ADVANCED CONDUCTORS ON EXISTING TRANSMISSION CORRIDORS TO ACCELERATE LOW COST DECARBONIZATION

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MARCH 2022

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This report was prepared with funding from the American Council on Renewable Energy (ACORE), CTC Global Corporation, Lamifil Inc North America, Natural Resources Defense Council (NRDC), Taihan Electric USA Ltd., and TS Conductor Corporation

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I. EXECUTIVE SUMMARY

The U.S. transmission network needs to meet 21st century challenges with 21st century solutions. Decarbonization and clean energy procurement targets set by states, utilities, and corporations for the not-so-distant future will require high levels of new renewable energy capacity to be quickly and efficiently integrated onto the power grid. The large influx of generation will require an increase in overall system transmission capacity to manage its integration and to alleviate congestion and reliability issues that might arise. While new, large-scale transmission infrastructure will be key to enabling the clean energy transition, regulatory and planning obstacles often delay their construction for years or make the lines entirely impossible to build.

For near-term solutions, we must look to the existing grid. Transmission planning and selection processes, however, have not historically considered solutions that improve the operational efficiency of existing transmission hardware, leaving a significant opportunity to improve the efficiency of existing infrastructure on the table. Further, the existing grid infrastructure is aging. Extrapolating American Electric Power (AEP) transmission data demonstrates that over 200,000 miles of transmission line will need replacement over the next 10 years across North American Electric Reliability Corporation (NERC) regions.[1]

Technology capable of simultaneously addressing both capacity expansion and aging infrastructure needs exists today. Transmission lines that use Advanced Conductors with carbon and/or composite cores, instead of the steel wire cores used for conventional conductors, can carry more capacity while maintaining better performance at higher operating temperatures. As this report will show, these highly efficient Advanced Conductors can provide significant emission reductions, customer savings, and resilience benefits.

1 30% of AEP transmission lines will need replacement over the next 10 years. *See* AEP, "UBS Winter Conference," at 46, January 10, 2022. If we assume 30% of NERC lines (100 kV+) are replaced over the next 10 years, we estimate ~150,000 miles of transmission will be replaced. We increase this estimate by ⅓ as a reasonable approximation of transmission in NERC regions that are 69 kV+.

Reconductoring and rebuilding existing transmission pathways using Advanced Conductors can help accelerate the decarbonization of the power grid by creating a significant amount of new transmission capacity more quickly and more cost-effectively than new, large-scale transmission. Advanced Conductor deployment can also offset some of the upfront total costs associated with infrastructure replacement through the more efficient transfer of electricity compared to traditional conductors. Despite the benefits that Advanced Conductors offer, they are not widely deployed due to outdated transmission planning practices and outmoded economic incentives, among other barriers.

Based on this report's analysis, we find that the incremental capacity generated by deploying Advanced Conductors to address just 25% of aging infrastructure needs in NERC regions can facilitate the interconnection of at least 27 Gigawatts (GW) of zero-carbon generating capacity annually over the next 10 years. We estimate this increase in renewable capacity has the potential to reduce cumulative power sector CO_2 emissions by approximately 2.4 billion metric tons over the 10 year period — the equivalent of cumulative CO_2 emissions over 10 years from approximately 22 coal-fired power plants.[2] During the same period, energy savings from newly created transmission capacity would save consumers at least $140 billion.[3]

Using conclusions drawn from the analysis, as well as a thorough literature review of grid decarbonization reports and initiatives, we recommend the following actions be taken to leverage the benefits of Advanced Conductors. Federal and state officials, as well as transmission planners and owners, should expeditiously adopt the following policies and practices:

- The Federal Energy Regulatory Commission (FERC) should:
    - Specify in its planning rules that when new generation is interconnected, Transmission Service Providers must consider reconductoring and new line solutions with high-efficiency Advanced Conductors for required grid upgrades.
    - Require transmission planners to move to a futures-based planning process to optimize net value by looking to likely future scenarios and where additional renewable energy generation resources will likely be connected to the grid.
    - Direct that energy efficiency should be a design criterion for every transmission project and seek to have the utilities show in their rate requests how energy efficiency was included in project design.
    - Establish "independent transmission monitors" in each region to assess opportunities for greater efficiency and reliability from alternative operations methods or technologies, including Advanced Conductors.

2 Coal-fired power plants in the U.S. emitted an average of 2 million metric tons of CO_2 annually in 2020. *See* EIA, "2020 Carbon Dioxide Emissions at Electric Power Plants," 2020.

3 As we note in section VI.B, these CO_2 emission reductions and consumer savings are likely much higher. This piece of our analysis only considers new transmission capacity generated from the higher operating temperatures of Advanced Conductors, and not from additional capacity from reduced line losses.

- United States Department of Energy (DOE) should:
  - Consider implementing a conductor efficiency and/or resistance-based standard.
  - Establish bold reconductoring targets to accelerate grid decarbonization.
  - Demonstrate commitment to deploying Advanced Conductors by considering them a priority for select Power Marketing Administration (PMA) projects and for other projects which DOE supports via grants, loans, or other financing mechanisms.
  - Collaborate with grid operators and planning authorities to leverage the North American Energy Resilience Model (NAERM), as well as capabilities and tools at the national labs, to identify key corridors for transmission capacity increases (including reconductoring opportunities).
  - Develop a library and set of resources available for the public and electric industry stakeholders on how various transmission technologies can be used, and their market readiness, similar to what the European Network of Transmission System Operators for Electricity (ENTSO-E) provides.[4]
- Transmission planners and owners should:
  - Integrate Advanced Conductor evaluations into all transmission expansion and interconnection plans and studies.
- State regulators should:
  - Require utilities to provide analyses on the opportunities for deploying state-of-the-art transmission technologies, including Advanced Conductors.
  - Shift their evaluations from "least cost" to "maximum net benefits" when reviewing technology options for long term plans.

4 ENTSO-E, "ENTSO-E Technopedia," (n.d.).

THE CURRENT STATE OF THE U.S. GRID AND FUTURE NEEDS

States, utilities, and corporations have adopted a wide range of clean energy targets. 31 states and the District of Columbia, for example, have adopted renewable portfolio standards (RPSs), which have contributed to approximately 50% of the total growth in renewable generation over the last 20 years.[5] Almost all electric utilities in the country have significant decarbonization goals set to phase in over the next couple of decades. In fact, 81% of U.S. customers are served by a utility with a carbon reduction goal.[6] Since 2013, corporations have contracted approximately 43 GW of renewable energy projects through power purchase agreements, green power purchases, green tariffs, or privately-owned projects.[7] Many studies outlining pathways to decarbonize the power sector and U.S. economy find that more physical movement of much more electricity over much longer distances is needed to achieve the fastest, least-cost transition to a zero-carbon future.

In January 2022, the U.S. DOE posted in the Federal Register its "Building a Better Grid" initiative, which is designed to set into motion a huge expansion of the nation's electric grid with upgrades and new transmission lines.[8] In announcing the initiative, DOE stated, "[i]ndependent estimates indicate that we need to expand electricity transmission systems by 60% by 2030, and may need to triple it by 2050."[9] Anyone familiar with the bulk power system recognizes the immensity of this need. The challenges of getting approvals, permits and consensus of who pays for major transmission expansion projects are well known. Due to these challenges, current expansion plans from "business-as-usual" planning processes will be lucky to provide a 10% gain in transmission system capacity in the next 8 years.

5 FERC, "Joint Statement from Chairman Glick & Commissioner Clements on Building Transmission for the Future," July 15, 2021, and EIA, "Five States Updated or Adopted New Clean Energy Standards in 2021," February 1, 2022.

6 Smart Electric Power Alliance, "Utilities' Path to a Carbon-Free Energy System," last accessed February 17, 2022.

7 Clean Energy Buyers Association, "CEBA Deal Tracker," last accessed February 17, 2022.

8 Building a Better Grid Initiative To Upgrade and Expand the Nation's Electric Transmission Grid To Support Resilience, Reliability, and Decarbonization, 87 Fed. Reg. 2769, January 19, 2022.

9 DOE, "DOE Launches New Initiative From President Biden's Bipartisan Infrastructure Law To Modernize National Grid," January 12, 2022.

So, how do we fill the gap? We must get more from the existing electric grid.

A necessary component of the path forward includes the unprecedented deployment of Advanced Transmission Technologies (ATTs), including Advanced Conductors, to better utilize existing assets and leverage the value of current and planned infrastructure. As a recent article in *The Electricity Journal* explained:

> When faced with the need to expand transmission capacity, the first inclination of many transmission planners is to consider new lines. However, there are a number of options that can increase capacity significantly using rights of way. Many of these have the advantage that they face much lower regulatory barriers. Transmission planners would be well advised to give such strategies much more attention as concerns continue to arise about reliability, and as the need to move more power grows as a result of using electrification to reduce the carbon intensity of the economy.[10]

Increasing grid efficiency must be a higher priority when it comes to grid planning and transmission solution selection. The marginal transmission losses in delivery of energy from generators to load centers can be significant. Increasing transmission capacity in constrained areas can lead to significant benefits such as lowering congestion costs and reducing renewable energy curtailment. The project selection process for competitive transmission expansion, however, does not weight transmission efficiency as much as it should. In the Southwest Power Pool (SPP), for example, the Industry Expert Panel that reviews and evaluates proposals submitted in response to Transmission Owner (TO) selection requests for proposal only provides a 2% weighting for transmission efficiency.[11] Traditionally, transmission solutions have been driven by the need to provide reliable service at the lowest cost, and while ATTs like Advanced Conductors have the potential to create a more efficient grid, the project selection process does not consider the full extent of their benefits.

Furthermore, new transmission technology deployment overall has been slow in the U.S. In 2019, DOE recognized that "[t]he U.S. currently lags behind other countries in the deployment of some advanced transmission technologies."[12] A key reason, it continued, is "…the difference in regulatory environments; the U.S. provides transmission owners little incentive to deliver more power over existing lines or to reduce transmission congestion…"[13]

Adoption of new technologies is especially challenging for entities responsible for the safety and security of critical infrastructure like the bulk power system. But the transformation of the electricity sector is well underway. Proven and innovative approaches must be considered and implemented where appropriate to decarbonize the energy system. According to Gretchen Bakke, Ph.D., in her 2016 book, *The Grid*, "[t]he grid will have to be reimagined, it will have to be reinvented, and part of it will have to be rebuilt. This would have happened without the mass introduction of wind and solar power, but these have hastened the realization of the necessity of change."[14]

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10 Liza Reed et al., "Expanding Transmission Capacity: Examples of Regulatory Paths for Five Alternative Strategies," Volume 22, Issue 6, 106770, July 2020.

