UNLOCKING THE GRID:

A Playbook on High Performance Conductors for State and Regional Regulators and Policymakers

AMP COALITION

Grid Strategies

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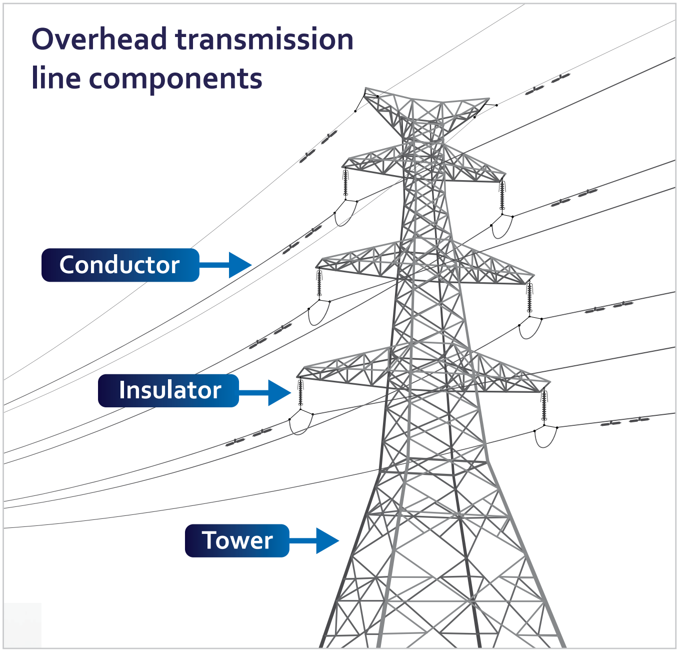
Technology Description

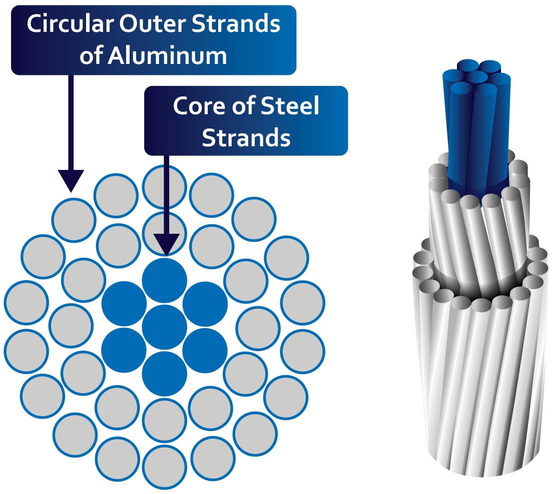
What is a Transmission Line?

Power lines are the physical wires that deliver electricity from generators to customers. They are typically composed of two parts, a core, which provides the strength for the line to hang between transmission towers, and the electrical wire, which carries the electricity.

Overhead transmission line components



Cross section of aluminum-conductor steel-reinforced (ACSR) conductor



What are High Performance Conductors?

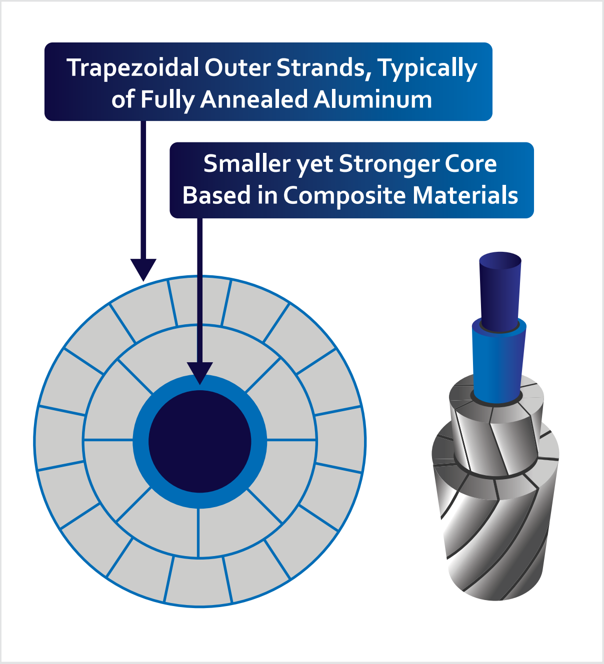
High Performance Conductors (HPCs) is a term that encompasses modern conductor technologies which have greater performance characteristics when compared to traditional aluminum-conductor steel-reinforced (ACSR) conductors, including increased capacity, higher efficiency, and less thermal sag.

For 100 years, power lines have used ***ACSR conductors***, which are often still the default conductor choice. The electricity flows through the aluminum and heats the line over time because of resistance in the metal. The steel core keeps the line strong, but with enough heat the line will soften and start to sag. This effect limits the amount of electricity a line can safely transmit.

