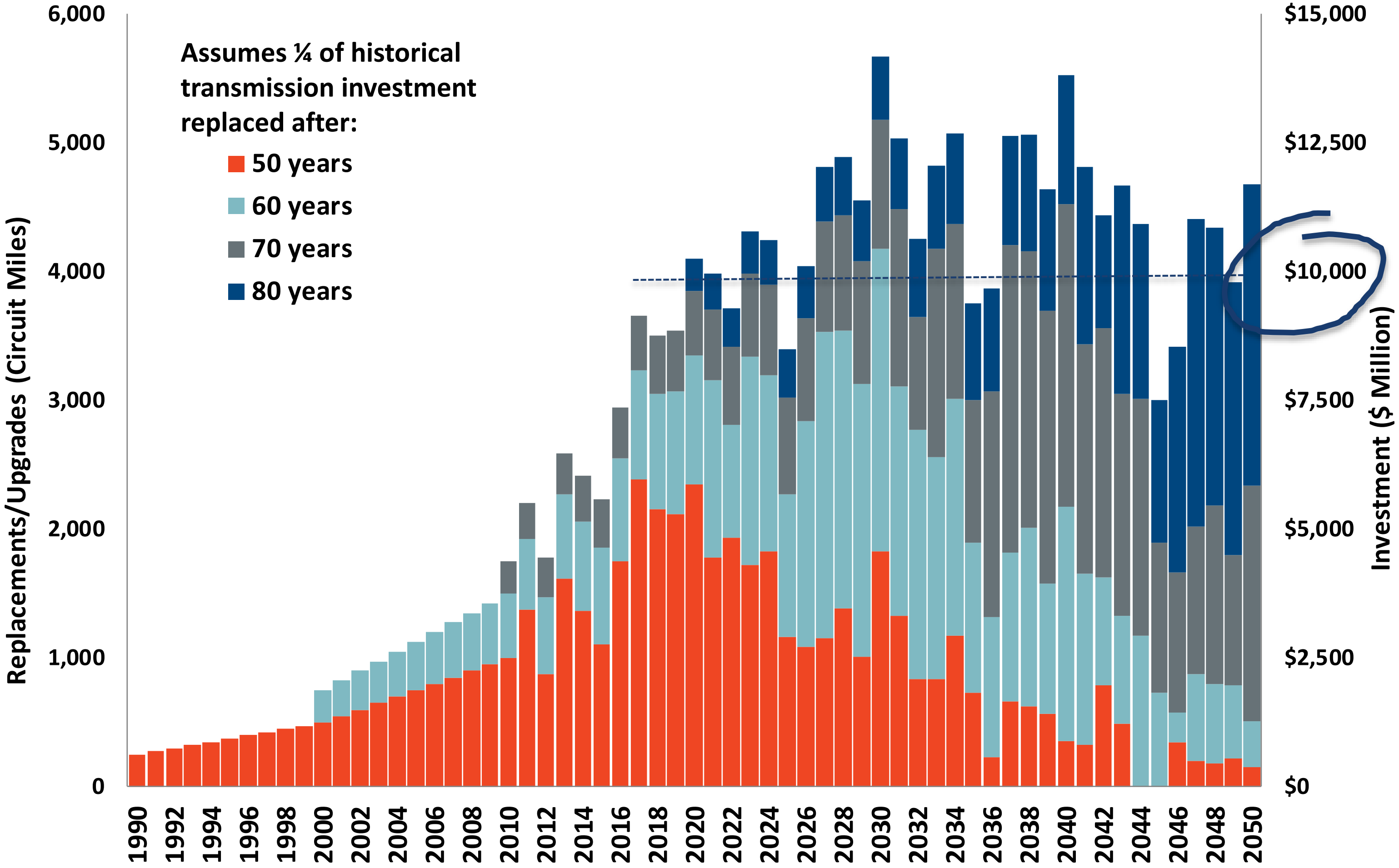
$20-25 billion in annual U.S. transmission investment: almost 20% of total by regulated utilities



Source: EEI, Electric Power Industry Outlook, Feb 10. 2021

Challenge: Aging Transmission Infrastructure

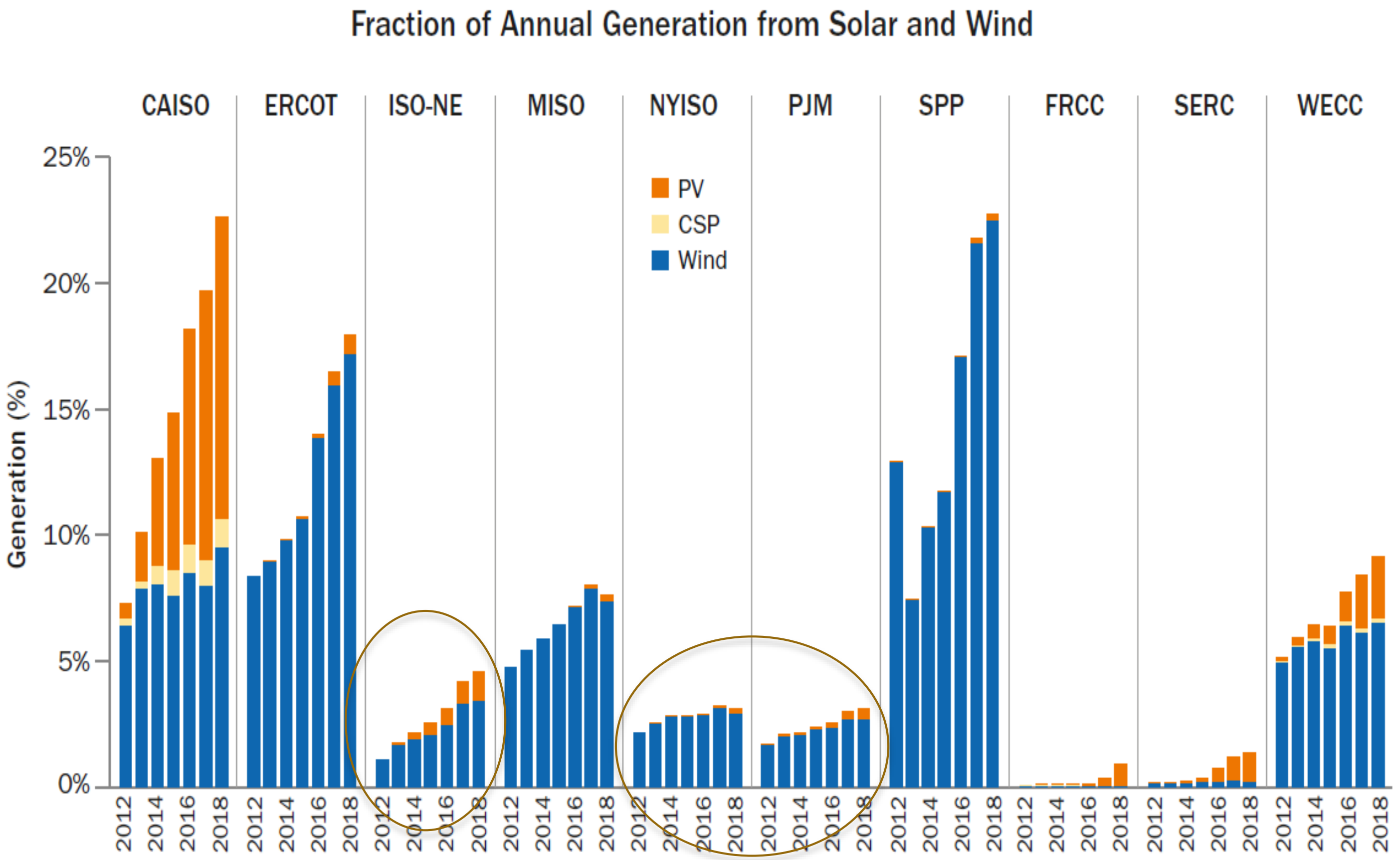
- Much of today's grid was built in the 1960s and 70s
- Facilities that need to be replaced after 50 to 80 years, now likely account for $10 billion in annual transmission investment
- Might have reached 80% of total in some regions, such as PJM
- Some of these replacements are on highly-valuable right of way that could be used to "upsize" new facilities in support of emerging public policy goals