11 SPP, *Industry Expert Panel Transmission Provider Public Report*, at 13, October 12, 2021.

12 DOE, *Dynamic Line Rating: Report to Congress*, at iv, June 2019.

13 *Id.*

14 Gretchen Bakke, *The Grid: The Fraying Wires Between Americans and Our Energy Future*, Bloomsbury USA, 384, July 7, 2017.

ADVANCED CONDUCTORS: WHAT ARE THEY?

- Aluminum Conductor Steel Reinforced (ACSR) is the most common conductor used in the bulk power system today. The fundamental design of ACSR conductors has changed very little since it was first strung in the early 1900s.
- Aluminum Conductor Steel Supported (ACSS) is designed to operate at much higher temperatures without loss of strength and the sag characteristics associated with ACSR.[15] While ASCR is made from hard drawn aluminum, ACSS uses soft or annealed aluminum and is slightly more efficient. ACSS was introduced in the 1970s and has been used to upgrade existing transmission lines as well as in new construction. ACSS has become the standard design conductor for several utilities.
- Advanced Conductors use composite and/or carbon cores, which better manage thermal sag at high temperatures. The initial composite core Advanced Conductor deployments were generally limited to niche applications such as river crossings and long structure-to-structure installations. More recent composite/carbon core Advanced Conductors have better performance characteristics and ease of installation.

Modern conductors that are built around a composite and/or carbon core and provide higher capacities and lower losses compared to more traditional conductors, like ACSR and ACSS with steel cores, are referred to as "Advanced Conductors." Even though about 200 reconductoring projects using Advanced Conductors have been installed in the U.S.,[16] the majority of recently completed reconductoring projects continue to use ACSR or ACSS conductors, which increase capacity but do not improve grid efficiency. These projects are often implemented on lower voltage 69-138kV facilities, which often become congested when contingency conditions occur on a parallel Extra High Voltage (EHV) path.

Advanced Conductors can operate at higher temperatures than conventional conductors and can do so for an extended period of time with low sag, which allows a tremendous increase in the emergency (above normal or continuous ratings) loading capabilities. Even though the rated operating capacity of a line using an Advanced Conductor might be 40%-65% of the available capacity, Advanced Conductors can

15 The original name was Steel Supported Aluminum Conductor (SSAC).
16 Communications with industry.

double the power density on paths using existing structures, which can be valuable during system emergencies when system operators desperately need capacity to keep the lights on.

The capabilities of Advanced Conductors continue to improve and develop. As an example, some Advanced Conductors have embedded fiber-optic sensors with high resolution monitoring capabilities. The benefits of these newer capabilities are important, but limited in their applications today; however, the expectation is that these improved Advanced Conductors will provide continuous and precise real-time readings throughout the length of the conductor and provide data on temperature, sag, strain from wind and ice loadings, and offer accurate dynamic loading capability. Down the road, that feature, among others that Advanced Conductors can offer, needs to be considered as part of any analysis regarding the value proposition of alternative solutions for existing transmission line upgrades as well as new construction.

IV ADVANCED CONDUCTOR BENEFITS

Advanced Conductors are capable of generating significant consumer savings and carbon emission reductions through their ability to operate the grid more efficiently, integrate more renewables onto the grid, and increase grid resilience.

A. Efficiency

When deployed on existing lines, Advanced Conductors are capable of lowering line losses for lines originally constructed using less efficient conventional conductors. As we explore in our analysis in section VI.A, the incremental capacity generated by Advanced Conductor deployment on existing lines can offer cumulative savings that have the potential to outweigh the upfront costs.

B. Clean energy interconnection

In addition to the newly created capacity created through loss reductions, Advanced Conductor deployment can also provide additional, incremental capacity increases due to expanded power density from high temperature operation. This capacity can be utilized to integrate more, much needed renewable capacity onto the grid. Some Transmission Service Providers have started to consider the use of ATTs, such as advanced power flow control devices, as potential solutions to expedite the commercial operation of renewable projects that have been assigned prohibitively high network upgrades based on traditional study approaches and solution development. It would be helpful for system planners to evaluate the merits and effectiveness of reconductoring overloaded transmission lines with Advanced Conductors as well. The short lead time to reconductor existing lines can help manage risk and uncertainties and significantly increase system capacity to mitigate identified overloads identified in interconnection studies. As we explore further in our analysis in section VI.B, the incremental capacity from deploying Advanced Conductors can generate significant consumer savings and emission reductions.

C. Resilience

The ability to reconductor existing structures or construct new lines with Advanced Conductors provides an effective way to address grid congestion and increase transmission capacity at critical points on the grid. The resilience benefits of a more robust grid are significant. Extreme weather can stress grid operations in ways well beyond any future planning scenario, as demonstrated by Winter Storm Uri and its impact on the Electric Reliability Council of Texas (ERCOT) and surrounding grids in February 2021. Inadequate transmission capacity into ERCOT meant that underutilized generation in other regions could not be delivered, resulting in curtailments of energy transactions and load reductions. Advanced Conductors have much higher loading limits compared to traditional conductors which could accommodate critically important transfers from one or two systems away. The bottlenecks to large interregional transfers can easily be identified in reliability analyses to identify candidate lines where incremental capacity associated with Advanced Conductors can mitigate load loss and support rapid restoration if necessary.

V OPPORTUNITIES FOR ADVANCED CONDUCTORS

There is a widespread opportunity for the industry, as well as state and federal regulators, to upgrade existing grid capacity through reconductoring using Advanced Conductors. Taking advantage of these rebuild opportunities to "right-size" select facilities can serve to interconnect more clean generating resources, replace aged assets with more efficient technology with greater capacity, and support a more resilient future grid. Transmission line rebuilds and newly constructed lines are also important applications for Advanced Conductor deployment.

A. Reconductoring: what is it and how can Advanced Conductors be applied?

Reconductoring is the replacement of a conductor (wire) on an existing transmission or distribution structure. Reconductoring can replace an old line with a new one with the identical conductor technology, or it can utilize different conductor technologies. In many cases, reconductoring is driven by the need to manage congestion and avoid service curtailments that threaten to overload a key transmission element under stressed system conditions. Often the stress is due to an outage on a parallel transmission element or a critical resource in the bulk power system network.

Power flows follow the path of least resistance, determined by the electrical equivalent of friction (impedance), which results in some energy losses to heat in deliveries between sources and sinks (loads) in the network. When older lines were placed in service, transmission planners had no reason to expect the increased loadings that later resulted from the formation of regional markets and the replacement of local generation with more cost-effective but distant resources. Many of the best candidate lines for reconductoring were originally designed to serve local loads with local resources.

A good case study of reconductoring is the 345 kilovolt (kV) outlet for the LaCygne coal-fired station in southeast Kansas. The original project was installed in the mid-1970s using traditional B-954 ACSR conductor, which was prominent for that vintage of Extra High Voltage (EHV) backbone facilities in the Midwest. Reconductoring the LaCygne — Stilwell 345kV line early in the original conductor's life with higher capacity ACSS conductor was highlighted in the 2003 SPP Annual report as a win-win for SPP members and customers. The project resolved a constraint in just four months that would otherwise have required a much more expensive new line and several years of permitting and construction.[17] Similarly, high projected loadings and system security needs drove AEP to reconductor its Lower Rio Grande Valley 345kV double circuit backbone transmission line in 2015.[18] For that reconductor project, Advanced Conductors were installed since they have been proven in other applications and were a cost-effective alternative.

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17 SPP, *Auditors' Report and 03/Financials: Growth While Retiring*, at 7-9, 2003.
18 Power Engineers, "Lower Rio Grande Valley 345 kV Reconductor Project," (n.d.).

A major obstacle to increasing grid capacity through the construction of new transmission is that Rights of Way (ROWs) are scarce and new ones are difficult to establish. Existing transmission ROWs should be seen as valuable assets that are often significantly underutilized. The identification of key corridors for capacity enhancement is a critical step for the development of a least-regrets pathway to a decarbonized future. Reconductoring the large amount of aging infrastructure currently in service today using Advanced Conductors is the perfect place to begin.

An estimated 70% of transmission and distribution (T&D) lines are well into the second half of their 50-year life expectancy, and some lower voltage components are even over 100 years old.[19] PJM Interconnection (PJM) states that two-thirds of all bulk electric system assets on their grid are more than 40 years old and more than one third of their transmission assets are more than 50 years old.[20] Regions like the Western Area Power Administration (WAPA) and Southwestern Power Administration (SWPA), for example, built the backbone grid in the Central U.S. in the 1940s and 1950s to deliver hydro power and interconnect to adjacent systems. Reconductoring aged lines that will be replaced anyway using Advanced Conductors is low hanging fruit. Capitalizing on existing assets provides a unique opportunity in the grid's evolution to install Advanced Conductors to increase system capabilities and lower losses compared to traditional upgrades.

1. Measuring the need for aged asset replacement

TOs have a responsibility and obligation to maintain their equipment to provide reliable service in a safe and effective manner. Regional planning would benefit from the incorporation of expected replacements of aging assets into long-range scenarios to optimize system performance while addressing the need to replace/rebuild key assets to the bulk power network.

AEP is one of the largest TOs in the U.S. AEP shares key data regarding equipment age in quarterly financial reports. In its most recent report, AEP notes that 30% of the existing transmission conductors will reach or exceed an assumed 70-year life expectancy in the next decade. Almost all of that conductor is traditional ACSR design which has been serving the utility industry and bulk power system for the past 100 years.

Figure 1 below shows transmission line life expectancies based on conductor age. As one can see from this graph, the majority of the bulk power system was built in the 1950s and 1960s, which creates a once in a lifetime opportunity to leverage existing structures and ROWs to increase system capability with Advanced Conductors.

19 American Society of Civil Engineers, *2021 Report Card for America's Infrastructure*, Energy, at 46, 2021.
20 PJM, *The Benefits of the PJM Transmission System*, at 5, April 16, 2019.