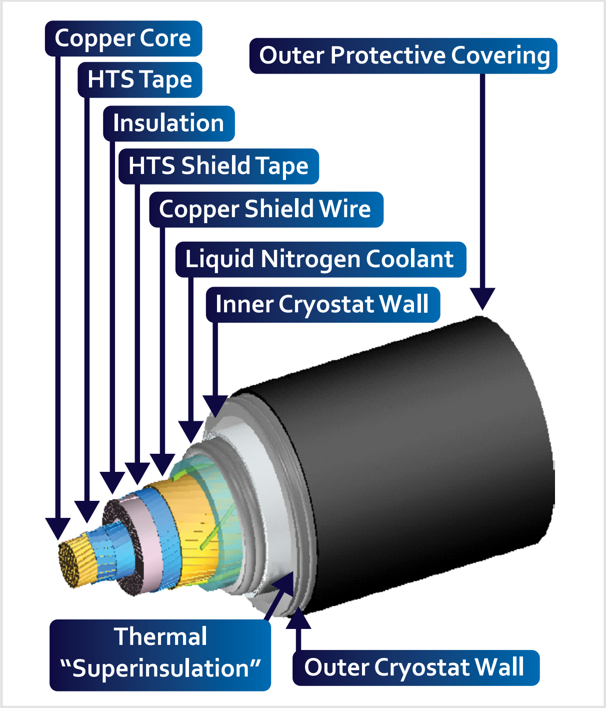
The Two Main Types of HPCs

Carbon and Composite Core Conductors	Superconductors
Carbon and Composite Core Conductors, also known as Advanced Conductors or High-Temperature, Low-Sag (HTLS), are overhead, bare conductors that use a trapezoid shaped wire of annealed aluminum to carry electrical current and use a carbon or composite core for support. Used commercially for 20 years, the conductors are deployed in over 60 countries across 5 continents. **Carbon and composite core conductors have three key advantages over traditional (ACSR) conductors:** • Have stronger and lighter weight cores, which allows for more aluminum to be added to the conductor, doubling the capacity. • Are 20% or more efficient. • Have half as much thermal sag.	***Superconductors*** use a class of metallic compounds that exhibit negligible resistance when cooled using liquid nitrogen, enabling very low losses and very high power-flow capacities. Developed in the 1980s, countries in Europe and Asia, as well as the U.S., have installed superconductors over the past 20 years. **Superconductors have three key advantages over traditional (ACSR) conductors:** • Increase capacity 5-10 times (AC vs. DC line) at lower voltages, reducing substation build and cost. • Have no thermal sag and line sag does not vary with ambient weather conditions or exposure to elements. • Are at least 50% more energy efficient than ACSR conductors.

Cross section of Carbon/Composite Core Conductor



Superconducting Cable



Reconductoring and Rebuilding 101

What is Reconductoring and Rebuilding?

Transmission lines have a finite life expectancy and over time require replacement for several reasons, including age, extreme weather events, or changes in use or need of the line, such as new load growth. One of the most common reasons for replacement is simply wear and tear of a transmission line due to age. The expected useful lifespan of a conductor is typically 50 to 70 years.

Reconductoring is the act of replacing an old conductor with a new one, often reusing the original tower and right-of-way. Simultaneous replacement of aged transmission towers, other infrastructure, or terminal equipment due to changes in use or need of the line are considered a "rebuild." Reconductoring and rebuilding transmission lines are usually routine utility processes, but they can be complex. The process usually begins with inspection of the existing infrastructure to determine if existing structures are suitable for reuse. After inspection, a plan is made for the reconductor or rebuild, and new conductors are installed along with any other infrastructure as needed, such as new transmission towers or terminal equipment. After the new conductor is installed, additional testing is required to ensure the new conductor will meet all safety and reliability requirements.

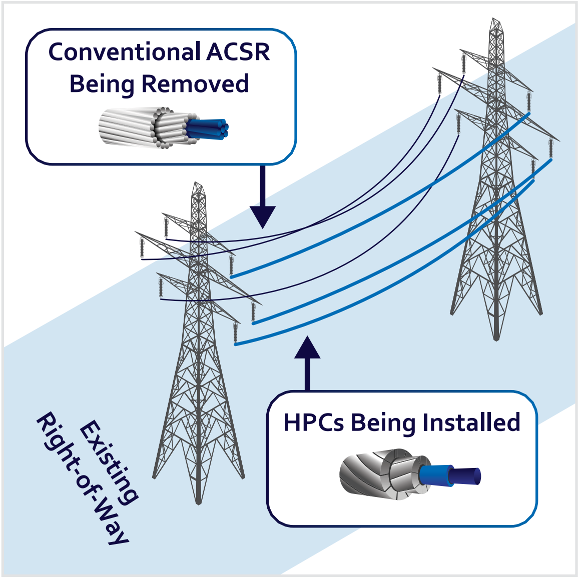
Reconductoring and rebuilding transmission lines is a common part of utility operations and maintenance practices. However, under the current status quo, many lines are reconductored or rebuilt with the same type of conductor previously used on the line, usually a conventional steel-core conductor. This practice is often referred to as "like-for-like" replacement, and it misses out on the additional benefits HPCs can provide.

Reconductoring and Rebuilding with HPCs

Reconductoring with HPCs (also called "advanced reconductoring") uses the same process described above, but instead of a "like-for-like" replacement, the existing transmission line's conductor is replaced with a HPC using the existing towers and right-of-way. In some cases, upgrades to terminal equipment are required. For rebuilds, transmission towers along with the conductor are replaced, either due to age or to accommodate larger conductors within an existing right-of-way.

Reconductoring and rebuilding with HPCs enables faster deployment of new grid capacity compared to building new transmission lines. **Reconductoring generally takes 1-3 years and can double the capacity of a transmission line at approximately half the cost of a new transmission line**, while rebuilding with a superconductor can add 5 times the capacity or more. The value of time-saving and other benefits, such as reductions in congestion, lower generation curtailment, and faster interconnection to the grid are significant and often not considered in current decision-making frameworks.