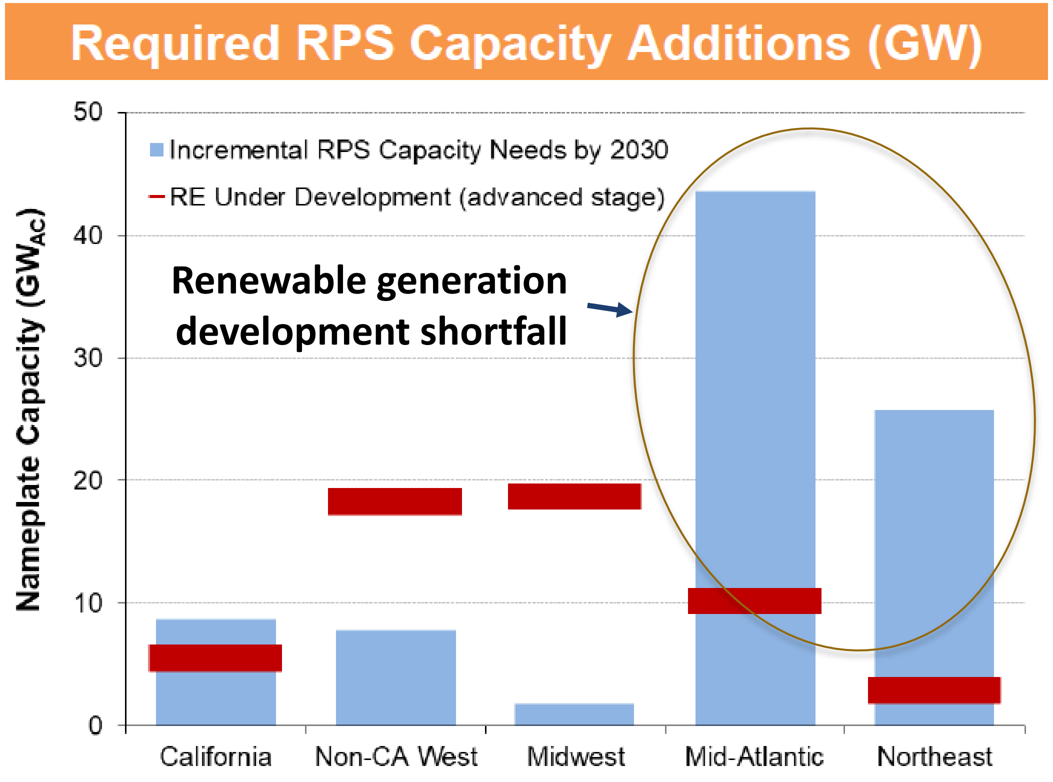
Source: Brattle estimate. Assumes circuit mile costs equal to those of new lines

Renewable Development vs. Clean Energy Goals

Increasingly ambitious clean-energy goals of Mid-Atlantic and Northeastern states are in contrast to low levels of renewable generation development … a gap caused in part by transmission-related barriers



Source: *2018 Renewable Energy Grid Integration Data Book*, U.S. Department of Energy, National Renewable Energy Laboratory (NREL) and the Lawrence Berkeley National Laboratory (LBNL), March 2020.

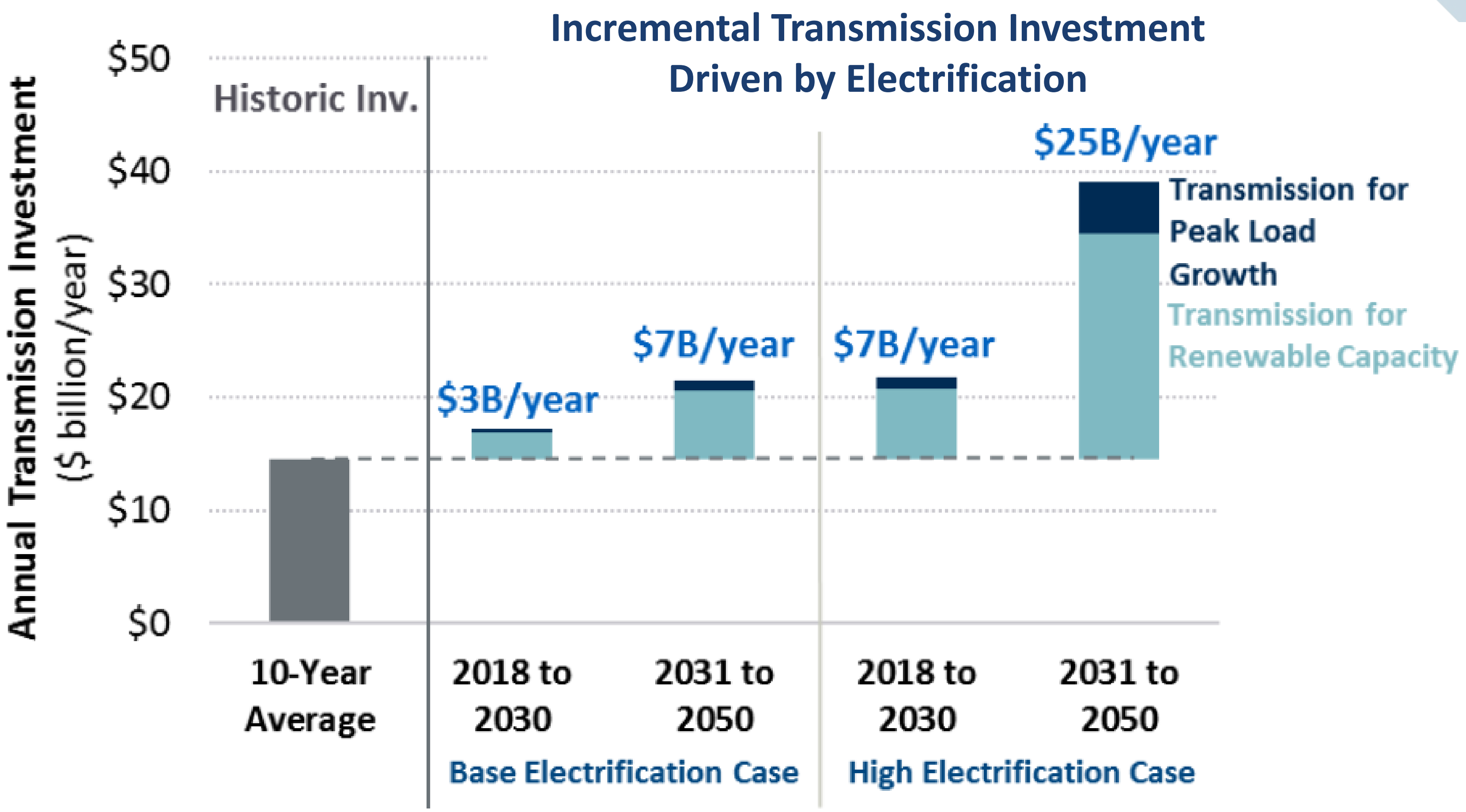


Source: Galen Barbose, "U.S. Renewables Portfolio Standards: 2021 Status Update (Early Release)," Lawrence Berkeley National Lab, Feb 2021. rps.lbl.gov

U.S. Transmission Investment Will be Driven by Need for Economy-Wide Electrification

Electrification of transport and home heating will add $3-7 billion/year of transmission needs over the next decade

- Estimate increases to **$7-25 billion/yr** for 2030-2050



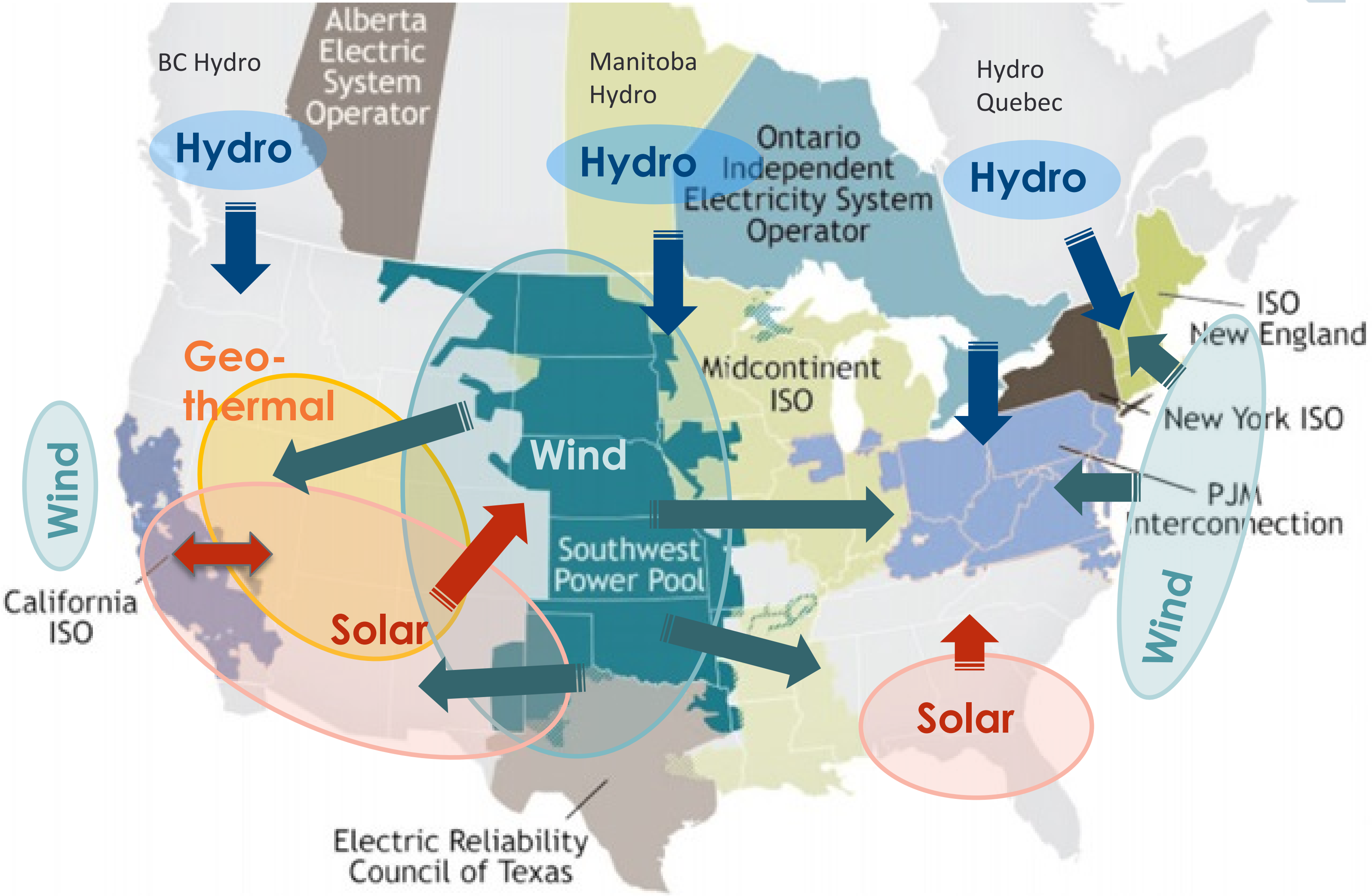
Source: Weiss and Hagerty, "The Coming Electrification of the North American Economy," The Brattle Group, prepared for WIRES, March 2019.