FIGURE 1. *AEP Transmission Line Age Profile*[21]

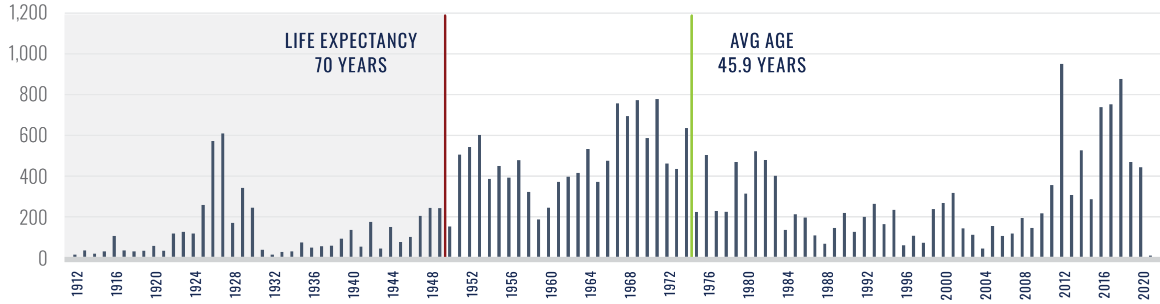


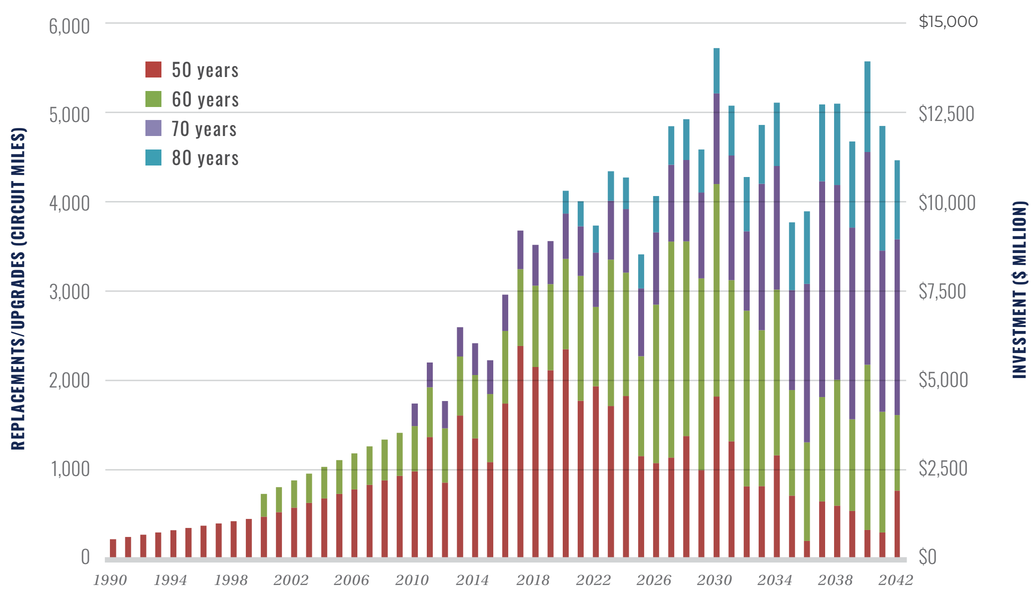
FIGURE 2. *Percent of AEP Transmission System in Need of Replacement*[22]

AEP TRANSMISSION ASSETS	LINE MILES	TRANSFORMERS	CIRCUIT BREAKERS
Life Expectancy (Years)	70	60	50
Current Quantity Over Life Expectancy	6,107	208	808
Quantity That Will Exceed Life Expectancy in Next 10 Years	4,513	165	329
Total Replacement Need Over Next 10 Years	10,620	373	1,137
% of AEP System	30%	30%	12%

In Figure 2, AEP concludes that 30% of its existing transmission lines need replacement over the next 10 years to ensure that conductors do not exceed a life expectancy of 70 years. Extrapolating AEP's conclusions about transmission line rebuilds and replacements of aging conductors suggests an opportunity to consider the deployment of Advanced Conductors in excess of 200,000 miles of transmission facilities across NERC regions over the next 10 years.[23] Other estimates for investment needed in the next decade to replace aging assets include those from the Brattle Group, as shown in Figure 3 below. Brattle Group analysts have estimated that if just one-fourth of historical U.S. transmission investment is replaced after 50-80 years, then approximately $10 billion in annual transmission investment will be needed over the next 20 years to replace, rebuild, or upgrade 80,000 miles of aged transmission assets.[24] If one assumes that 100% of historical transmission investment is replaced after 50-80 years, per the Brattle group analysis, then approximately $40 billion in annual transmission investment will be needed over the next 20 years to replace, rebuild, or upgrade 320,000 miles of aged transmission assets.

21 AEP, "UBS Winter Conference," at 46, January 10, 2022.
22 AEP, "UBS Winter Conference," at 46, January 10, 2022.
23 NERC, "Element Inventory," last accessed February 17, 2022.
24 This analysis assumes ¼ of historical transmission investment is replaced after 50-80 years. *See* Johannes Pfeifenberger and John Tsoukalis, "Transmission Investment Needs and Challenges," at 3, June 1, 2021.

FIGURE 3. *Projected Circuit Miles Replaced/Upgraded and Total Projected Investment ($ million)*[25]



2. Current reconductoring efforts

Despite the clear need for replacements and upgrades over the next few decades, utilities, Independent System Operators (ISOs), and Regional Transmission Organizations (RTOs) have surprisingly few planned reconductoring projects expected to be placed in service before 2030. A look into transmission projects that have been approved through previous regional transmission expansion plans in both the Midcontinent Independent System Operator (MISO) and PJM shows that reconductoring projects constitute 3% and 5% of total approved investment (in each RTO respectively) that are expected to be placed in service in the next 8 years.[26] Figures 4 and 5 below identify approved transmission projects currently in planning or construction phases with an approximated in-service date in 2022 and beyond.[27] Few of these expected projects consider the use of high-efficiency Advanced Conductors.[28]

Figure 4 shows that MISO plans to reconductor a total of 153 miles of existing transmission between 2022 and 2025 at a total cost of $208 million. For reference, the MISO grid is composed of approximately 65,800 miles of transmission.[29] These numbers suggest that in the next few years, MISO plans to reconductor less than a .025% of its network.

25 AEP, *Transmission's Future Today*, at 5, 2015, citing Johannes Pfeifenberger, Judy Chang, and John Tsoukalis, "Dynamics and Opportunities in Transmission Development," December 2, 2014 (assumes circuit mile costs equal to those of new lines).

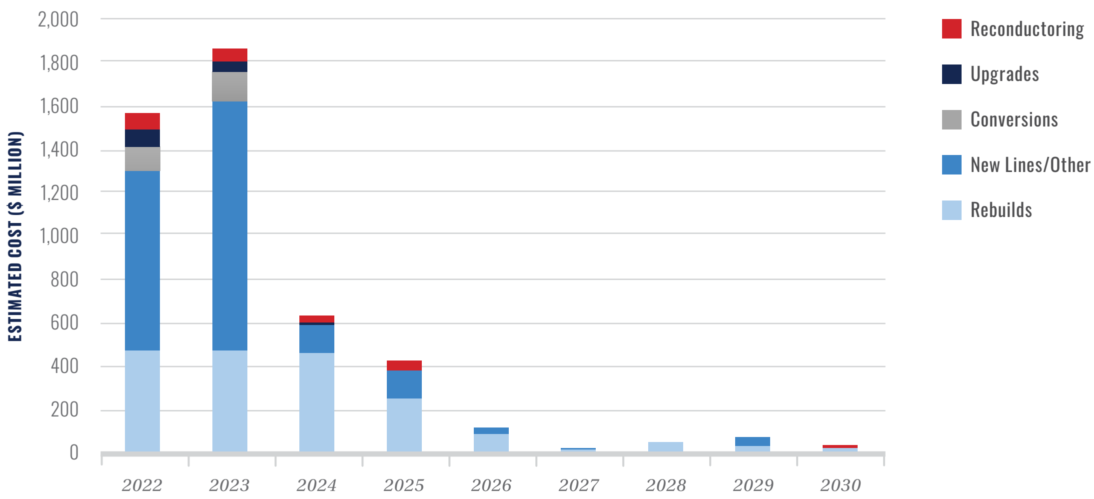
26 MISO, "2021 MTEP appendix A Status Report," 2021, and PJM, "Project Status & Cost Allocation," last accessed February 17, 2021.

27 The data may not be entirely indicative of what can actually be expected in the future beyond the first few years. This is due to the understandable reluctance of TOs to share rebuilds and other upgrades given planning uncertainties beyond the near term and the need to only reflect known commitments in ISO/RTO base planning models.

28 The "rebuild" and "upgrade" categories may capture a small portion of total reconductoring projects, but most reconductoring projects are captured in the "reconductoring" category.

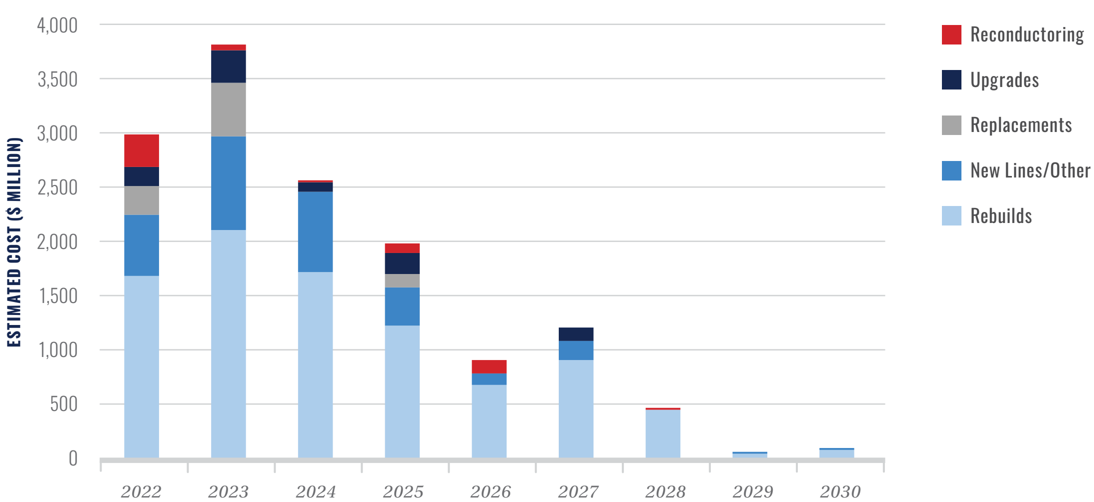
29 MISO, "Corporate Fact Sheet," December 2021.