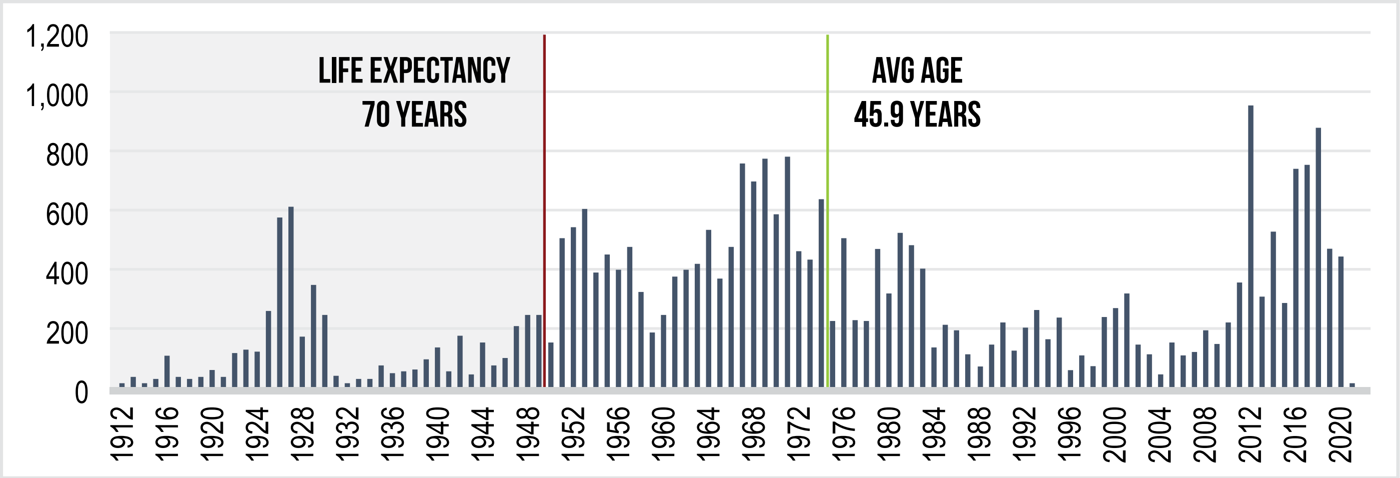
Advanced Reconductoring



Potential to Unlock Transmission Capacity

STATUS QUO: An Aging U.S. Grid	SOLUTION: Unlocking Transmission Capacity Through Reconductoring and Rebuilding with HPCs
The U.S. currently has an aging transmission grid that will require significant renewal investments. The American Society of Civil Engineers estimated 70% of power lines are well into the second half of their 50-year life expectancy, and some lower-voltage components are even over 100 years old.[1] The largest grid operator in the U.S., PJM Interconnection, reports similar findings, estimating that two-thirds of its transmission system is over 40 years old, one-third is more than 50 years old, and some lower-voltage transmission facilities are nearly 90 years old.[2] American Electric Power, one of the largest transmission-owning utilities in the U.S., also estimates they will need to replace over 10,000 miles of transmission lines over the next 10 years, or 30% of their system.[3]	1. Maximizing the use of HPCs in **reconductoring can add ~4x the transmission capacity** when compared to the current rate of new transmission development, **accounting for ~80% of the transmission capacity needed** to achieve 90% clean energy by 2035.[4] 2. Reconductoring 25% of transmission lines that need to be replaced over the next decade with HPCs would **enable the integration of roughly 27 gigawatts (GW)** of new generation per year.[5]

AEP Transmission Line Age Profile[6]



1 American Society of Civil Engineers, 2021 Report Card for America's Infrastructure, Energy, at 46, 2021, https://infrastructurereportcard.org/wp-content/uploads/2020/12/Energy-2021.pdf.

2 PJM Interconnection, The Benefits of the PJM Transmission System, at 5, April 16, 2019, https://www.pjm.com/-/media/library/reports-notices/special-reports/2019/the-benefits-of-the-pjm-transmission-system.pdf.

3 AEP, "UBS Winter Conference," at 46, January 10, 2022, https://www.aep.com/Assets/docs/investors/eventspresentationsandwebcasts/UBSWinterConference01-10-22.pdf.

4 Emilia Chojkiewicz, Umed Paliwal, Nikit Abhyankar, Casey Baker, Ric O'Connell, Duncan Callaway, and Amol Phadkel, "Reconductoring with Advanced Conductors Can Accelerate the Rapid Transmission Expansion Required for a Clean Grid," GridLab, April 2024, https://www.2035report.com/wp-content/uploads/2024/06/GridLab_2035-Reconductoring-Technical-Report.pdf.

5 Jay Caspary and Jesse Schneider, "Advanced Conductors to Accelerate Grid Decarbonization," ACORE and Grid Strategies, March 2022, https://acore.org/resources/advanced-conductors-on-existing-transmission-corridors-to-accelerate-low-cost-decarbonization/.

6 Id.

Upgrading Underground Conductors with Superconductors

Beyond reconductoring and rebuilding transmission lines, underground lines can also be upgraded using HPCs. This is particularly useful in urban areas where additional transmission and distribution system capacity will be needed to accommodate load growth from new data and manufacturing centers as well as to replace aging assets.

Traditionally, when utilities needed to increase capacity, they would rebuild an existing corridor using a higher-voltage conductor, which would require the installation of additional transformers, or in some cases new high-voltage substations. However, replacing underground conventional conductors with superconductors provides several benefits, particularly for corridors that are in urban areas where construction and access to the conductor are very challenging. Upgrading to a superconductor allows for:

Higher capacity transfers at lower voltages. Superconductors have almost no resistance which allows the conductor to carry high currents at low voltages with limited line losses. Underground superconductors can add 3-10 times more capacity at the same voltage as a conventional underground conductor.

Avoided upgrades and reuse of existing infrastructure. Because superconductors can operate at lower voltages it helps avoid the need for costly and difficult voltage upgrades in substations and the need for new transformers that would traditionally be needed to add new capacity. Superconductors are also more compact than conventional conductors, which allows for easier and less costly installation in crowded urban infrastructure, and often allows reuse of existing low- or medium-voltage conductor ducts.

Minimized impacts on surroundings. Superconductors have almost no external magnetic fields and are cooled. These properties minimize the impact on surrounding electronic and communication systems and result in no thermal restrictions on their placement underground, as well as no thermal requirements to allow spacing between phases. This reduces the space required for installation and eliminates the overheating related failures associated with conventional underground conductors.

Lower environmental impacts. Superconductors reduce the need for bulky infrastructure associated with higher-voltage conventional conductors, and fewer maintenance requirements minimizes the environmental disruption typically associated with conventional underground systems. In addition, superconductors use 97% less copper than conventional copper conductors which provides significant upstream environmental benefits.

Benefits and Use Cases

Benefits of High Performance Conductors

HPCs are modern conductor technologies which have greater performance characteristics when compared to traditional ACSR conductors, such as increased capacity, higher efficiency, and less thermal sag, and include carbon and composite core conductors and superconductors. The benefits of HPCs include:

Increased Capacity

- 2x for carbon and composite core conductors.
- ~5x for superconductors compared to conventional conductors.

Greater Efficiency

- Carbon and composite core conductors can reduce energy losses by 20% or more.
- Superconductors can reduce losses by 50-80%.

Additional Resilience

- Carbon/composite core conductors are stronger and have half as much thermal sag reducing interactions with underbrush and potential for sparking.
- Superconductors are cooled and insulated, meaning there is no thermal sag, and the line sag does not vary with ambient temperatures and is not exposed to the elements.

Reduced Land Impacts

- Reconductoring and rebuilds use existing ROWs, eliminating the need to disturb land for construction in new corridors.
- HPCs can reduce the number of transmission towers needed for new line builds also reducing land disturbed for new builds.