Notes: The historical average reflects transmission investments from 2006 to 2016 based on transmission capital expenditures reported on FERC Form 1.

Interregional Transmission Would Help Access and Diversify Low-Cost Clean-Energy Resources

Beyond providing access to low-cost resources, grid-based resource diversification offers significant benefits:

- Regional diversification of resources (and customers' electricity usage) reduces the investment and balancing cost in a future with high levels of intermittent resources
- Diversity of resources (and load) increases the value of transmission between them
- The scale of robust grid solutions needs to exceed the size of large weather systems

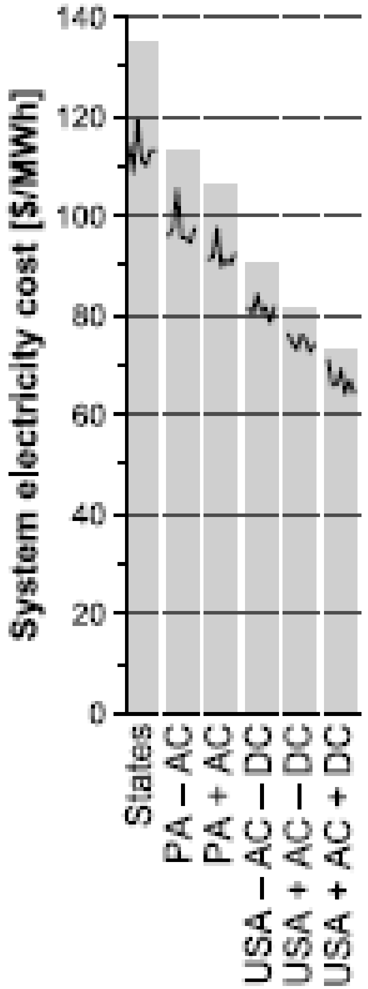


National Studies: Large Benefit of Interregional Transmission

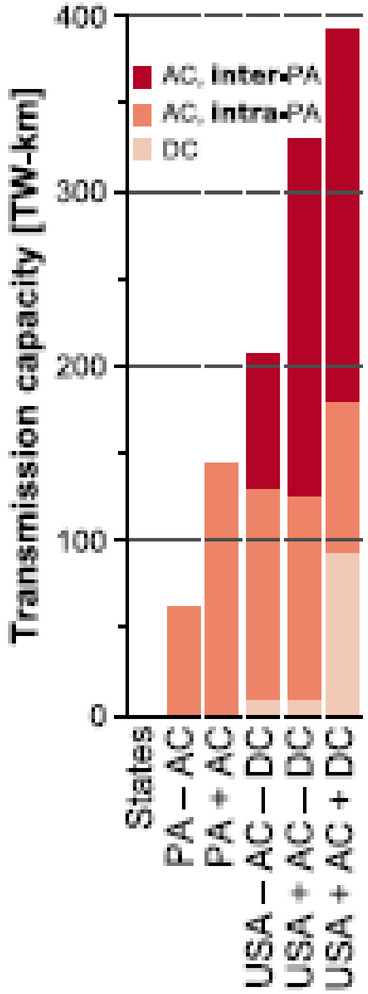
Study	Region	Findings
MIT Value of Interregional Coordination (2021)	Nation-Wide	• National coordination of **reduces the cost of decarbonizing by almost 50% compared to no coordination between states** • The lowest-cost scenario builds almost 400 TW-km of transmission; including **roughly 100 TW-km of DC capacity between the interconnections** and over 200 TW-km of interregional AC capacity • **No individual state is better off implementing decarbonization alone** compared to national coordination of generation and transmission investment • Low storage and solar costs still result in significant cost effective interregional transmission
Princeton Net Zero America Study (2020)	Nation-Wide	• Achieving net-zero emissions by 2050 requires **700-1,400 TW-km of new transmission** • Investment in transmission needed ranges **$2-4 trillion dollars by 2050**
U.C. Berkeley 90% by 2035 (2020)	Nation-Wide	• Study results suggest relatively little interregional transmission would be needed to achieve 90% clean electricity, but its zonal expansion model does not utilize a nodal transmission representation nor chronological hourly granularity to analyze the operation of renewable resources, which underestimates the value of interregional transmission
Vibrant Clean Energy Interconnection Study (2020)	Eastern Interconnect	• **40 to 90 TW-km of transmission is built by 2050** to meet climate goals • Transmission development can create **1-2 million jobs in the coming decades**, more than wind, storage, or distributed solar development • Transmission **reduces electricity bills by $60-90 per MWh**
Wind Energy Foundation Study (2018)	ERCOT, MISO, PJM, and SPP	• Transmission planners are not incorporating this rising tide of voluntary corporate renewable energy demand into plans to build new transmission
NREL Seams Study (2017)	Eastern and Western Interconnects	• Major new ties between interconnections saves $4.5-$29 billion over a 35 year period

Example: MIT Value of Interregional Coordination (2021)

TOTAL COST

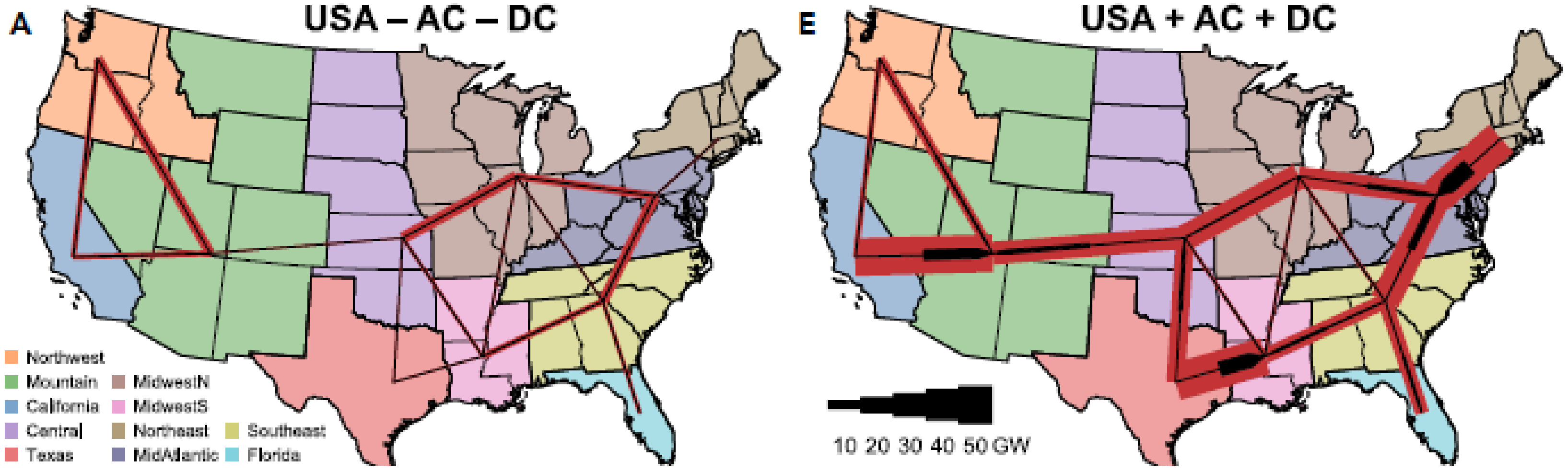


TRANSMISSION



Key Result: A more robust national grid would reduce the total cost of decarbonizing the grid … but (higher-cost) regional and more local solutions may also be feasible