FIGURE 4. *MISO-Approved Transmission Investment by Project Type and Expected In-Service Year*[30]



The numbers are similar in PJM, as shown in Figure 5. The chart below shows the small red sliver representing reconductoring compared to the other kinds of transmission investment.

FIGURE 5. *PJM-Approved Transmission Investment by Project Type and Expected In-Service Year*[31]



"Business-as-usual" transmission expansion planning does not consider the use of Advanced Conductors to accelerate grid decarbonization or improve transmission operations, and will lead to a lost opportunity unless a different planning approach is adopted. However, transmission planners are starting to recognize the significance of Advanced Conductor benefits. SPP created its Design Best Practices and Performance Criteria Task Force in 2011, which resulted

30 "New Lines/Other" includes investments in both new transmission lines as well as adjustments to existing lines such as relocation or undergrounding. The latter constitute only a small portion of the project category.

31 *Id.*

in the minimum standards for regionally funded lines. The need to focus on grid efficiency was supported by SPP stakeholders when the Task Force suggested that "TOs should consider the application of advanced conductors for reconductoring projects if existing structures are adequate and have sufficient life expectancy to preclude tear down and rebuilds."[32]

B. Advanced Conductors also need to be considered for transmission line rebuilds and new construction alike

Reconductoring aging infrastructure is not the only application of Advanced Conductors, and there are other opportunities to strategically increase grid capacity with this technology. Even newer lines that are frequently congested should be replaced with Advanced Conductors. Additionally, transmission infrastructure can be completely rebuilt with new structures and higher power densities to provide even more capacity. In the case of a total rebuild, using Advanced Conductors from the start can generate more capacity, efficiency, resilience, and reliability benefits than rebuilds using traditional conductors. Advanced Conductors sag less than traditional conductors under the same heat conditions. This allows total rebuilds to use shorter towers and/or longer spans than typically required during a rebuild using traditional conductors. These same benefits can also be realized by considering Advanced Conductors during the construction of entirely new transmission pathways when new ROWs can be established. Using Advanced Conductors in total rebuilds or new line pathways may add approximately 5%-10% to the total project cost; however, the benefits can defray most or all of the upfront costs.

Some new line projects are already considering Advanced Conductors today. For example, the use of Advanced Conductors in lieu of standard ACSR conductors was evaluated as part of the Colorado Public Service Commission's Certificate of Public Convenience and Necessity for the Colorado Power Pathway project. Analysis in that case demonstrated that "...advanced core conductors provided the best long term solution when due consideration was given to changes in line design and the resulting efficiency gains in terms of lower capacity and energy losses on renewable energy deliveries."[33]

C. Lessons from abroad

The U.S. can learn from the use of Advanced Conductors abroad. For example, TenneT, a transmission system operator in the Netherlands and parts of Germany, has used Advanced Conductors in the Netherlands to increase the capacity of existing 380kV double circuit network facilities, which helps support the integration of offshore wind developments in the North Sea.[34,35] With the help of the increased transmission capacity, TenneT has been able to connect 7 GW of offshore wind to the German grid, and will be able to connect an additional 13.5 GW to the Netherland and German grids during the next 4 years.

32 SPP, *Study Estimate Design Guide: Introduction*, July 19, 2011.

33 Testimony of Larry Milosevich, Hearing Exhibit 1700, Proceeding 21A-0096E, filed September 24, 2021.

34 Dave Bryant, "The TenneT DIM-LLS 380kV ACCC® Reconductor Project Continues," November 2, 2021.

35 TenneT, "The North Sea is Becoming the Powerhouse of Northwest Europe — Offshore Wind Energy as a Central Lever for the Energy Transition," January 20, 2021.

Additionally, ENTSO-E highlights best practice applications for High Temperature Low Sag (HTLS) conductors and includes the field testing of several Advanced Conductors in 2014 in Northern Germany.[36] ENTSO-E also outlines the 2017 Best Paths Demo 4 research project led by 50 Hertz Transmission, which focused on innovative repowering of AC corridors.[37] This reconductoring project in Ragow, Germany focused on the need to improve and repower existing power lines and enhance technical knowledge with new conductor technologies among European Transmission Service Operators.

While reconductoring is the most common application for Advanced Conductors world-wide, the energy savings, carbon reduction, and high-capacity flexibility are understood and directly captured by some new line projects. In a grid expansion project in Bangladesh that included a new 230 kV line and a new 400 kV line, the Asian Development Bank (ADB), who financed the project, selected Advanced Conductors "with higher power transmission capacity and lower energy loss in both the 230 kV and 400 kV transmission lines."[38] The project was focused on addressing deficiencies in the transmission system and enhancing the power transfer capacity to the load centers. ADB noted in its recommendations to the Board for financing that the project "will use advanced efficient conductor technology as a cost-effective solution to allow more power transfer at lower energy loss in the new transmission lines."[39] They also noted that due to the low-sag characteristics of Advanced Conductors, the project will "reduce ROW requirements by limiting blow-out clearance for the new transmission corridors."[40]

For this project, ADB estimated that reduced energy losses from the use of the Advanced Conductors would also generate significant CO_2 emission reductions. The ADB, World Bank, and several other multilateral financing institutions have an objective to reduce carbon emissions in the projects they finance. This example demonstrates that ADB was clearly able to meet their objective by using high-efficiency, Advanced Conductors in their new line transmission expansion projects.

36 ENTSO-E, *Technology Factsheets*, at 60-61, 2021.

37 Best Paths, "Demo 4: Innovative Repowering of AC Corridors," (n.d.).

38 Asian Development Bank, *Proposed Loan and Administration of Grants People's Republic of Bangladesh: Southwest Transmission Grid Expansion Project*, July 2018.

39 *Id.*

40 *Id.*

VI ANALYSIS

Advanced Conductors are capable of providing enormous benefits to power grid operations, consumers, and the environment. Subsection VI.A below demonstrates how Advanced Conductor deployment can reduce transmission losses, which creates generation and consumer savings, and subsection VI.B demonstrates how Advanced Conductor deployment can facilitate high levels of renewable resource integration.

A. Advanced Conductor efficiencies from reduced line losses

Widespread Advanced Conductor deployment has the potential to lower transmission losses and introduce generation and consumer cost savings that more than pay for the Advanced Conductor investment. Over the last decade, national-level T&D losses have remained relatively stagnant at just over 5%, with total losses falling by only 2% from 1990 levels.[41] This same general trend can be found at the state-level.[42] T&D losses increase costs to consumers and waste electricity.

The following analysis uses 2020 U.S. Energy Information Administration (EIA) State Electricity Profile data to estimate the generation and cost savings that would arise if all transmission lines in the U.S. were to be reconductored using Advanced Conductors.[43] We assume that (1) Advanced Conductors are only deployed on transmission and not distribution lines, (2) transmission-only (T) losses make up one-third of total T&D losses,[44] (3) Advanced Conductors are capable of reducing T-only losses by 30%, and (4) all T-only lines are eligible for reconductoring.[45]

41 EIA, "United States Electricity Profile 2020," November 4, 2021. See Tab No. 10 in the spreadsheet with "Full data tables 1-17). T&D losses can be calculated by dividing estimated losses by the result of total disposition minus direct use.

42 EIA, "State Electricity Profiles," November 4, 2021. *See* Tab No. 10 in the spreadsheet with "Full data tables 1-17).

43 *Id.*

44 *Id. See* and footnote 41 for how to estimate state and national-level T&D losses. After calculating T&D losses we multiplied values by ⅓ to estimate T-only losses.

45 Note this analysis does not consider terminal equipment constraints.

At the national level, we find Advanced Conductors can prevent annual transmission losses of approximately 21 million megawatt-hours (MWh).[46] Figure 6 below shows a map of state-level generation savings, which range from 1,063 MWh in the District of Columbia to almost 2.5 million MWh in Texas:

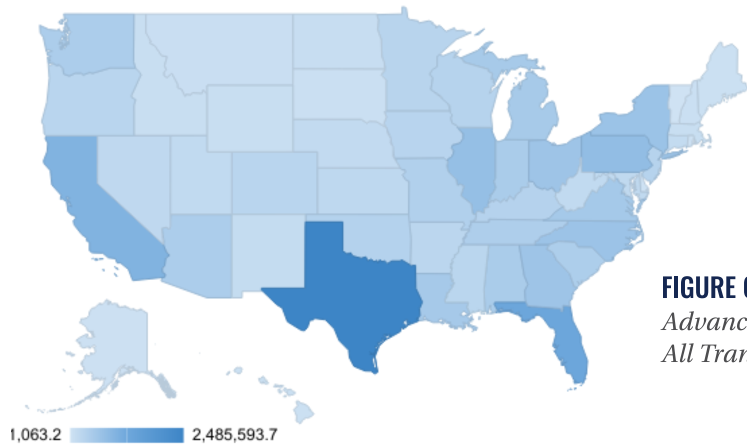


FIGURE 6. *Generation Savings Due to Advanced Conductor Deployment on All Transmission (MWh)*

While energy savings from reduced losses are significant, total net summer capacity savings due to lower demand losses are important too. This conservative analysis shows that the use of Advanced Conductors for reconductoring the existing system would be expected to lower annual total system peak demand by 5.9 GW.[47]

Similarly, at the national level, we find Advanced Conductor deployment can generate over $2.2 billion in annual consumer savings.[48] Figure 7 below shows the range of state-level consumer savings, which ranges up to $208 million annually for Texas:

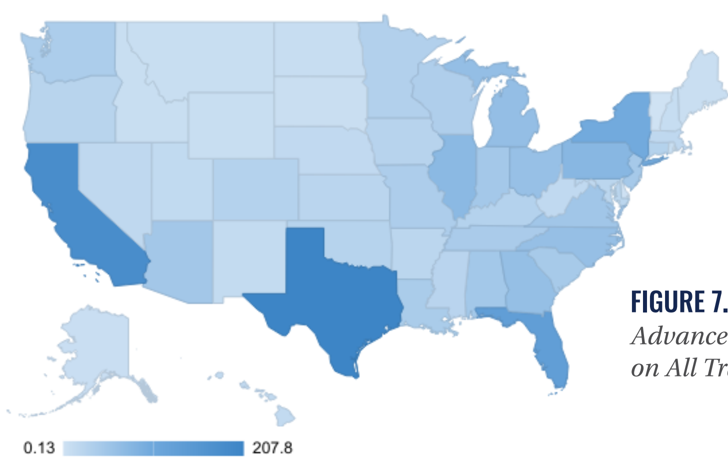


FIGURE 7. *Customer Savings Due to Advanced Conductor Deployment on All Transmission ($ million)*

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46 U.S. net generation in 2020 totaled approximately 4 billion MWhs. *See* EIA, "State Historical Tables for 2020," revised February 2022.