Time Savings

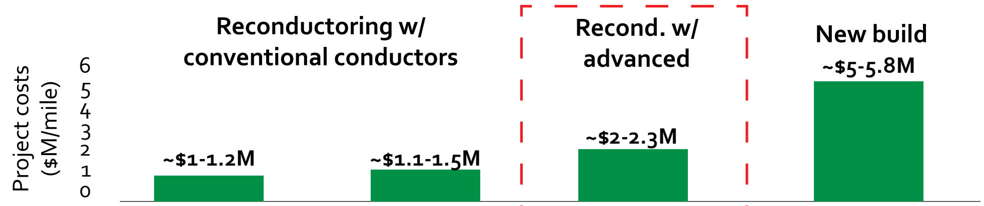
- Using existing rights-of-ways (ROWs) for reconductoring and rebuilds reduces permitting and construction needs, as well as the need to acquire new land. In some cases, this saves a year or more compared to new builds.

Cost Effective

- Reconductoring with HPCs is approximately half the cost of building new transmission lines.
- HPCs can reduce the number of transmission towers needed for new line builds saving costs as well.

Figures Depict the Benefits and Costs of Reconductoring with HPCs Compared to Other Alternatives.[7]

Benefits & Costs Vs. Alternatives



Conductor type	ACSR	ACSS	ACCC	New Txm Build (with ACSR)
Upfront CAPEX cost	✓ (Cheapest)	✓	~Med	X (Most expensive)
Capacity	X	~Med	✓	✓
Reliability	X	X	✓	X
Energy efficiency	X	X	✓	X
Implementation speed	✓	✓	✓	X
Existing ROW	✓	✓	✓	X

Benefits not typically considered in current valuation methods (Capacity through Existing ROW)

		Conventional Conductors (including ACSS)	Carbon and Composite Core Conductors	Superconductors (Closed Loop Cooling)	Superconductors (Passive Cooling)
Application	Overhead	✓	✓		✓
	Underground	✓		✓	✓
Line Length	Short Distance	✓	✓	✓	✓
	Long Distance	✓	✓		✓
Capacity Increase Relative to ASCR, at a Given Voltage	0-50%	✓	✓	✓	✓
	50-150%	✓	✓	✓	✓
	150-300%		✓	✓	✓
	300-1,000%			✓	✓
Resilience Benefits	Half the thermal sag or no thermal sag		✓	✓	✓
	Current Rating Independent of Ambient Conditions			✓	✓
	Can Operate at Emergency & Load-Dump Ratings Indefinitely			✓	✓
	Inherently Fault-Limiting			✓	✓
Energy Efficiency Improvement Relative to ACSR	0-20%	✓	✓	✓	✓
	20-40%		✓	✓	✓
	40-80%			✓	✓

Reconductoring with HPCs can provide similar capacity at half the cost of building a new line to deliver the same capacity. However, numerous benefits provided by HPCs are not considered in current valuation models. These benefits deliver additional value that would make up for the higher incremental upfront cost of the conductor.

7 Grid Strategies; U.S. Department of Energy, "Innovative Grid Deployment: Pathways to Commercial Liftoff Interim Webinar Update," December 2023, https://www.energy.gov/sites/default/files/2023-12/Grid%20Liftoff%20Webinar%20Final.pdf.

High Performance Conductor Use Cases

HPCs Unlock Cost Savings

HPCs have the potential to save money across several areas, including avoided infrastructure costs, lower line losses, and access to cheaper generation. **A 2022 American Council on Renewable Energy (ACORE) and Grid Strategies report found that reconductoring with HPCs has the potential to save consumers at least $140 billion over 10 years**.[8]

Similarly, **a 2024 GridLab and University of California (UC), Berkeley study found reconductoring with HPCs results in $85 billion in total savings by 2035 and $180 billion by 2050.** These cost-savings are achieved by unlocking access to lower-cost, higher-quality generation in more locations across the country, thereby lowering wholesale electricity costs.[9] The study also found that pursuing widespread reconductoring with HPCs alongside development of new transmission lines without restrictions on transmission build-out can further yield significant cost savings of over $400 billion by 2050, over the business-as-usual case.[10]

Specific examples of cost savings include:

1. **Entergy saved $9.6 million by reconductoring a 230 kilovolt (kV) transmission line** using HPCs to increase line capacity. Not rebuilding with alternative enhanced steel core conductor (ACSS) reduced project costs from $18.1 million to $8.5 million, while also improving efficiency.[11]
2. **Montana-Dakota Utilities unlocked 40% cost savings** in a reconductoring project using HPCs when compared to rebuilding with ACSS conductor. The project also came in $1.8 million under the original budget.[12]
3. **An American Electric Power (AEP) West reconductoring project saved customers $15 million annually** through a reduction in line losses due to the use of HPCs.[13]
4. **Southern California Edison (SCE) saved consumers $85 million** by reconductoring using HPCs rather than building a larger transmission line with conventional conductors.[14]

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8 *See* "Advanced Conductors to Accelerate Grid Decarbonization."

9 *See* "Reconductoring with Advanced Conductors Can Accelerate the Rapid Transmission Expansion Required for a Clean Grid."

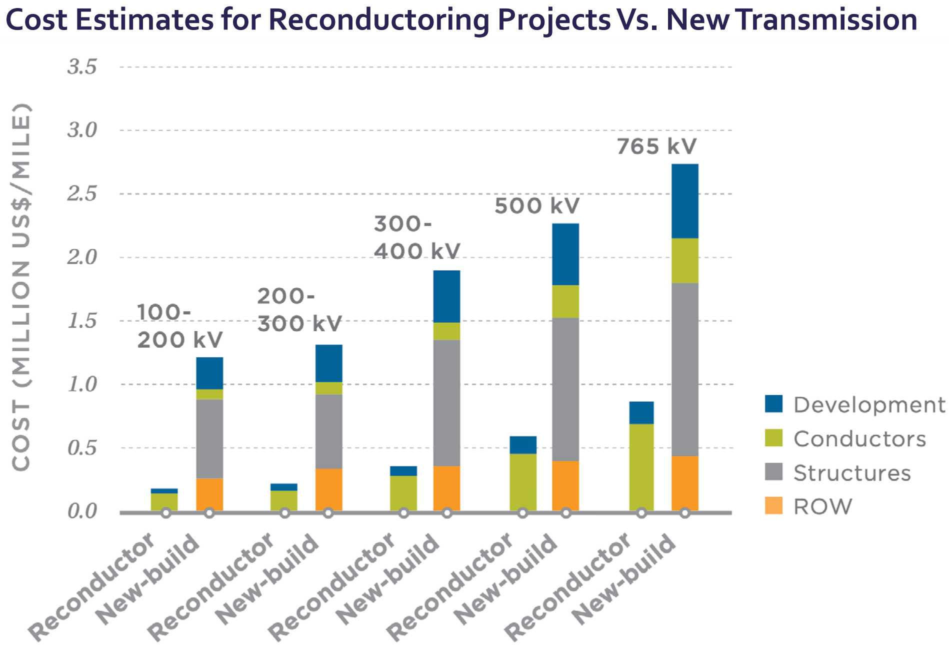
10 Id.