Optimal Transmission Build:
With and Without National Transmission Coordination



Limitations of National Studies

Although demonstrating benefits of more transmission, the national studies have not been successful in motivating actual transmission developments. The reasons include:

- Many studies tend to analyze only aspirational clean energy targets (e.g., 90% by 2035 or 100% by 2050), not actual policies and mandates applicable for the next 10-15 years
  - By not modeling actual state or federal policies, clean-energy mandates, and renewable technology preferences, the studies cannot demonstrate a compelling "need" to policy makers, regulators, and permitting agencies
- The studies are not transmission planning studies that produce specific transmission projects that can be developed to deliver the identified benefits and they do not support a need for specific projects
  - The results of these studies do not connect with RTO planning processes and needs identification
  - The studies typically do not consider how to recover ("allocate") transmission costs
- Studies fail to identify how benefits and costs are distributed across utility service areas, states, or RTO/ISO under different scenarios, as would be necessary to gain support and develop feasible cost recovery options
- There has not been an analysis of the state-by-state economic impact and job creation from interregional transmission development, reduced electricity prices, and shifts in the locations of clean-energy investment
- Most studies do not address the many barriers to planning and the development of new regional and interregional transmission projects

The Additional "HVDC Challenge" of Macro Grid Proposals

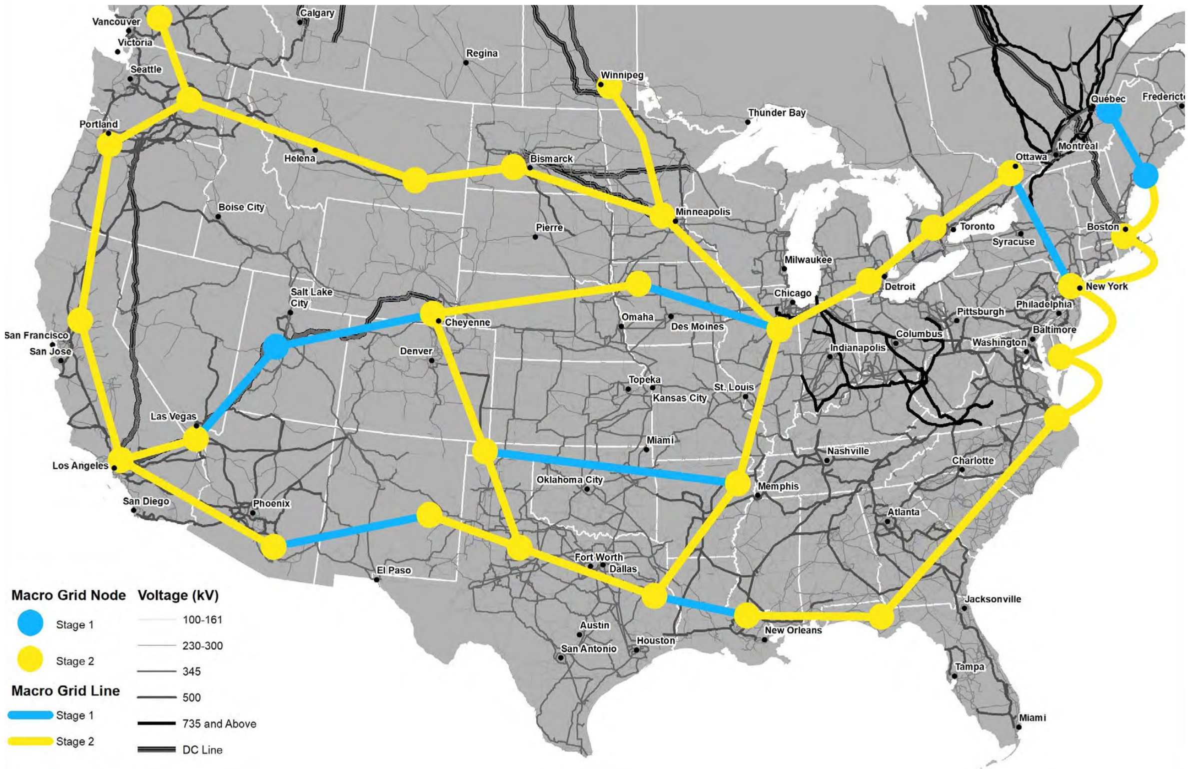
Several studies analyzed the benefits of bulding an "HVDC Macro Grid" in the U.S.

- Show that there would be clear benefits of an HVDC grid that connects multiple regions
- Most prominent examples are ARPA-E, NREL, ESIG, MIT, and Princeton Studies

However, these studies do not address the many barriers to developing an HVDC overlay system

- To integrate an HVDC overlay there would need to be significant upgrades to the AC system leading to the DC ties
- HVDC grid cannot easily be built incrementally
- HVDC lines have had difficulty gaining state regulatory approval as "fly-over" states may not experience benefits from the grid
  - Example: Plains and Eastern Clean Line Project
  - This problem may be overcome by building in additional ties with the AC system, but that adds significantly to the cost of an HVDC system

Proposed ESIG HVDC Macro Grid

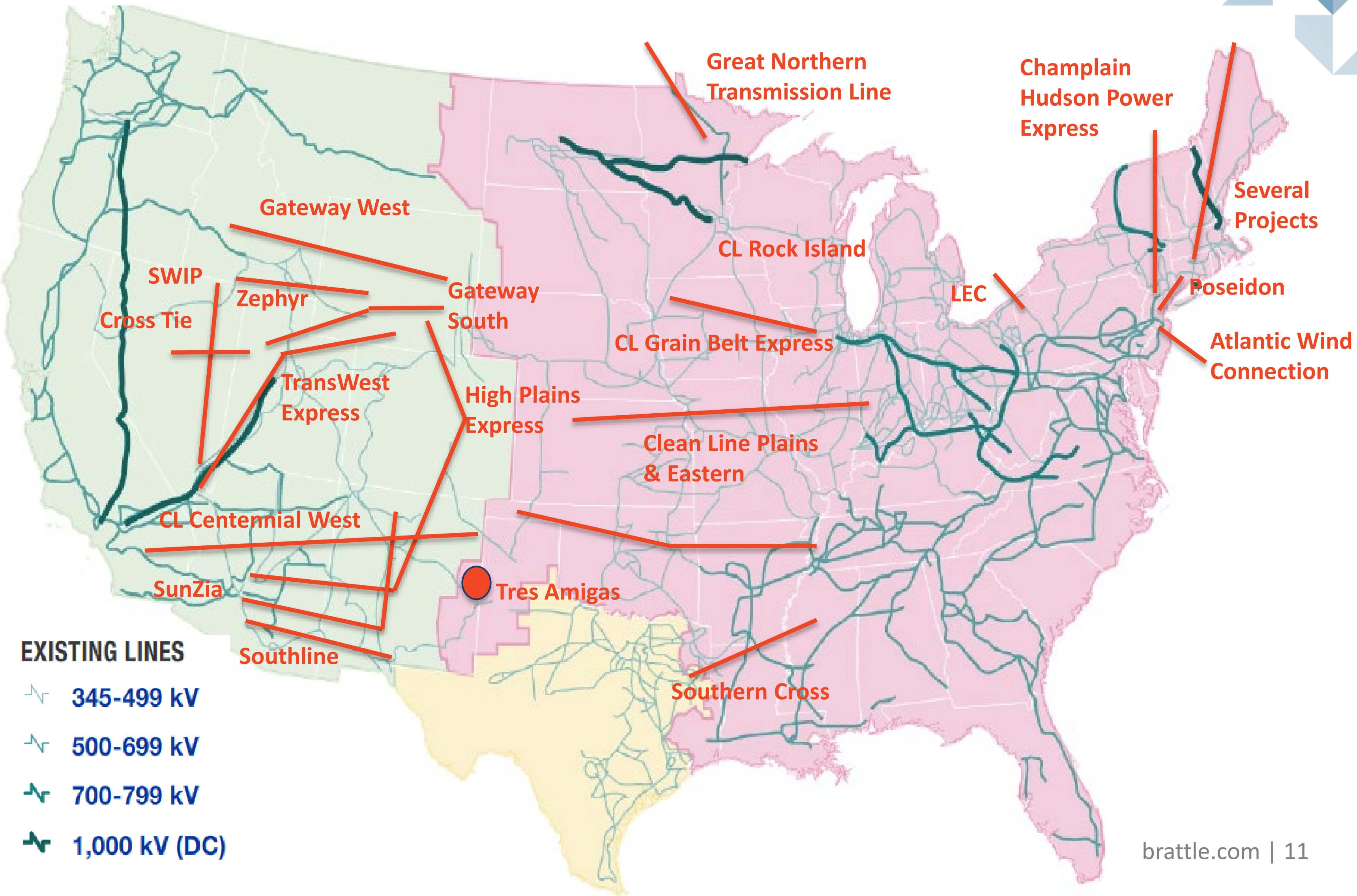


[Transmission Planning for 100% Clean Electricity - ESIG]