47 Total 2020 net summer capacity in the U.S. totaled approximately 1.1 million MW. *See* EIA, "Existing Nameplate and Net Summer Capacity by Energy Source, Producer Type and State, 1990-2020," 2021.

48 *See* EIA, "State Electricity Profiles," November 4, 2021 for average national and state-level retail rates. In 2020, the national average retail rate was an estimated 10.59 cents/kWh.

The environmental benefits generated from lower line losses due to mass Advanced Conductor deployment would also be substantial. The higher efficiency of Advanced Conductors would serve to displace a portion of the existing fossil resources that would have served those losses, which would reduce CO_2 emissions. To continue our analysis, we use 2020 EIA electric power industry emissions data[49] and the same assumptions above to estimate that reduced transmission line losses due to Advanced Conductor deployment on all eligible T-only lines in the U.S. would reduce power sector CO_2 emissions by 8 million metric tons annually – the equivalent of removing 1.8 million passenger vehicles off the road. [50]

B. Integrating additional renewable resources by reconductoring existing lines using Advanced Conductors

A decarbonized future will ask more of the existing grid than what it can currently provide. A literature review in Appendix A reviews various studies exploring renewable energy futures and ATTs, as well as historical ISO/RTO renewable energy and transmission expansion initiatives. The studies reviewed show that in every conceivable future scenario, transmission capacity will need to increase to facilitate the evolving resource mix. This is because productive, low-cost renewable resources are often located far from load centers. When there is a large amount of transmission capacity available, the grid can draw from resources sited in a geographically broad area and move power back and forth as areas of load and generation change over time. This mitigates the intermittency of renewable output and improves grid operation.

Despite the potential for capacity expansion and efficiency savings, none of the studies considered the benefits of Advanced Conductors. Additionally, historical ISO/RTO transmission expansion initiatives or studies, including the Texas Competitive Renewable Energy Zones (CREZ), SPP Priority Projects, MISO Multi-Value Projects (MVP), and the California Renewable Energy Transmission Initiatives (RETI) predominantly focused on the levels of renewable capacity that could be integrated using new, large-scale transmission. Few studies considered reconductoring during the processes, and if they did, they were assumed to be completed using conventional conductors.

Given this gap in the literature, we ask: what would be the value of using Advanced Conductors on a select group of lines to increase capacity and integrate more renewables into the bulk power system?[51]

We begin with an assumption that 200,000 miles of transmission will need to be replaced across NERC regions over the next decade, as we estimate in section V.A.1. To be conservative, we assume 25% of these projects are reconductored using Advanced Conductors, or 5,000 miles of transmission annually, and that these projects break down into 100 50-mile rebuild projects that are each capable of providing an additional 200 MW of capacity. Reconductoring 5,000 miles of transmission using Advanced Conductors creates 20,000 MW of transmission

49 EIA, "U.S. Electric Power Industry Estimated Emissions by State," revised February 2022.
50 EPA, "Greenhouse Gases Equivalencies Calculator — Calculations and References," (n.d.).
51 Note the savings quantified in this section only relate to the incremental capacity generated by Advanced Conductor higher temperature operation compared to conventional conductors and NOT through the separate, additional capacity generated through line loss reductions.

capacity each year, which can integrate up to 64 million MWh[52] of renewable resource generation, equivalent to roughly 27 GWs of renewable capacity annually, and reduce power sector CO_2 emissions by 44 million metric tons annually.[53] By continuing the reconductoring over the entire 10-year time period, we estimate that cumulative renewable resource generation integration increases to 3.5 billion MWh and cumulative CO_2 emission reductions increase to nearly 2.4 billion metric tons. The 3.5 billion MWh of energy savings from the use of high-efficiency Advanced Conductors would save U.S. consumers about $140 billion or more over the decade.[54]

52 We assume new renewable capacity additions will be composed of 50% onshore wind and 50% utility PV. We also assume a 40% overbuild of wind capacity, a 30% overbuild of solar capacity, and the national-level onshore wind and utility PV capacity factors (CF) of 28.44% and 25.26%, respectively. *See* EPA, "Avoided Emission Rates Generated from AVERT," October 2021.

53 *Id.* We assume the national-level avoided CO_2 emission rate for onshore wind and utility PV are 1,385 lbs/MWh and 1,417 lbs/MWh, respectively.

54 Assuming marginal energy prices are $40/MWh. *See* EIA, "Wholesale Electricity Prices Trended Higher in 2021 Due to Increasing Natural Gas Prices," January 7, 2022.

VII TECHNICAL AND REGULATORY BARRIERS TO DEPLOYING ADVANCED CONDUCTORS

There are many institutional, market, and technical barriers to getting Advanced Conductors considered as part of the transmission planning phase and deployed on the bulk power system. The terms "inertia" and "resistance" are not only electrical properties, but in this case the terms apply to people, organizations, and processes. These barriers include:

- higher upfront costs than traditional conductors;
- efficiencies may be limited by terminal constraints;
- existing planning practices and reliability rules that do not consider Advanced Conductors;
- outmoded economic incentives, including cost recovery for TOs;
- current practices that replace in-kind, and even upsized, conductors with conventionally approved conductors;
- lack of education about the capabilities that new ATTs have when deployed as part of new line designs and retrofits; and
- insufficient regulatory pressure to reconsider and change, as appropriate, past practices.

A. Technical barriers

1. Upfront costs

The material and installation costs for Advanced Conductors are more expensive per foot than conventional conductors. The MISO Cost Estimation Guide for MTEP22, which is currently under review, has added Advanced Conductors with the intention of comparing them to available alternatives (mainly for retrofit and reconductor projects). According to the guide, Advanced Conductor materials costs are approximately 181% higher than ACSR and ACSS, while installation costs are approximately 4% higher.[55,56] However, while the upfront cost is higher, the savings generated by the conductor efficiencies more than offset the cost in a short period of time. Unfortunately, current project selection processes do not fully take into account savings due to efficiencies over the life of the asset. Nonetheless, these savings do exist and should be accounted for in the planning process.

2. Terminal constraints

Reconductoring existing lines with Advanced Conductors provides lower line losses immediately, but may require substation upgrades to significantly increase capacity. Many

55 MISO, *Transmission Cost Estimation Guide for MTEP 22*, at 24, April 2022 (note the final version of this report is forthcoming).

56 For this example, the Advanced Conductor cost premium for the "Bittern" line seems to be over twice the expected premium, according to industry sources. We expect MISO staff and stakeholders to address this in future comments.

existing transmission lines are limited by terminal constraints, which are limits to the capacity of equipment at the ends of the line, such as breakers, switches, protection, and other devices. Where equipment is in series with the transmission conductor and has thermal ratings lower than the conductor, increasing the rating of a conductor does not necessarily increase the capacity that can be delivered across the line. The capacity of substation devices was not a concern when the majority of existing transmission lines were designed and placed in service because anticipated flows were not expected to approach a fraction of the static thermal load ratings associated with the line conductors. These terminal limits were the product of least-cost, prudent utility planning at the time. Initial transmission and substation design specifications are in many cases no longer appropriate and the grid has evolved with time to accommodate new demands and needs. Upgrades to substation equipment may be required to more fully access the capacity made available by the Advanced Conductors.

As an example of limited capacity on terminal equipment, Entergy built its 500kV backbone transmission network in the 1960s with triple bundled ACSR conductor, which can support approximately 3,000 amp flows. But the associated substation equipment for those lines were designed with 2,000 amp breakers because flows on the Ultra High Voltage (UHV) network were not expected to approach the thermal capabilities of the line conductors. Fortunately, many of the major substation components like breakers and switches have since been upgraded to 3,000 amp capabilities due to age and other considerations including projected loadings. Terminal limits are more common on some systems than others based on design philosophy and future use planning considerations. Many approved projects in current expansion plans include the upgrades of terminal equipment to increase line ratings up to the conductor limits.

B. Regulatory incentives

1. State regulators are more likely to approve the "least cost" revenue requirements option

State regulators are more likely to approve the "least cost" revenue requirements option to meet a defined need, rather than to approve paying slightly more to see additional benefits in the long run. None of the benefits afforded by Advanced Conductors are included in a revenue requirements model. A broader, longer-term benefit-cost analysis that focuses on maximizing net benefits would be a better approach than "least cost" revenue requirement planning. In fact, accepting the "least cost" revenue requirement for an ACSR conductor, which has one of the highest conductor resistance values, means that the consumers will be paying higher energy costs for the "wasted" energy (line losses) for the next 40+ years.

As a capital-intensive business, it is no surprise that utilities have historically tended to focus on "least cost planning." Regulators and utilities have historically stressed the need to minimize net present value revenue requirements of expansion options. If energy efficiency benefits over the long term are ignored or heavily discounted, the consumer will realize higher energy costs as a result of approving a lower initial cost solution. Given uncertainties, land use pressures and the need to replace and upgrade a tremendous amount of existing infrastructure in the near term, the need for flexibility and optionality in future transmission expansion plans results in the need to maximize net benefits of all pertinent metrics to provide a least regrets path forward.

C. Business practices

1. Transmission efficiency has not been a priority

Historically, meeting reliability objectives has been a top priority in transmission planning. In past planning cycles without many conductor technology options to choose from, TOs have traditionally chosen the least cost option provided they satisfy such objectives. The efficiency (delivery service per unit of capacity) of conventional conductors do not vary much, so conductor efficiency and benefits have rarely been considered. Even since Advanced Conductors have come to market and these benefits have come to light, the planning approach has remained the same. Given their responsibilities to maintain and operate a safe and reliable power system, system planners are slow to change their processes, but that should not preclude consideration of new solutions with evident system benefits.

VIII RECOMMENDATIONS

There are a number of opportunities at the federal, state, and transmission planning levels to motivate Advanced Conductor deployment. Each of the following recommendations would be valuable as part of a toolkit of policy options, and while there are pros and cons to each, they can all be used to encourage deployment to open up much needed grid capacity.