11 Idaho National Laboratory, "Advanced Conductor Scan Report," at 143, April 2024, https://inl.gov/content/uploads/2024/02/23-50856_R8_-AdvConductorszScan-Report.pdf, ("INL Report").

12 Montana-Dakota Utilities, "Montana-Dakota Utilities believes it is the first in North America to deploy aluminum-encapsulated carbon fiber conductor, March 2021, https://www.montana-dakota.com/montana-dakota-utilities-first-in-north-america-to-deploy-carbon-fiber-conductor/, ("MDU Press Release").

13 CTC Global, "American Electric Power Doubles Capacity, Saves Time and Money," accessed September 2024, https://ctcglobal.com/aep-reconductor-project/ ("CTC AEP Case Study").

14 CTC Global, "SCE Uses ACCC® Conductor to Mitigate Sag and Increase Capacity," March 2021, https://ctcglobal.com/sce-uses-accc-conductor-to-mitigate-sag-and-increase-capacity/, ("CTC SCE Press Release").



The chart above from the GridLab and UC Berkeley study[15] shows a key takeaway that reconductoring with HPCs is lower cost overall than building new transmission at all voltage levels. Reconductoring eliminates the need to invest in new structures and rights-of-way, and even though conductor costs are higher, conductors are a small percentage of the overall project cost.[16]

HPCs Unlock Low-Cost Power Generation

HPCs can unlock significant amounts of grid capacity, allowing for connection of new generation and load. The The U.S. Department of Energy (DOE)'s 2024 Pathways to Commercial Liftoff: Grid Innovation Report found that **deploying HPCs nationally can increase the capacity of the existing grid to support over 100 GW of incremental peak demand**, which is enough to meet the North American Electric Reliability Corporation (NERC)'s estimated 10-year peak demand growth.[17] An ACORE and Grid Strategies 2022 report estimated that **reconductoring with HPCs would enable the integration of roughly 27 GW of additional generation capacity** by replacing 5,000 miles of aging (50+ years old) transmission lines annually.[18] A 2024 GridLab and UC Berkeley study found that **reconductoring with HPCs can add approximately four times the transmission capacity** when compared to the current rate of new transmission development, accounting for roughly 80% of the transmission capacity needed to achieve 90% clean energy by 2035.[19]

15 Emilia Chojkiewicz, Umed Paliwal, Nikit Abhyankar, Casey Baker, Ric O'Connell, Duncan Callaway, and Amol Phadkel, "Reconductoring with Advanced Conductors Can Accelerate the Rapid Transmission Expansion Required for a Clean Grid," GridLab, April 2024, https://www.2035report.com/wp-content/uploads/2024/06/GridLab_2035-Reconductoring-Technical-Report.pdf ("Reconductoring Technical Report").

16 *See* "Reconductoring with Advanced Conductors Can Accelerate the Rapid Transmission Expansion Required for a Clean Grid."

17 U.S. Department of Energy, "Pathways to Commercial Liftoff: Innovative Grid Deployment," April 2024, https://liftoff.energy.gov/innovative-grid-deployment/, ("DOE Liftoff Report").

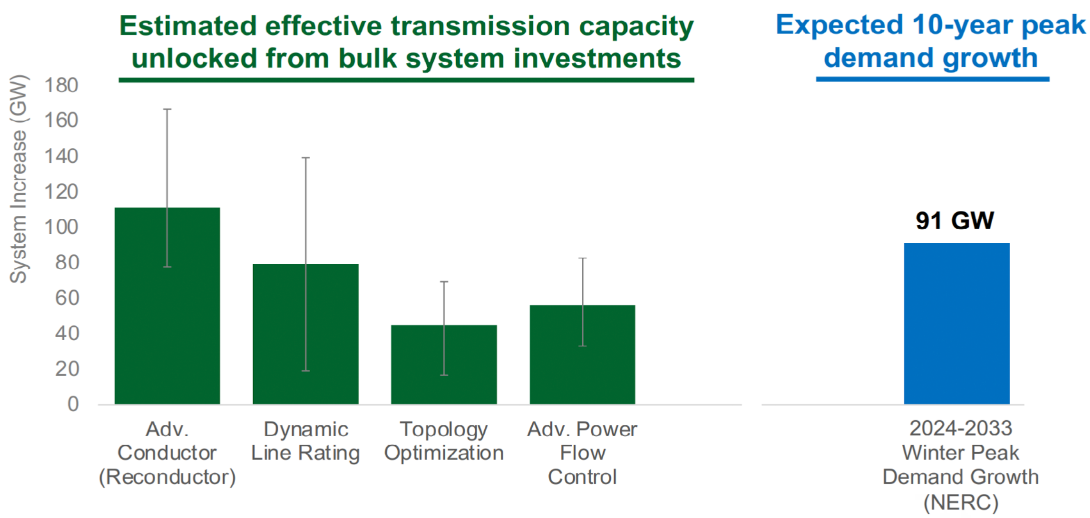
18 *See* Advanced Conductors to Accelerate Grid Decarbonization.

19 *See* Reconductoring with Advanced Conductors Can Accelerate the Rapid Transmission Expansion Required for a Clean Grid.