Still: Many HVAC and HVDC Projects Have Been Proposed

Numerous proposed transmission projects attempt to deliver low-cost renewables to regions with clean energy needs

But **<u>many of these projects will not get built</u>** unless regional and interregional planning and cost allocation is improved



Transmission Planning: Urgent Improvements are Needed

Efforts to improve planning processes are urgently needed for at least three reasons:

- Transmission projects require at least 5–10 years to plan, develop, and construct; as a result, **planning has to start early to more cost-effectively meet the challenges** of changing market fundamentals and the nation's public policy goals in the 2020–2030 and 2030+ timeframe
- A continued reliance on traditional transmission planning that is primarily focused on **reliability and local needs leads to piecemeal solutions** instead of developing integrated and flexible transmission solutions that enable the system to meet public policy goals will be more costly in the long run
- U.S. is in the midst of an investment cycle to replace **aging existing transmission** infrastructure, mostly constructed in the 1960s and 70s; this provides unique **opportunities** to create a more robust electricity grid at lower incremental costs and with more **efficient use of existing rights-of-way** for transmission

Understated benefits and disagreements over cost allocation have derailed many planning efforts and created barriers for valuable transmission projects

Too Much Focus: Addressing only Reliability and Local Needs

Transmission planning often is too focused on addressing solely reliability and local needs, without considering the multiple values that transmission can provide

- For example: what is the lowest-cost option to address a specific reliability need based on current forecasts? What is the lowest-cost option to replace an aging facility?

Least-cost transmission solutions focused solely on a specific need do not always offer highest-value, lowest total costs to customers:

- Up-sizing projects may capture additional economic benefits (market efficiencies, reduced transmission losses, reduced costs of future projects such as renewables overlay, reliability upgrades, plant interconnection, etc.)
- More expensive regional or interregional transmission may allow integration of lower-cost renewable resources and reduce balancing cost, losses, etc.
- Modest additional investments may create option value of increased flexibility to respond to changing market and system conditions (e.g., single circuits on double circuit towers)
- Least-cost replacements of aging existing facilities may mean lost opportunities to better utilize scarce rights-of-way with up-sized projects
- More robust & flexible solutions may mitigate short- and long-term risks

Barrier: Transmission for Large-Scale Renewable Generation

The ISOs "generation interconnection" processes are workable for connecting individual plants where there is headroom on the existing grid

- Still, existing generation interconnection study processes are challenging
  - Generators face long study timelines and highly uncertain network upgrade costs
  - Queue-based processes can reduce competition among OSW developers
- Does not work well for large-scale renewable generation developments and offshore grids

ISO "regional transmission planning" processes often are not ready to develop cost-effective plans for renewable generation in a timely fashion

- ISO planning processes are time consuming and frequently ineffective for public policy needs
- Exceptions: NYISO (PPTPP), SPP (ITP), CAISO (TEAM, LCR*), ERCOT (CREZ*), MISO (MVP*)

(* = not currently used)

The Mid-Atlantic and New England states will face the most significant challenges to integrate the renewable resources needed to meet state public policy goals

- Neither PJM nor ISO-NE current have effective public-policy/multi-value planning processes

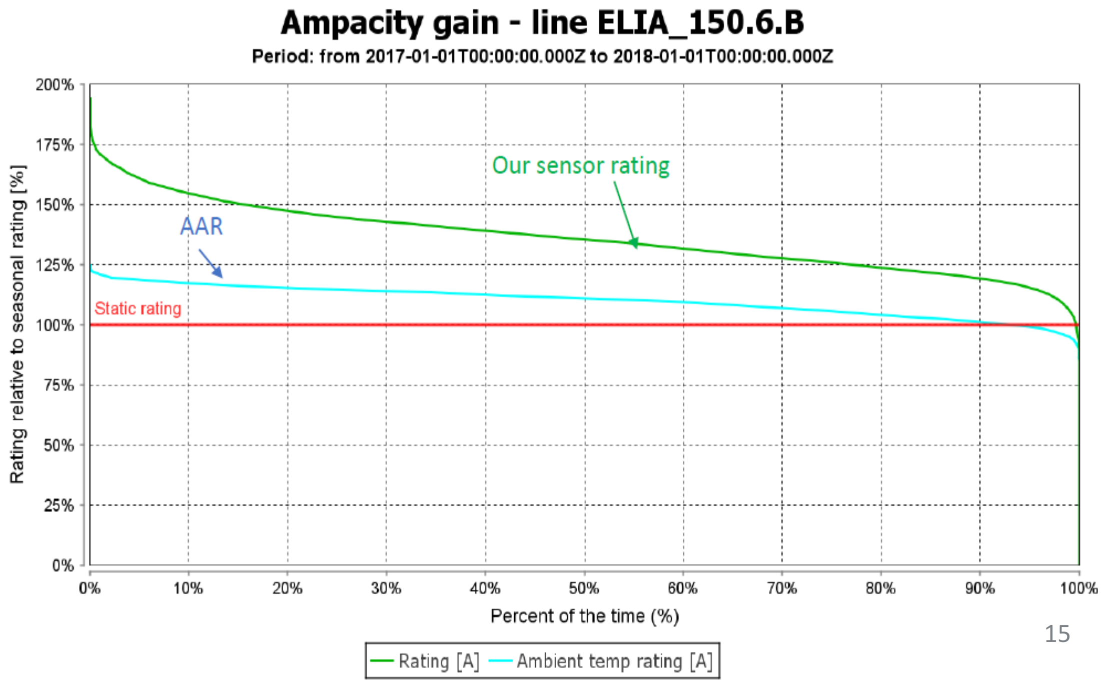
Partial Solution: Advanced Grid Technologies

Advanced transmission technologies can create significant "headroom" to integrate renewable generation on the existing grid and make new transmission projects more cost effective

- Increasingly well-tested and commercially applied technologies include: dynamic line rating, smart wires and flow control devices, grid-optimized storage, and topology optimization.
- Can be deployed quickly to increase headroom on existing grid (see Chapter III of NY Power Grid Study)
- Brattle study in SPP shows DLR, topology optimization, and advanced power flow controls can cost-effectively double existing renewable generation headroom

Example: Dynamic Line Ratings (DLR)

- DLR can increase transmission ratings above static ratings by 25-30% on average over a year
  - Increase exceeds 10% during 90% of the year, 25% during 75% of the year, and 50% during 15% of the year
  - Only during 2% of the year dynamic line ratings are below static ratings, increasing reliability.
- Particularly effective in reducing (on-ramp-related) curtailments of wind energy
- Elia, the grid operator in Belgium, has successfully used DLR since 2008; now used on 35 major transmission lines



Offshore Wind: Better Planning Offers Significant Benefits

Thousands of MW of new clean resources will need to be built to achieve state decarbonization goals—including substantial offshore wind beyond the 30,000 MW of current commitments.

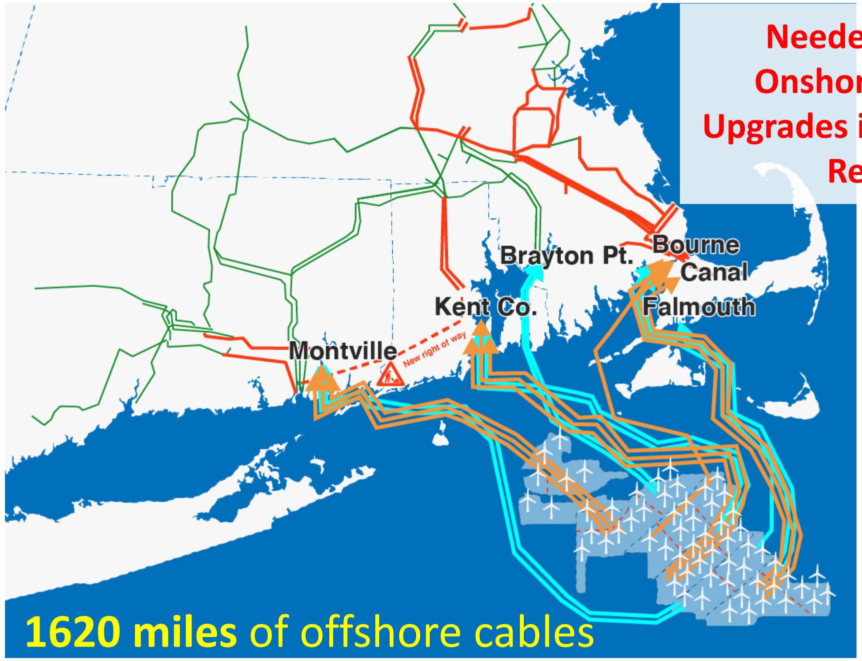
A key challenge: **ensuring a pathway low-cost, low-impact solutions** for delivering offshore wind energy to onshore grid and population centers