Recommendations for FERC

1. ***Require Transmission Service Providers to consider Advanced Conductors in generator interconnection planning rules.***

   FERC should specify in its planning rules that when new generation is interconnected, Transmission Service Providers must consider reconductoring and new line solutions utilizing high-efficiency Advanced Conductors for required grid upgrades. Interconnection studies for individual generators or groups of generators often identify costly grid upgrades needed to integrate the capacity onto the grid. Advanced Conductors used in a reconductoring application can assist by increasing transmission capacity to more efficiently integrate new generation, while potentially replacing the need for a more costly rebuild or new line.

   Additionally, in recent years, grid upgrades for location-constrained renewable resources have generally become larger and more expensive as the projects are located in regions far from load centers where resources are the best. Because of this, longer radial lines are sometimes needed to allow capacity to reach the bulk power system. Requiring Transmission Service Providers to consider utilizing Advanced Conductors for radial lines could similarly lead to more efficient integration.

2. ***Require transmission planners to move to a futures-based planning process.***

   A futures-based planning process can optimize net value by taking into account a broad range of plausible long-term future scenarios with assumptions and sensitivities regarding the location and amount of incremental renewable capacity. Requiring a futures-based planning process would allow planners to estimate where solutions like Advanced Conductors would be helpful in accommodating large amounts of new resources in certain areas of the grid, but also would allow planners to foresee where Advanced Conductors might be able to assist in the event of an extreme weather event. FERC action would support increasing grid efficiency with prudent transmission expansion that can be implemented with minimal lead time.

3. ***Direct that energy efficiency should be a design criterion for every transmission project.***

   The transmission solution selection process gives little weight to projects that improve the operational efficiency of the grid. The operational benefits of Advanced Conductors and other ATTs should be taken into account because they are highly efficient. Both planning processes and interconnection plans should determine the best technology to fit a given need. FERC should seek to have utilities show how energy efficiency was included in project design in their rate requests.

4. ***Establish "independent transmission monitors" in each region to assess opportunities for greater efficiency and reliability from alternative operations methods or technologies, including Advanced Conductors.***

   A regional independent transmission monitor would allow for a more thorough consideration of transmission solutions and alternatives without bogging down ISO/RTO interconnection and planning processes. The monitors could review entity compliance with FERC transmission planning rules and could review utility rate requests to ensure transmission solution efficiency is taken into account.

Recommendations for DOE

1. ***DOE conductor efficiency standard.***

   DOE should consider implementing a conductor efficiency and/or a resistance-based standard. These standards would ensure a more efficient starting point for all new projects — both reconductoring and new line projects. Advanced Conductor technologies are proven grid technologies with tens-of-thousands of miles of deployment around the globe, so it makes sense to implement efficiency standards for Advanced Conductors similar to those that currently exist today for other grid assets. For example, manufacturers have been required to comply with DOE energy conservation standards for distribution transformers since 2007.[57] This could serve as a model for a new conductor and resistance-based standard.

2. ***Establish bold reconductoring targets to accelerate grid decarbonization.***

   DOE has historically developed technical targets for new technologies in various industries that have yet to reach widespread commercial deployment.[58] DOE could assess Advanced Conductors in a similar manner. Developing targets for Advanced Conductors could serve to educate TOs and planners about what the costs and specifications of Advanced Conductor technologies might look like in 5-10 year increments. DOE could also take this a step further to assess the potential for Advanced Conductor use in reconductoring applications and establish similar 5-10 year targets in terms of miles reconductored using Advanced Conductors.

57 DOE, "Transmission Transformers," (n.d.).

58 *See*, for example, DOE, "DOE Technical Targets for Polymer Electrolyte Membrane Fuel Cell Components," (n.d.), and DOE, "DOE Technical Targets for Onboard Hydrogen Storage for Light-Duty Vehicles," (n.d.).

3. ***Demonstrate commitment to deploying Advanced Conductors by considering them a priority for select Power Marketing Administration (PMA) projects and for other projects which DOE supports via grants, loans, or other financing mechanisms.***

   Each of the PMAs, except for the Southeastern Power Administration, develop and own transmission. They could utilize Advanced Conductors in any new transmission lines they develop.

4. ***Leverage the North American Energy Resilience Model (NAERM) to identify key corridors for transmission capacity increases (including reconductoring opportunities).***

   In 2019, DOE announced it had initiated the development of NAERM – a "first-of-its-kind" modeling tool capable of providing real-time situational awareness and analysis capabilities to proactively anticipate damage to energy system equipment and outages from extreme events.[59] In addition to identifying the impacts of predicted and real-time events on the grid, NAERM will also be able to recommend mitigation solutions. DOE notes in their announcement that traditional, long-lead-time solutions may be needed in the long term, but new and innovative technologies may complement NAERM.[60] DOE should collaborate with grid operators, planning authorities, and/or national labs to leverage NAERM and identify key areas that would benefit from the deployment of Advanced Conductors.

5. ***Develop a library and set of resources available for the public and electric industry stakeholders on how various transmission technologies can be used, and their market readiness, similar to what the European Network of Transmission System Operators for Electricity (ENTSO-E) provides.[61]***

   Breaking out of "business-as-usual" transmission planning and selection will necessitate more education on the benefits and capabilities of Advanced Conductors. A library dedicated to reports, analyses, and real-world applications of ATTs like Advanced Conductors will help give grid planners a better look into how the efficiencies and savings created by Advanced Conductors can assist in accommodating high levels of renewables capacity.

Recommendations for transmission planners and owners

1. ***Integrate Advanced Conductor evaluations into all transmission expansion and interconnection plans and studies.***

   Transmission planners and owners should consider Advanced Conductors in transmission and interconnection plans regardless of whether FERC requires them to or not. The benefits are substantial, and would free up capacity on systems far quicker than waiting for large-scale transmission approval and construction.

59 DOE, North American Energy Resilience Model, July 2019.
60 *Id.*, at 6.
61 ENTSO-E, "ENTSO-E Technopedia," (n.d.).

Recommendations for state regulators

1. ***Require utilities to provide analyses on the opportunities for deploying state-of-the-art transmission technologies, including Advanced Conductors.***

   State regulators can require or encourage their regulated utilities to deploy Advanced Conductors.

2. ***Shift their evaluations from "least cost" to "maximum net benefits" when reviewing technology options for long term plans.***

   A "least cost" planning approach excludes Advanced Conductors due to their higher upfront costs. The cost savings from Advanced Conductors in the long run; however, more than offset the higher premium. When long term benefits are taken into consideration, the benefits-based approach does, in fact, become the true "least cost" approach.

IX CONCLUSION

It is clear that if utilities, states and the nation are to meet carbon reduction goals, "business as usual" is no longer an option when planning for and expanding transmission grid capacity. Bold new actions are needed to rapidly integrate new renewable generation. This report reviewed a dozen recent studies and grid initiatives, each of which conclude that much more grid capacity is needed to integrate the renewable energy necessary to displace fossil-fueled generating plants. While new, large-scale transmission lines are needed to help integrate renewable generation, other less expensive and fast-to-implement tools for increasing transmission capacity should be fully utilized. Reconductoring existing lines with Advanced Conductors can allow for high levels of renewable integration at a quicker pace, while generating significant savings and emission reduction benefits.

As this report observed, approximately 30% of the existing transmission lines need to be replaced in the next decade due to age and condition. The U.S. should take the opportunity to upgrade, rebuild, and reconductor the existing system with Advanced Conductors. We estimate that using high-efficiency, high-capacity Advanced Conductors to address just one-fourth of that opportunity can enable the annual integration of 27 GW of new renewable capacity over the next 10 years, which would lower cumulative power sector CO_2 emissions by 2.4 billion metric tons over the next 10 years. Energy savings from this newly created transmission capacity would save consumers at least $140 billion over the same time frame.

Advanced Conductors are a necessary technology to meet the challenges of a carbon-free electric grid, and opportunities exist at the federal, state, and transmission planning levels to encourage their deployment and create a more efficient, more flexible, and more resilient grid.

APPENDIX A

LITERATURE AND ACTION REVIEW

Studies:

- *Offshore Wind Transmission Study: Phase 1 Results* (PJM)
- *The Interconnections Seam Study* (National Renewable Energy Laboratory)
- *Just & Reasonable? Transmission Upgrades Charged to Interconnecting Generators Are Delivering System-Wide Benefits* (ICF Resources, LLC for American Council of Renewable Energy)
- *Net-Zero America: Potential Pathways, Infrastructure, and Impacts* (Princeton University)
- *LA100: The Los Angeles 100% Renewable Energy Study* (National Renewable Energy Laboratory)
- *Repowering America: Transmission Investment for Economic Stimulus and Climate Change* (London Economics International LLC for WIRES)
- *Advanced Transmission Technologies* (U.S. DOE)
- *The Future of Electric Power in the United States* (National Academies of Sciences, Engineering, and Medicine)

Initiatives:

- Texas Competitive Renewable Energy Zones (CREZ)
- SPP Priority Projects
- MISO Multi-Value Projects (MVP)
- California Renewable Energy Transmission Initiative (RETI)

A. Studies

Offshore Wind Transmission Study: Phase 1 Results (PJM)[62]

The PJM *Offshore Wind Transmission Study* is a PJM-wide reliability study with the purpose of determining the upgrades to the onshore transmission system necessary to deliver 14,268 MW of announced offshore wind in the PJM region, as well as meet state RPS targets within the PJM footprint. The study focuses on five scenarios ranging from offshore wind injections of 6,416 MW to 17,016 MW, with one short-term scenario modeled through 2027 and the remaining four modeled through 2035.

62 PJM, *Offshore Wind Transmission Study: Phase 1 Results*, October 19, 2021.

When modeling each scenario, PJM identified reliability violations caused by the integration of these renewable resources. While the study does not identify optimal transmission solutions as part of this Phase 1 study, it does estimate upgrade costs required to mitigate each individual reliability violation that was identified. In doing so, PJM used transmission line conductor limits to establish the transmission line overloads and capture the most costly onshore transmission requirements. Where the violation on a transmission line was relatively small, it was assumed that the line could be reconductored and the towers and insulators could be reused. Where the overload was more significant, it was assumed that the transmission line and associated structures would need to be fully rebuilt.

For the five scenarios, the cost estimates to upgrade the existing onshore transmission system were identified to be $627.34 million in the short-term scenario and between $2.16 billion and $3.21 billion for the long-term scenarios. Although this study does not identify the locations and costs of the individual transmission upgrades themselves, the conclusion is clear: achieving high levels of offshore wind integration and meeting RPS targets requires transmission grid upgrades, including extensive transmission reconductoring.