Specific examples of increasing transmission capacity include:

1. **Montana-Dakota Utilities increased capacity of a line 50%** by reconductoring using HPCs.[20]
2. **AEP West doubled line capacity** in Texas by reconductoring the line using HPCs, helping the utility address significant load growth.[21]
3. **SCE doubled capacity on a line** by reconductoring using HPCs.[22]
4. **Arizona Public Service Company almost doubled the capacity of a line (~850 to 1600 amps)** in Tempe, AZ without needing to modify or replace the existing structures by reconductoring with a HPC.[23]
5. **Dominion Energy increased capacity on a line by 90% using HPCs** to complete a line near Dulles airport in Loudoun County, VA, an area of the country experiencing significant load growth.[24]

Estimated Transmission Capacity Unlocked by Advanced Transmission Technologies Compared to NERC's Expected 10-Year Peak Demand



The chart above estimates that reconductoring with HPCs could increase transmission system capacity by 110 GW (possibly up to 170 GW), which is more than enough to meet projected demand growth over the next 10 years.[25]

20 MDU Press Release.

21 Reconductoring Technical Report.

22 CTC Global SCE Press Release.

23 INL Report at 131; See also CTC Global, "Arizona Public Service Completes ACCC® Conductor Installation in Tempe, Arizona," July 2020, https://ctcglobal.com/arizona-public-service-completes-accc-conductor-installation-in-tempe-arizona/ ("CTC Global Arizona Press Release").

24 INL Report at 139.

25 Figure adapted from U.S. Department of Energy, "Pathways to Commercial Liftoff: Innovative Grid Deployment," April 2024, https://liftoff.energy.gov/innovative-grid-deployment/, ("DOE Liftoff Report").

HPCs Unlock Energy Efficiency

HPCs also provide significant energy efficiency savings by reducing line losses. A 2022 ACORE and Grid Strategies report estimated **reconductoring with HPCs can prevent annual transmission losses of approximately 21 million megawatt-hours (MWh) and lower annual total system peak demand by 5.9 GW, generating over $2.2 billion in annual consumer savings** at the national level.[26]

Specific examples of reducing line losses include:

1. **AEP West saved customers $15 million annually** through a reduction in line losses by reconductoring a line using HPCs.[27]
2. **South Texas Electric Cooperative reduced energy losses by just over 5,000 MWh** in the first year after reconductoring a line using HPCs.[28]
3. **It was estimated Montana-Dakota Utilities will save almost $13 million from reduced lines losses** over the first 30 years of a reconductoring project with HPCs.[29]

HPCs Unlock Reliability and Resilience

HPCs can increase grid resilience against fire and major climatic events in areas of frequent grid failure, rural or urban. Carbon and composite core conductors are stronger and sag about half as much as conventional conductors, limiting exposure to undergrowth and under-build. Superconductors are actively cooled, meaning that their capacity ratings are constant and that the sag of overhead superconductors does not vary with ambient temperatures.

Specific examples of increased resilience or reliability include:

1. A Montana-Dakota Utilities reconductoring project utilized HPCs because it was the **only technical solution available to manage 1.5 inches of ice.**[30]
2. Southern California Edison reconductored a transmission line using HPCs. In 2020, **the line avoided damage during a wildfire likely helped by HPC low-sag characteristics.**[31]
3. In 2021, a Commonwealth Edison superconductor project in Chicago connected two substations in the city, **increasing reliability and avoiding the need to acquire additional land and disturb existing infrastructure.**[32]
4. Oklahoma Gas and Electric installed a HPC that was impacted by a tornado which passed directly over a stretch of the line. A piece of flying debris struck one of the steel monopole structures, leaving it bent at a 45-degree angle. The resulting tension placed on the HPC caused the aluminum strands to snap in one location, but **the composite core remained fully intact. Line crews were able to repair this section within 24 hours and ultimately bring the entire line back into service within about a week.**[33]

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26 *See* Advanced Conductors to Accelerate Grid Decarbonization.

27 CTC AEP Case Study.

28 CTC Global presentation at NRECA Tech Advantage 2023.

29 TS Conductor presentation.

30 MDU Press Release.

31 CTC Global SCE Press Release.

32 M. Ross, "Utility applications and experience with resilient electric grid systems utilizing high temperature superconductor wires in Chicago," Science Direct Physica C: Superconductivity and its Applications, Volume 614, November 2023, https://doi.org/10.1016/j.physc.2023.1354374 ("AMSC").

33 INL Report at 158.

HPCs Reduce the Time Needed to Expand Capacity

Reconductoring and rebuilding with HPC enables faster deployment of new grid capacity and generally only takes 1-3 years, due to reduced permitting requirements and not needing to acquire new rights of way, compared to building new transmission lines which can take over 10 years.

Specific examples of time savings include:

1. **The Montana-Dakota Utilities reconductoring project using HPCs was implemented in 3 months instead of the 15 months originally planned, an 80% reduction in construction time.** Using HPCs avoided the need to rebuild the line with conventional conductors, which would have added additional time.[34]
2. AEP West chose to reconductor 240 miles of transmission line with HPCs because other options, such as a new line or rebuilding, raised concerns of permitting delays. **The project was also completed using energized reconductoring, which kept the corridor in service throughout the process because the Electric Reliability Council of Texas could not schedule an outage.**[35]
3. **Southern California Edison reconductored an existing line with HPCs reducing construction time by approximately 30 months** and avoided having to build a bigger transmission line with conventional conductors.[36]

VEIR's first outdoor superconducting power transmission line, capable of transmitting 4 kilovolts (kV) in a single-phase overhead conductor.[37]

34 MDU Press Release.

35 CTC AEP Case Study.

36 CTC Global SCE Press Release.

37 Overhead Superconducting Power Transmission," ELECTRA, accessed October 2024, https://electra.cigre.org/330-october-2023/technology-e2e/overhead-superconducting-power-transmission.html.

HPCs Unlock Reduced Land Impacts

Reconductoring and rebuilds with HPCs utilize existing rights-of-way and avoid the need to disturb new land for new transmission builds. Additionally, **HPCs can reduce the number of transmission towers required for new builds by 30-50% or shorten tower height**, reducing both land and visual impacts.