Region	Already Contracted	Total Committed	Potentially Needed
New England	3,120 MW	5,900 MW	25-40,000 MW by 2050
New York	4,316 MW	9,000 MW	10-25,000 MW by 2040
Mid-Atlantic	4,129 MW	13,900 MW	

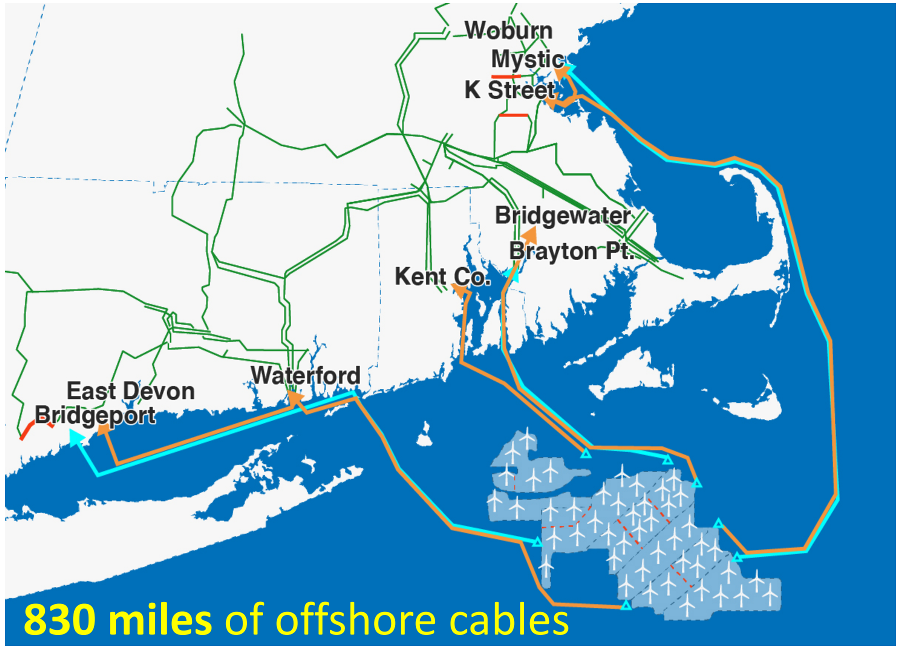
Sources: **Contracted and committed**: ACP_FactSheet-Offshore_Final (cleanpower.org), 2021. **Potentially needed**: Brattle Study of NE by Jurgen Weiss and Michael Hagerty, "Achieving 80% GHG Reduction in New England by 2050," September 2019. Brattle Study for NYISO by Roger Lueken et al., "New York's Evolution to a Zero Emission Power System: Modeling Operations and Investment Through 2040." May 18, 2020. E3, "Electric Reliability under Deep Decarbonization in New England," August 4, 2020. E3, "Pathways to Deep Decarbonization in New York State," June 24, 2020. https://www.nyserda.ny.gov/All-Programs/Programs/Offshore-Wind/Focus-Areas/NY-Offshore-Wind-Projects. Initial Report on New York Power Grid Study, January 19, 2021.

Example: Integrating OSW Generation in New England

Plausible Gen-Tie Approach



Planned Grid Approach



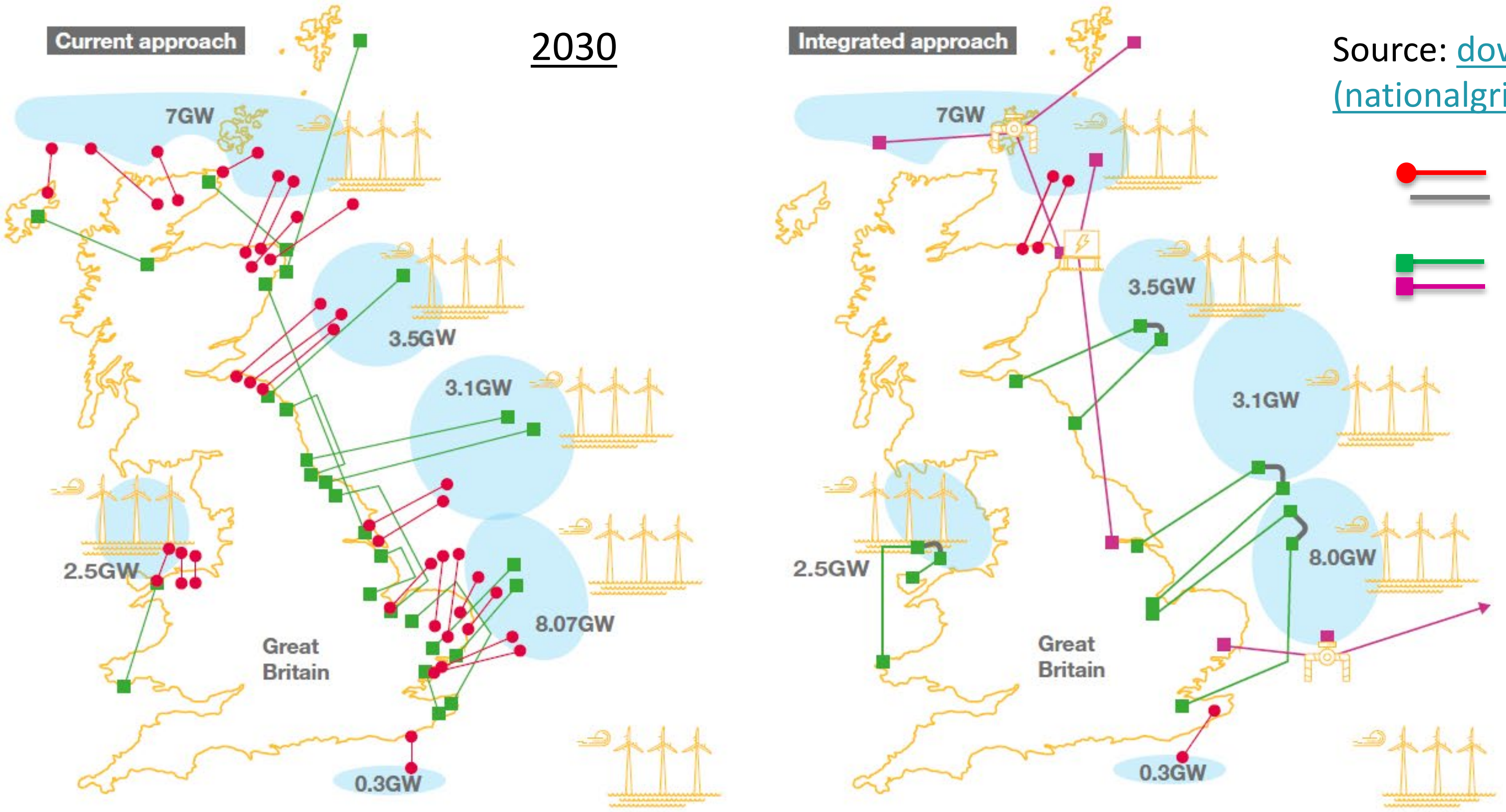
A planned grid could reducing the number of offshore platforms, cabling, seabed disturbance, and necessary coastal and marine-life impacts by 50%. Avoiding high costs of onshore upgrades could also reduce total costs and risks … with estimated savings of approx. 10%

But ISO-NE renewable generation interconnection processes does not look for lower-cost, higher-value regional transmission solutions to address multiple needs → creating a long-term barrier to achieving the region's public policy goals

Similar UK results: Start Planning for OSW Transmission Now

If planning for 18,000 MW of new OSW generation during 2025-30 (and 41,000 MW during 2030-50) starts now, the "integrated" solution **reduces estimated transmission costs by 19%** and the number of **landing points by 50-70%**. Delaying planning by only 5 years reduces 2050 benefits by half.