The Interconnections Seam Study (National Renewable Energy Laboratory)[63]

The *Interconnections Seam Study*, conducted by the National Renewable Energy Laboratory (NREL), analyzes the costs and benefits of optimized nationwide transmission expansion modeled between 2024-2038. The study develops four transmission designs with various levels of increased transmission capacity aimed at increasing electricity transfer between the Eastern and Western interconnections under eight scenarios with different assumptions regarding transmission costs, renewable generation levels, wind and solar costs, gas prices, and generator retirements.

The grid designs assessed are as follows: Design 1 (D1) — existing B2B facilities are maintained at their 2017 capacity; Design 2a (D2a) — existing B2B facilities are allowed to expand in the optimization, Design 2b (D2b) — three HVDC transmission segments (along with the expansion of the B2Bs) are built between the EI and WI; and Design 3 (D3) — a national-scale HVDC transmission network is built.

Study results show that with increased intercontinental transmission, the system was able to balance generation and load with less total system installed capacity across each of the generation scenarios due to load and generation diversity and increased operating flexibility. Increased transmission capacity also allowed for the integration of a 40% variable generation mix, composed of wind and solar generation, which generated a benefit-to-cost ratio of 2.9 – the highest of the scenarios studied. More grid capacity means more renewable generation can and will be interconnected, and thus further reductions in carbon emissions can be achieved by a displacement of fossil fuels.

63 NREL, "Interconnections Seam Study," 2021.

***Just & Reasonable? Transmission Upgrades Charged to Interconnecting Generators Are Delivering System-Wide Benefits* (ICF Resources, LLC for American Council of Renewable Energy)**[64]

This report evaluates the regional economic benefits of transmission network upgrades required by increased generation interconnection requests in MISO and SPP footprints. As noted in the report, over 92% of the 79 GW of active requests in the MISO generation interconnection queue and over 95% of the 103 GW of active queue requests in SPP are composed of solar, wind, and hybrid resources.[65] As renewable generation is projected to increase in coming years due to clean energy goals and declining costs, the report aims to identify transmission upgrades necessary to achieve 3 future scenarios with varying levels of renewable integration in the MISO and SPP regions.

Key findings include the identification and cost-benefit analyses of 12 network upgrades in MISO and SPP designed primarily to interconnect generation resources. These upgrades were picked from MISO's Definitive Planning Phase (DPP) reports published for all cycles from 2016 onwards and SPP's Definitive Interconnection System Impact Study (DISIS) reports published for all clusters from 2014 onwards to come up with an initial list of network upgrades that could be evaluated.

In calculating the Adjusted Production Cost (APC) savings aspect of the cost-benefit analyses for each upgrade, the authors note that higher generation capacity was not the only driver of savings. They emphasize another important factor affecting observed levels of APC savings are the upgrades in locations with frequent and persistent congestion. These upgrades provided benefits even with a relatively lower percentage of associated generation interconnection projects. The report concludes that the cost of transmission network upgrades in MISO and SPP have become a significant hurdle for the integration of low-cost new renewable generation, which is needed to decarbonize the electric grid.

***Net-Zero America: Potential Pathways, Infrastructure, and Impacts* (Princeton University)**[66]

Net-Zero America outlines five energy system pathways the U.S. can potentially choose to reach net-zero emissions by the year 2050. Each of the pathways, which range in terms of end-use electrification and renewable energy penetration levels, contains different configurations of transmission expansion and rebuilds (alongside other priority actions by 2030) necessary to achieve decarbonization goals by 2050.

The report provides capacity and cost estimates of new transmission modeled for three of the five pathways through 2050. In their analysis, the authors find that new transmission needed in scenarios that consider a high electrification future, assume base siting availability, and include varying levels of renewable penetration are estimated to represent between 151,600 GW-km and 1,309,000 GW-km of cumulative transmission capacity built through 2050. The increase in grid capacity is accompanied by a price tag of between $945 billion and $3.5 trillion over the

64 ICF, *Just & Reasonable? Transmission Upgrades Charged to Interconnecting Generators Are Delivering System-Wide Benefits*, September 9, 2021.

65 The MISO queue as of August 18th, 2021 did not include projects from DPP-2021 queue. The SPP queue as of August 19th, 2021 includes projects proposed in DISIS-2021 cluster.

66 Eric Larson et al., *Net-Zero America: Potential Pathways, Infrastructure, and Impacts*, December 15, 2020.

same time frame. By 2030 alone, transmission expansion in most scenarios will facilitate up to 4 times the amount of wind and solar generation capacity currently available, which could supply roughly half of all U.S. electricity demand. The use of Advanced Conductors to expand grid capacity through reconductoring and rebuilding was not considered in this *Net-Zero America* study.

Apart from demonstrating a clear need for increased transmission capacity to reach a decarbonized future, it is also important to note that Princeton's analysis also compares a high electrification scenario with base siting availability to a high electrification scenario with constrained siting availability. Without base siting availability, the cumulative costs of building new transmission rises by 11%.

LA100: The Los Angeles 100% Renewable Energy Study **(National Renewable Energy Laboratory)[67]**

The *LA100* develops pathways to allow for the City of Los Angeles to reach a 100% clean energy future and inform the City of LA, the Los Angeles Department of Water and Power (LADWP), and other stakeholders of key opportunities and challenges. The four scenarios assessed are as follows:

1. California Senate Bill SB100: requires zero-carbon resources to supply 100 percent of electric retail sales to end-use customers by 2045 and allows for transmission upgrades. Allows up to 10% of the target to be natural gas offset by renewable electricity credits,
2. Transmission Focus: 100% clean energy by 2045 and can build new transmission corridors.
3. Early & No Biofuels: 100% clean energy by 2035 and allows transmission upgrades.
4. Limited New Transmission: 100% clean energy by 2045 and is the only scenario to not allow upgrades beyond currently planned projects.

While not all scenarios allow expansion of the transmission network beyond currently planned upgrades, all scenarios that allow such expansion upgrade the system within the LA Basin. Some scenarios allow for both upgrades within the Basin as well as upgrades outside of the LA basin to provide further access to out-of-basin geothermal, wind, and solar and increased injection into the periphery of the LADWP network. These out-of-basin upgrades, however, may include purchasing transmission rights or physically upgrading the lines. The Transmission Focus scenario is the only scenario that can specifically construct new lines to access generation outside of the Basin to bring directly into the Basin (~1,700 MW of new transmission).

Under a moderate energy efficiency and electricity demand growth sensitivity, transmission upgrades, which include both new transmission as well as rebuilds and reconductoring, hover between 10,000 MW and 20,000 MW of cumulative transmission capacity added through 2045.[68] The Transmission Focus scenario, however, adds approximately 30,000 MW of new capacity due to its ability to build new corridors. For reference, the moderate sensitivity's

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67 NREL, *LA100: The Los Angeles 100% Renewable Energy Study*, March 2021.
68 NREL, *LA100: The Los Angeles 100% Renewable Energy Study*, Chapter 6. Renewable Energy Investments and Operations, at 48, March 2021.

estimates of LADWP peak demand ranges from 6,020 MW in 2020 to 7,811 MW in 2045.[69]

Consistent with current LADWP operations, out-of-basin generation continues to make up the majority of total energy needs to meet load. As modeled by the report, reconductoring plays a large role in increasing transmission expansion to allow for more out-of-basin generation.

Repowering America: Transmission Investment for Economic Stimulus and Climate Change (London Economics International LLC for WIRES)[70]

Repowering America looks to the electric industry for opportunities that could lead to economic stimulus to combat the residual economic shocks of the COVID-19 pandemic. Specifically, the report focuses on federal policies and economic stimulus measures that could be utilized to support planned transmission investment and encourage transmission expansion to reach environmental policy goals. These projects will not only serve to bolster decarbonization efforts by interconnecting more renewables and reducing congestion and curtailment, but will also increase construction-related spending and support new construction and technical jobs.

The report recommends the following regulatory and economic stimulus measures to encourage investment:

- Improve planning processes;
- Refine pricing and cost allocation policies;
- Reduce siting and permitting delays;
- Financial measures to complement regulatory reforms; and
- Incentives to encourage private investment.

The authors stress that despite the benefits of introducing such measures, the construction of new transmission itself remains a challenge. They state, "[t]he main challenges have been institutional barriers around securing customer commitments and/or allocation of costs, regulatory approval for siting, and conflicting and unclear planning frameworks. In addition, the financial environment for investors specifically in relation to ROE policies, has also been in flux."[71]

Advanced Transmission Technologies (U.S. DOE)[72]

In this report, the U.S. DOE recognizes the ability of ATTs to improve efficiency and effectiveness of electricity delivery, and their ability to increase the reliability and resilience of the system. The authors conclude that a full suite of tools must be used to address transmission challenges, rather than simply transmission expansion alone.

Apart from other Grid Enhancing Technologies like Dynamic Line Ratings, Topology Optimization, and Power Flow Controllers, the report also addresses the opportunities and barriers to deploying advanced conductors and superconducting technologies. Opportunities for advanced conductors include their ability to increase the capacity of existing transmission

69 NREL, *LA100: The Los Angeles 100% Renewable Energy Study*, Chapter 3. Electricity Demand Projections, at 226, March 2021.
70 London Economics International LLC, *Repowering America: Transmission Investment for Economic Stimulus and Climate Change*, May 2021.
71 *Id.*, at 5.
72 DOE, *Advanced Transmission Technologies*, December 2020.

lines while using existing towers and ROWs, their lower costs compared to new transmission expansion, and their ability to lower total project costs of new lines as reduced weight and sag means fewer or less robust towers are needed. Additionally, advanced conductors exhibit 25%-40% lower electrical losses compared to conventional conductors, which reduce operating costs. Advanced conductors are also better at withstanding stress from extreme weather events and, in the event of nearby contingencies, are more capable of delivering higher amounts of power than conventional conductors would allow. The composite core does not expand like steel cores, so they pose less risk of sagging close to vegetation which can cause the lines to trip. Advanced conductors are recognized for their ability to improve the resilience as well as the reliability of the electric grid.

DOE states the barriers to deploying advanced conductors include limited need for them in the event of a low electric growth rate future and the fact that implementation can introduce greater complexity due to new material properties and designs.