Specific examples of reduced impacts include:

1. **Arizona Public Service Company did not need to modify or replace the existing structures by choosing to reconductor with** HPCs almost doubling the capacity of the line and eliminating concerns about clearance issues and replacing structures.[38]
2. The Munich SuperLink project will connect Munich's grid to the larger transmission system using a superconducting cable. **The cable will partially use existing conduits, some less than half a foot in diameter, to minimize construction disruptions or additional corridor acquisitions.** The planned 110 kV line can deliver 500 megawatts (MW), a roughly 67% capacity increase over conventional conductors, despite the very small corridor needs. When completed, the Munich SuperLink project will be the longest superconducting project in the world.[39]
3. **In 2008, Long Island Power Authority (LIPA) installed a superconducting AC transmission cable with 574 MW of capacity in a right-of-way only one meter wide.** Because of the high energy density of the cables, LIPA was able to substantially increase transmission capacity while utilizing existing underground utility conduits.[40]
4. **Commonwealth Edison's superconductor project in Chicago connected two substations in the city and avoided the need to acquire additional land and disturb existing infrastructure** while increasing reliability.[41]

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38 INL Report at 131; CTC Global Arizona Press Release.

39 Transformer Magazine, "The Munich Superlink Project," 2021, https://ivsupra.de/wp-content/uploads/2021/05/Transformer-Magazine_SuperLink-140521.pdf.

40 Advanced Energy United, "THIS IS ADVANCED ENERGY: High Temperature Superconducting Transmission," December 2016, https://blog.advancedenergyunited.org/this-is-advanced-energy-high-temperature-superconducting-transmission.

41 AMSC.

Challenges to Adoption

Institutional Barriers to High Performance Conductor Deployment

Current Incentives Do Not Encourage HPC Deployment

There are several incentives that slow the deployment of HPCs. When utilities are deciding which conductor to use for a project, some incentives may be in tension:

1. Most utilities earn revenue from a return on new capital investments and can increase their revenue through spending on more capital-intensive projects, such as new generation or transmission, or distribution lines and related equipment. This model made sense when the utility industry was forming, and policymakers wanted to incentivize the expansion of the power system to ensure residential, commercial, and industrial customers received service. This means utilities have historically added new transmission capacity to the grid by building new transmission lines or rebuilding existing lines to higher voltages. Reconductoring has generally been reserved for replacing aging transmission lines, and given an equal choice, a utility would make more money building a new line over reconductoring if both added the same amount of grid capacity.
2. Separately, utilities have generally addressed transmission line maintenance and replacement independent of planning for transmission capacity expansion, and due to differences in upfront costs, there is typically less regulatory resistance to replacing an aging line with the same, newer conductor, known as "in-kind replacement." For these reasons, utilities may be more hesitant to replace or reconductor aging lines with HPCs if those projects are met with more skepticism from regulators, cannot be approved due to "least cost" requirements, or the utility cannot demonstrate immediate need for the additional capacity.

In addition, there are very few incentives for utilities to innovate on the grid on behalf of customers. Utilities are rightfully focused on reliability, but that emphasis can make them overly risk-averse and create a preference for status quo technologies. Because of this focus, utilities rarely have incentives to improve the grid for customers, such as by eliminating congestion, curtailment, or reducing line losses.

Regulators May Be Required to Only Consider Lowest Upfront Costs

Regulators may be hesitant to approve the deployment of HPCs because of a focus or requirement to use lowest upfront costs, or because the utility cannot demonstrate there is an immediate need.

State utility regulators are economic regulators tasked with monitoring utilities to ensure they don't overinvest in new capital projects at the expense of customers. The financial incentive for utilities to potentially overinvest in the system is known as "gold-plating" and has led to requirements or a focus on the lowest upfront costs solutions, rather than considering longer-term net-benefits for customers. HPCs have a higher upfront cost compared to traditional conductors but often have greater long-term cost savings for customers. However, regulators may not accept such investments for utilities as

HPCs may be viewed as "gold-plating." In addition, regulators may be required or may face pressure to use traditional conductors for reconductoring and rebuilding aging transmission lines rather than reconductoring or rebuilding HPCs, despite more long-term savings because of the higher initial price tag.

Insufficient Information Limits Understanding of HPCs

The number and type of advanced transmission technologies and smart grid technologies on the distribution side have significantly increased over the past 20 years. This added complexity can make it difficult for utilities, regulators, and policymakers to track and evaluate all the new capabilities of different technologies. Given the host of advanced transmission technologies now available for deployment, utilities and regulators are faced with the challenge of identifying optimal solutions given the different benefits, costs, and uses of each technology.

New technology adoption often requires development of new processes and education for planners, engineers, and regulators. While HPCs are not new to utilities, some may require installation training, and planners and engineers may need to update planning models with correct conductor technical specifications and costs. Regulators and policymakers also need access to information about the additional benefits and costs of HPCs, as evaluating the technologies was previously not as important.

Current Planning and Permitting Models Do Not Holistically Incorporate HPCs

In current transmission planning paradigms, asset replacements are not generally integrated into broader planning for transmission expansion. Within transmission planning and development, decisions regarding conductors are often considered an engineering choice that occurs after planning. Given the additional benefits beyond basic ampacity requirements (i.e. reliability, efficiency, speed, etc.) HPCs can provide, considering them as a part of the set of transmission solutions developed in the planning context would help optimize planning results.

While reconductoring projects often avoid the permitting required for new lines, the U.S. has an aging grid, and many older lines were developed before environmental permitting was meaningfully required. Any significant upgrade to an existing transmission line, including reconductoring, could lead to new environmental permitting reviews. These new permitting requirements eliminate a significant benefit of reconductoring, which is the time saved compared to building a new line. The DOE took a step to address this in 2024 by approving a Categorical Exclusion to National Environmental Policy Act (NEPA) to streamline the permitting process for reconductoring and rebuild projects subject to DOE authority.

State Policies Promoting High Performance Conductor Deployment

Summary of State Policy Recommendations for HPCs

1. Study the potential and benefits of HPCs.
2. Require evaluation of HPCs in state planning processes.
3. Change or develop incentives for HPCs to encourage further deployment by utilities.
4. Shift utility and public utility commission (PUC) planning and project evaluations from a "least upfront cost" to a "maximum net benefits" framework, with a particular focus on energy efficiency.
5. Make permitting changes to more closely align with federal exclusions for reconductor and rebuild projects.
6. Encourage or require the creation of utility working groups to study and share lessons learned on HPCs.

Study the Potential and Benefits of HPCs.

State policymakers and regulators can conduct or contract for their own study or require utilities to study the technical potential and benefits to ratepayers from the holistic deployment of HPCs in their state. Policymakers can also require the submission of these studies to the PUC.