2030



Source: download (nationalgrideso.com)

HVAC

HVDC

Key Challenges in U.S. Transmission Planning

Current planning processes do not yield the most valuable transmission infrastructure. Key barriers to doing so are:

- Most projects are build solely to address **reliability and local needs**; the substantial recent investments in these types of projects now make it more difficult to justify valuable new transmission that could more cost-effectively address economic and public policy needs
- Planners and policy makers **do not consider the full range of benefits** (i.e., beyond reliability needs) that transmission investments can provide, understating the expected value of such projects and how these **values change over time**
- Planners and policy makers do not sufficiently account for the **risk-mitigation and option value of transmission** infrastructure that can avoid the potentially high future costs of an insufficiently-robust and insufficiently-flexible transmission grid
- Regional **cost allocation** is overly divisive, particularly when applied on a project-by-project (rather than portfolio- or grid-wide) basis
- Ineffective **interregional planning processes** are generally unable to identify valuable transmission investments that would benefit two or more regions

Best Practices Transmission Planning and Cost Allocation

Experience with effective planning and cost-allocation processes shows that they should:

1. Approach every transmission project as a **multi-value project**, able to address multiple drivers and multiple needs and be able to capture full range of benefits
2. Evaluate **projects** based on a **broad range of** transmission-related **benefits** (taking advantage of increasing experience to quantify economic, public policy, reliability, and avoided cost benefits)
3. Account for **uncertainty** by evaluating projects for a range of plausible future scenarios and sensitivities
4. Consider "**least regrets**" planning tools to reduce the risks of an uncertain future (and regrets of having either built or not built transmission)
5. Determine **cost allocation** based on the total benefits for the entire portfolio of projects (to take advantage of more stable and wide-spread benefits for portfolios)

Brattle Group Reports on Transmission Benefit-Cost Analyses Summarize Much of the Available Experience

Well-Planned Electric Transmission Saves Customer Costs:
Improved Transmission Planning is Key to the Transition to a Carbon-Constrained Future

Link: https://bit.ly/3dnKrxe

PREPARED FOR
WIRES

PREPARED BY
Judy W. Chang
Johannes P. Pfeifenberger

May 2016

THE Brattle GROUP

Toward More Effective Transmission Planning:
Addressing the Costs and Risks of an Insufficiently Flexible Electricity Grid

PREPARED FOR
WIRES

PREPARED BY
Johannes P. Pfeifenberger
Judy W. Chang
Akarsh Sheilendranath

April 2015

Link: https://bit.ly/2GU4h7w

The Brattle Group

Link: https://bit.ly/3jS0PsB

The Benefits of Electric Transmission: Identifying and Analyzing the Value of Investments

July 2013

Judy W. Chang
Johannes P. Pfeifenberger
J. Michael Hagerty

Includes recommended approaches to quantify various benefits

Link: https://bit.ly/2KaFLAk

BU
Boston University Institute for Sustainable Energy

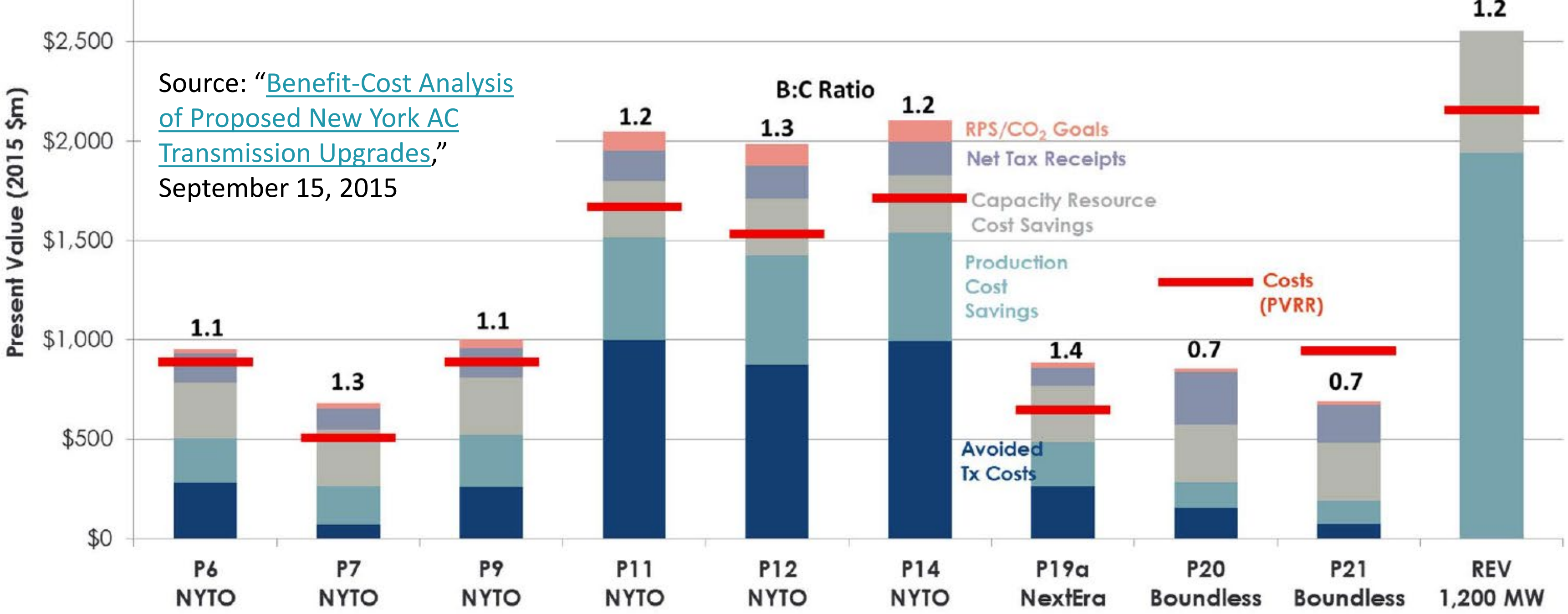
The Value of Diversifying Uncertain Renewable Generation through the Transmission System

September • 2020

Example: New York's (Multi-Value) "Public Policy" Transmission Planning Process

New York DPS recently modified its "public policy" transmission planning process by mandating that a full set of benefits be considered. Resulted in approval and competitive solicitation of two major upgrades to the New York transmission infrastructure

Summary of Quantified Benefits and Costs
(additional benefits considered qualitatively)



Source: "Benefit-Cost Analysis of Proposed New York AC Transmission Upgrades," September 15, 2015

Inadequate Transmission Creates High Risks of Costly Outcomes in both Short- and Long-term

Most transmission planning efforts do not adequately account for short- and long-term risks and uncertainties affecting power markets

- **Short-Term Risks:** transmission planning generally evaluates only “normal” system conditions
  - Planning process typically ignores the high cost of **short-term challenges and extreme market conditions** triggered by high-impact-low-probability ("HILP") events due to weather, transmission outages, fuel supply disruption, or unexpected load changes associated with economic booms/busts
  - Can be addressed through **sensitivities** that capture these short-term challenges
- **Long-Term Risks:** Planning does not adequately consider the full range of long-term scenarios
  - Does not capture the extent to which a less robust and flexible transmission infrastructure will help reduce the **risk of high-costs incurred under different (long-term) future market fundamentals**
  - Can be addressed through improved **scenario planning** that covers the full range of plausible futures

A more flexible and robust grid provides “insurance value” by reducing the risk of high-cost (short- and long-term) outcomes due to inadequate transmission

- Costs of inadequate infrastructure (typically are not quantified) can be much greater than the costs of the transmission investment
- Project may not quite be cost effective in “base case” future but be highly beneficial in 3 out of 5 futures

Insurance Value Example: ATC's Paddock-Rockdale Project

In evaluating the Paddock-Rockdale Project, ATC evaluated seven plausible futures, spanning the range of long-term uncertainties.

- The 40-year PV of customer benefits fell short of the $136 million PV of the project's revenue requirement in the "Slow Growth" future, but exceeded the costs in all other futures
- The net benefits in the other six futures ranged from:
  - $100 million (above cost) under the "High Environmental" future
  - to approx. $400 million under the "Robust Economy" and "High Wisconsin Growth" futures
  - reaching up to approx. $700 million under the "Fuel Supply Disruption" and "High Plant Retirements" futures

Analyses of multiple scenarios of plausible futures documents risk mitigation benefit:

- The estimated benefits can range widely across sets of plausible futures
- The project is beneficial in most (but not all) futures
- Not investing in the $136 million project can leave customers up to $700 million worse off in two of seven plausible futures

Cost-Allocation: A Barrier Even for Clearly-Beneficial Projects

Easiest: develop "needed" regional and local transmission projects that do not involve cost sharing (now majority in many regions)

Harder: regionally share costs of transmission projects "needed" to meet regional reliability standards

- Most TOs strongly prefer recovering costs associated with their own ratebase
- Policy makers reluctant to pay for transmission that benefit other states

Hardest: share costs of transmission projects that provide broad regional economic or public-policy benefits:

- Fundamentally different future views of the world
  - Planners and policy makers may disagree on the outlook of natural gas costs but they agree the cost exists; not so with carbon or other policy-related benefits, which are often ignored
- Large regional projects for clean-energy policies pit states that have policies (often major population centers) against states that don't have such policies (often more remote areas)
- Reluctance to pay for transmission that facilitates out-of-state generation investments with few direct local jobs