The Future of Electric Power in the United States (National Academies of Sciences, Engineering, and Medicine)[73]

This report is the most recent in a series of consensus report studies related to key power sector issues, which focuses on the main social, technical, and economic drivers that will alter the landscape of the U.S. Power System. Through identifying these key elements, the authors identify five broad needs and specific committee actions for each. The five needs include:

1. Improve our understanding of how the system is evolving.
2. Ensure that electricity service remains clean and sustainable, and reliable and resilient.
3. Improve understanding of how people use electricity and sustain the "social compact" to keep electricity affordable and equitable in the face of profound technological changes.
4. Facilitate innovations in technology, policy, and business models relevant to the power system.
5. Accelerate innovations in technology in the face of shifting global supply chains and the influx of disruptive technologies.

Meeting these needs requires an entire toolkit of grid technologies, new transmission, standards, and incentives, and no one approach will be able to address all drivers – the most daunting of which revolves around efforts to decarbonize the U.S. economy. The report does, however, point specifically to technologies and legal and regulatory developments that hold the potential to change how much transmission capacity would be able to expand over the next 30 years.[74] Among these developments with potential they include: "...reconductoring existing high-voltage, alternating current (HVAC) lines with new, more efficient conductors so that the same line can carry more power..."[75]

73 National Academies of Sciences, Engineering, and Medicine, *The Future of Electric Power in the United States*, The National Academies Press, 2021.
74 *Id.*, table 2.A.2., at 87.
75 *Id.*, at 63.

B. Initiatives

Texas Competitive Renewable Energy Zones (CREZ)

In 2005, the Texas legislature passed a bill ordering the Public Utility Commission of Texas (PUCT), in consultation with ERCOT, to develop a transmission plan connecting western Texas' sparsely populated wind-rich areas to load centers. The infrastructure plan that the PUCT ultimately selected consisted of approximately 3,600 miles of new 345 kV line capable of accommodating 18.5 GW of previously untapped wind resources. After completion in 2013-2014 at a total cost of $6.8 billion, wind curtailment fell from a previous high of 17% to 0.5%.[76] After the completion of the lines, Texas was able to surpass their 18.5 GW wind target, and was later able to utilize the CREZ lines to integrate newly constructed solar capacity in West Texas. CREZ lines were ultimately able to integrate as much renewable energy capacity as they were planned for.

Irby Construction Company provided transmission construction services for five of the ten Transmission Service Providers tasked with erecting the lines,[77] and constructed approximately 1,000 miles of line.[78] According to Irby, the conductors used for all 1,000 miles of line were ACSS Trapezoidal Wire.[79] Oncor, another Transmission Service Provider tasked with CREZ construction, used ACSS conductors for at least a portion of their lines.[80]

SPP Priority Projects

In 2009, SPP was sent a series of recommendations by the Synergistic Planning Project Team for creating a more flexible grid capable of meeting future needs. The SPP Board of Directors directed SPP to implement such recommendations, one of which included the construction of Priority Projects – large-scale transmission lines designed to improve the system by reducing congestion and better interconnecting SPP's eastern and western regions.

The final board approved plan consisted of one 138 kV and five 345 kV transmission lines designed to integrate a total of 3.2 GW of wind energy, as well as non-renewable capacity.[81] The total estimated engineering and construction of the lines totaled $1.11 billion and estimated benefit-to-cost ratio was calculated to be 1.78 due to large APC savings. According to SPP, each of the six lines were designed using ACSR or ACSS conductors.[82]

MISO Multi-Value Projects (MVP)

MISO MVP transmission lines grew out of a 2010 proactive planning effort called the Regional Generation Outlet Study (RGOS), [83] an effort which began by identifying beneficial, "no-regrets"

76 Jeff Billo, "The Texas Competitive Renewable Energy Zone Process," at 22, September 2017.

77 The five transmission service providers include: Electric Transmission Texas, Lower Colorado River Authority, Lone Star Transmission, Sharyland Utilities, and the South Texas Electric Cooperative.

78 Irby Construction, "CREZ 345kV Transmission Line Construction Projects," (n.d.).

79 Communications with Irby Construction.

80 FERC, *FERC Form No. 1: Annual Report of Major Electric Utilities, Licensees and Others and Supplemental Form 3-Q: Quarterly Financial Report*, Oncor Electric Delivery Company LLC, at 422.4-423.4 at line 1, 2020.

81 SPP, *SPP Priority Projects Phase II Final Report*, at 5-6, April 27, 2010.

82 *Id.*, at 45-47.

83 MISO, *RGOS: RGOS: Regional Generation Outlet Study*, November 19, 2010.

transmission projects in the region to help member states reach RPS goals. What began as a study evolved into a value-based transmission planning process for regional transmission solutions that meet at least one of the following goals: (1) reliably and economically enable regional public policy needs, (2) provide multiple types of regional economic value, or (3) provide a combination of regional reliability and economic value.[84]

The first portfolio of 17 MVP transmission lines, which was approved in 2011, has almost entirely been placed in service at a total cost of $6.7 billion.[85] The portfolio of new lines was designed to interconnect almost 16 GW of wind in the region and is estimated to generate between $12.1 and $52.6 in net benefits over the next 20-40 years.[86]

Of the TOs required to submit annual FERC form 1 filings, we were able to identify the types of conductors used for MVPs constructed within the footprints for a handful of them, including MidAmerican Energy Company, American Transmission Company, Ameren Corporation, and Northern Indiana Public Service Company. All lines identified through Form 1s were constructed with either ACSR and ACSS conductors.[87]

In addition to new lines, 2011 MVPs also included a fair amount of upgrades required to interconnect the large amount of new transmission. Included in these upgrades were approximately 60 miles of reconductored lines; however, it is hard to say what types of conductors were used for the projects.[88] Using the evidence found above, it would be reasonable to assume that these projects too would have used ACSR and ACSS.

California Renewable Energy Transmission Initiative (RETI)

The California RETI 1.0, initiated in 2007, was stakeholder processes charged with developing a conceptual transmission plan to access newly identified competitive renewable energy zones to meet California's RPS and other clean energy targets. The first phase of the RETI was assessed assuming a 33% renewables by 2020 goal, while a more recent RETI 2.0, initiated in 2015, revisited the process with new goals – a 50% RPS and a 40% statewide greenhouse gas emission reduction from 1990 levels by 2030.

1. RETI 1.0

The new, conceptual transmission lines identified in RETI 1.0 were not only selected to integrate renewables from designated renewable energy zones to meet a 33% RPS, but also selected to meet expected future demand growth. The specific assumptions used to develop the transmission plan included the following: "1) provide access for approximately 100,000 GWh/

84 MISO, "Multi-Value Projects (MVPs)," (n.d.).

85 MISO, "Regionally Cost Allocated Project Reporting Analysis: 2011 MVP Portfolio Analysis Report," January 2022.

86 MISO, *MTEP17 MVP Triennial Review*, September 2017.

87 FERC, *FERC Form No. 1: Annual Report of Major Electric Utilities, Licensees and Others and Supplemental Form 3-Q: Quarterly Financial Report*, MidAmerican Energy Company, at 422.1-423.1, 2019, FERC, *FERC Form No. 1: Annual Report of Major Electric Utilities, Licensees and Others and Supplemental Form 3-Q: Quarterly Financial Report*, American Transmission Company LLC, at 422-423, 2020, FERC, *FERC Form No. 1: Annual Report of Major Electric Utilities, Licensees and Others and Supplemental Form 3-Q: Quarterly Financial Report*, Ameren Illinois Company, at 422.4-423.4, 2020, FERC, *FERC Form No. 1: Annual Report of Major Electric Utilities, Licensees and Others and Supplemental Form 3-Q: Quarterly Financial Report*, Ameren Transmission Company of Illinois, at 422-423, 2019, FERC, *FERC Form No. 1: Annual Report of Major Electric Utilities, Licensees and Others and Supplemental Form 3-Q: Quarterly Financial Report*, Northern Indiana Public Service Company LLC, at 422-423, 2020, and FERC, *FERC Form No. 1: Annual Report of Major Electric Utilities, Licensees and Others and Supplemental Form 3-Q: Quarterly Financial Report*, Ameren Transmission Company LLC, at 433.1-433.1, 2020.

88 MISO, *Multi Value Project Portfolio: Results and Analyses*, at 27-39, January 10, 2012.

year of renewable energy (160% of the target for new renewable energy in 2020); 2) include some level of access to all CREZ; and 3) provide for import of approximately 15,000 GWh/year of renewable energy from out of state resources."[89] In the end, the initiative modeled lines capable of delivering 91,506 GWh of renewable generation at a total cost of $5.9 billion.

While RETI 1.0 did not determine the extent to which the existing grid could accommodate new renewable generation, the authors did specify that situations where existing lines could simply be reconductored or upgraded with new towers were identified before new line solutions were selected. Indeed, RETI 1.0 assumes 163 miles of existing transmission to be reconductored in the conceptual plan[90]

Since most new line segments in the plan did not take into account geographic routings, the lines were assumed to be located in existing transmission ROW or parallel existing transmission line ROW. Additionally, the initiative focused primarily on in-state renewables, and did not extend their analysis to evaluate solutions to assist in easing any congestion or curtailment issues from a large influx of out-of state renewable generation integration. RETI line segment costs were based on a generic set of standardized unit cost factors that include costs of existing line tear down, new line construction, line reconductoring, and line termination at a fixed value of 25% for all line segments.

2. RETI 2.0

RETI 2.0 sought to update the insights of RETI 1.0 with new and updated RPS levels and climate targets. Similar to RETI 1.0, RETI 2.0 also developed conceptual transmission that would be needed to meet higher levels of renewable capacity. In particular, the final report identified key transmission constraints in California and along major import-export paths that could hinder the interconnection of new resources.

One interesting takeaway from this updated initiative is that the authors found that as a whole, there was sufficient existing available transmission capacity to interconnect and deliver a substantial amount of new renewable generation in many areas.[91] Despite the additional need for new transmission, the authors explain, existing transmission could address many of the constraints identified in the report with the help of advanced technologies and non-wire alternatives. At multiple points in the report, the authors specifically point to advanced conductors as a key advanced technology that could be utilized to leverage existing transmission.[92]

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89 RETI Stakeholder Steering Committee, *Renewable Energy Transmission Initiative: Phase 2A*, at 1-11, August 2009.
90 *Id.*, Appendix I at I-42.
91 California Natural Resources Agency, CPUC, CEC, and CAISO, *Renewable Energy Transmission Initiative 2.0 Plenary Report*, at 58, February 23, 2017.
92 *Id.*, at 8, 40, 46, 48, and 57.