Almost impossible: share costs of inter-regional transmission projects

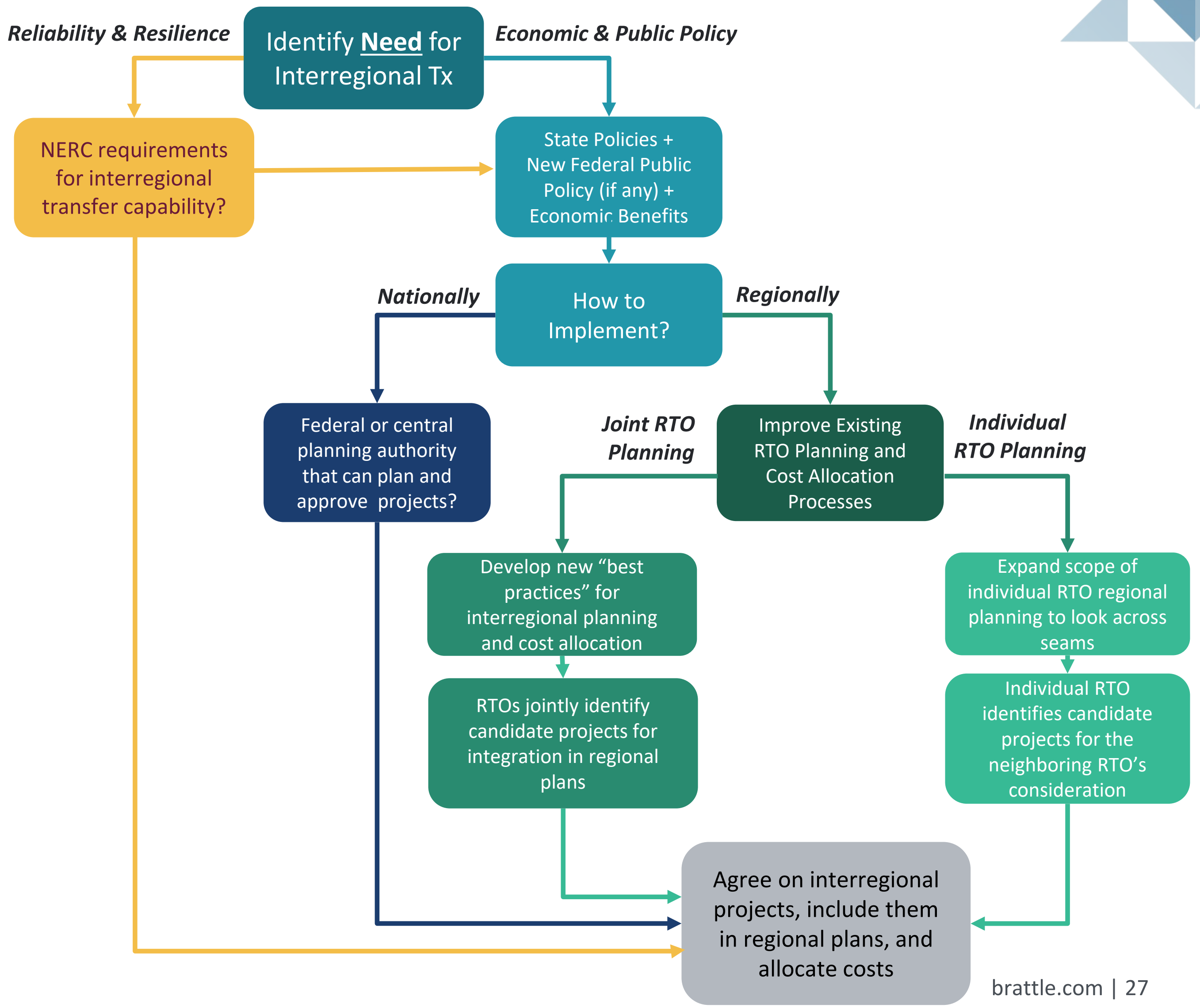
Survey: Barriers to Interregional Transmission

A. Leadership, Trust and Understanding	1. Lack of aligned **leadership** from federal, state & RTO policy makers 2. Mistrust among states, RTOs, utilities, & customers 3. Utilities fear loss of local **control** of transmission 4. Limited **understanding** of transmission issues, benefits & proposed solutions 5. Misaligned interests of RTOs, TOs, generators & policymakers 6. States prioritize **local interests**, such as development of in-state renewables
B. Planning Process and Analytics	**6. Benefit analyses are too narrow**, and often not consistent between regions 7. Lack of proactive planning for a full range of future scenarios 8. Sequencing of local, regional, and interregional planning **9. Cost allocation** (too contentious or overly formulaic)
C. Regulatory Constraints	10. Overly-prescriptive tariffs and joint operating agreements 11. State **need** certification, permitting, and siting

Based on interviews with 18 organizations representing state and federal policy makers, state and federal regulators, transmission planners, transmission developers, industry groups, environmental groups, and large customers

Options for Improving Interregional Planning Processes

- National studies show benefits … but do not create an actionable "need" for RTO and state approvals of projects
- Multiple **paths to establish the need** for and planning of interregional transmission projects based on:
  - the value provided to the electricity system
  - planning process implementation by federal and regional planning authorities
- These paths could be pursued simultaneously, yielding projects through:
  - **New NERC requirements?**
  - **New Federal planning?**
  - **Improved joint RTO planning**
  - **Expanded planning by individual RTOs**



Summary and Recommendations on Planning

Focus less on near-term reliability and local needs, but more on infrastructure that provides greater flexibility and higher long-term value at lower system-wide cost

- Recognize that every transmission project offers multiple values, including reliability and public policy value
- Lowest-cost transmission is not "least cost" from an overall customer-cost perspective

Benefit-cost analyses and cost allocations can be improved to offer more cost-effective and less controversial outcomes:

- More fully consider broad range of reliability, economic, and public-policy benefits, including experience gained though:
  - SPP value of transmission and RCAR benefits metrics
  - NYISO broad set of benefits quantified for public policy projects
  - MISO MVP benefits; CAISO economic and public policy projects
- Reduce divisiveness of cost allocation through broad set of portfolio-based benefits
  - Recognize broad range of benefits → more likely to be evenly distributed and exceed costs
  - Focus on larger portfolios of transmission projects → more uniform distribution of benefits
  - Broad range of benefits for a portfolio will also be more stable over time

Additional Reading on Transmission

Pfeifenberger, Transmission Options for Offshore Wind Generation, NYSERDA offshore wind webinar, May 12, 2021.
Pfeifenberger, Transmission Planning and Benefit-Cost Analyses presented to FERC Staff, April 29, 2021.
Pfeifenberger, New York Power Grid Study: Transmission Implications, presented to NY Bar Association, April 14, 2021.
Tsuchida et al., Unlocking the Queue with Grid Enhancing Technologies, prepared for WATT, February 1, 2021.
Pfeifenberger et al., Initial Report on the New York Power Grid Study, prepared for NYPSC, January 19. 2021.
Pfeifenberger, Transmission Cost Allocation: Principles, Methodologies, and Recommendations, prepared for OMS, Nov 16, 2020.
Pfeifenberger, Ruiz, Van Horn, The Value of Diversifying Uncertain Renewable Generation through the Transmission System, BU-ISE, October 14, 2020.
Pfeifenberger, Newell, Graf and Spokas, Offshore Wind Transmission: An Analysis of Options for New York, prepared for Anbaric, August 2020.
Pfeifenberger, Newell, and Graf, Offshore Transmission in New England: The Benefits of a Better-Planned Grid, prepared for Anbaric, May 2020.
Tsuchida and Ruiz, Innovation in Transmission Operation with Advanced Technologies, T&D World, December 19, 2019.
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Johannes (Hannes) Pfeifenberger, a Principal at The Brattle Group, is an economist with a background in electrical engineering and over twenty-five years of experience in wholesale power market design, renewable energy, electricity storage, and transmission. He also is a Senior Fellow at Boston University's Institute of Sustainable Energy (BU-ISE), a Visiting Scholar at MIT's Center for Energy and Environmental Policy Research (CEEPR), and serves as an advisor to research initiatives by the Lawrence Berkeley National Laboratory's (LBNL's) Energy Analysis and Environmental Impacts Division and the US Department of Energy's (DOE's) Grid Modernization Lab Consortium.

Hannes specializes in transmission and wholesale power markets. He has recent studied New York power grid needs, evaluated offshore wind transmission options in New York State and New England, analyzed the role of renewable generation and transmission in economy-wide decarbonization, and presented renewable integration challenges at a number of industry meetings, including the Atlantic Council and the Harvard Electricity Policy Group.

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John Tsoukalis is a Principal at The Brattle Group with experience assisting clients in across a broad range of issues related to wholesale electric power markets.

John has expertise in analyzing transmission investment opportunities and patterns in the United States. He has helped clients assess the transmission investment landscape and forecast the growth of investment in transmission development over the next 10-15 years. He has experience in electric market modeling, analyzing the benefits of regional market participation, market design, the benefits of transmission infrastructure, detection of market manipulation and damages analyses, and electric sector strategic planning. He has lead efforts to model the power system to assess the benefits of participation in wholesale power markets, value generation assets, and analyze the benefits of new transmission. John has worked with ISOs and RTOs to develop and implement market rules governing capacity auctions, wholesale power markets, ancillary services, and financial energy products. He has helped ISOs and RTOs design market power mitigation regimes and auction clearing mechanics for the markets they administer.

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