- **California's SB 1006, a 2024 law, requires utilities and the California Independent System Operator (CAISO) to jointly evaluate HPCs.** The evaluation is focused on identifying lines where reconductoring with HPCs can cost-effectively achieve one or more of the following benefits: "(A) Increase transmission or distribution capacity; (B) Reduce transmission or distribution system congestion; (C) Reduce curtailment of renewable and zero-carbon resources; (D) Increase reliability; (E) Reduce the risk of igniting wildfire, where the investment is consistent with the transmission utility's approved wildfire mitigation plan; (F) Increase capacity to connect new renewable energy and zero-carbon resources; (G) Reduce line losses; (H) Increase the ability to quickly energize new customers or serve increased customer load; and (I) Increase flexibility to reduce risks surrounding technology and permitting uncertainties and improve optionality."[42]
- **In 2023, Colorado passed legislation (SB23-016) requiring a study to evaluate the need for expanded transmission capacity.** The study examines the potential of "reduced land impacts by using existing rights-of-way, including large capacity transmission lines; co-locating multiple transmission lines; reconductoring transmission lines; and strategically siting new transmission lines." The modeling includes HPCs as an option for reconductoring and new lines.[43]

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42 Senator Padilla, California State Senate, S.B. 1006, February 2024, https://leginfo.legislature.ca.gov/faces/billStatusClient.xhtml?bill_id=202320240SB1006.

43 Colorado Electric Transmission Authority, "Transmission Capacity Expansion Study for Colorado," accessed September 2024, https://www.cotransmissionauthority.com/transmission-study.

Require Evaluation of HPCs in State IRP Processes and CPCN Proceedings.

State policymakers can require utilities to evaluate HPCs within a state's IRP context. Policymakers can also require utilities to consider HPCs as an alternative when filing a CPCN application.

- **A 2024 bill in Virginia (HB 862) initially required utilities to include a comprehensive assessment of HPCs as a part of the utility's IRP** and provide a detailed explanation on the reasoning if they are not included. The bill also required utilities to file a comprehensive analysis with the public utilities commission if HPCs were not selected for any transmission line requiring a CPCN as the preferred transmission solution. The final law only required utilities to evaluate HPCs in the Distribution IRP process. [44]
- **Legislators in Utah initially proposed a similar bill (SB 191) that modified future IRP filings to encourage utilities to include deployment of HPCs** and created a requirement to a summary of existing and planned HPC deployments.[45]

Change or Develop Incentives for HPCs to Encourage Further Deployment by Utilities.

State policymakers can require utilities to evaluate HPCs within a state's IRP.

- **In 2023, Montana passed (HB 729) which allowed the state's PUC to develop cost-effectiveness criteria,** specifically including consideration of energy efficiency, for projects using HPCs and allowed the commission to create a return on equity (ROE) adder for the projects.[46]
    - It is important to note that this type of incentive is only jurisdictional in states that do not have a Regional Transmission Organization (RTO). However, legislation affirming a PUC's ability to approve higher upfront cost projects that have greater long-term benefits can be a positive signal.
- **Utah's bill (SB 191) encouraging utilities to include deployment of HPCs in IRPs initially** also provided language that the commission can approve cost-recovery for projects that use HPCs if it is determined the deployment is cost-effective.[47]
- **In 2024, Washington's PUC approved an incentive for utilities seeking federal funding.** The commission approved a ROE adder of 50 basis points for the required matching funds if a utility is awarded a federal grant to ensure there is an appropriate incentive for utilities to pursue federal funding opportunities.[48]

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44 Delegate Hernandez, Virginia State House, H.B. 862, January 2024, https://legacylis.virginia.gov/cgi-bin/legp604.exe?241+sum+HB862.

45 Senator Blouin, Utah State Senate, S.B. 191, February 2024, https://le.utah.gov/~2024/bills/sbillint/SB0191.pdf, ("S.B. 191").

46 69-3-714, Montana State Code, https://leg.mt.gov/bills/mca/title_0690/chapter_0030/part_0070/section_0140/0690-0030-0070-0140.html.

47 S.B. 191.

48 Washington Utilities and Transportation Commission, "Policy Statement Addressing the Federal Inflation Reduction Act and the Infrastructure Investment and Jobs Act in Utility Planning," May 2024, https://apiproxy.utc.wa.gov/cases/GetDocument?docID=35&year=2024&docketNumber=240013.

- **States have also introduced legislation encouraging or allowing utilities to propose performance incentive mechanisms to their PUCs** that could be applied to projects using HPCs.
- **If a state is part of an RTO or Independent System Operator (ISO), state policymakers and regulators can also encourage their RTO or ISO to develop its own shared savings incentive** through their regional state committee.

Shift Utility and PUC Planning and Project Evaluations From a "Least Upfront Cost" to a "Maximum Net Benefits" Framework, with a Particular Focus on Energy Efficiency.

Policymakers and regulators can require evaluation of energy efficiency or lines loss reduction benefits when making choices on what conductor to use. Energy efficiency and reduction in line losses are two benefits not typically considered in utility decision-making. This requirement would help shift evaluations from a "least upfront cost" to a "maximum net benefits" evaluation.

- **In 2022, Vermont Electric Power Company (VELCO) used a benefit-cost analysis** to show that despite a slightly higher upfront cost, choosing double-bundled ACSR over aluminum conductor, steel supported (ACSS) reduced line losses enough that the incremental cost resulted in a lower lifetime expense. VELCO analysis relied on ISO New England (ISO-NE) approved methodologies to calculate benefits and costs.[49]
    - Legislators could require this type of benefit-cost analysis or this type of analysis could be encouraged by state commissioners.
    - If a state is part of an RTO or ISO, state policymakers and regulators can advocate adoption of a similar style of benefit-cost analysis for conductor selection through their regional state committee.
- **Legislators could allow utilities to use reduction in line losses from HPCs to help utilities meet state energy efficiency requirements.** For example, many states have energy efficiency goals for utilities which could be modified to allow utilities to adopt a more holistic approach to compliance, including counting energy savings from reduced line losses to meet goals. Legislators could also include savings from increases in grid efficiency.

Make Permitting Changes to More Closely Align with Federal Exclusions for Reconductor and Rebuild Projects.

Generally, reconductoring projects require limited state-level permitting, potentially only a maintenance permit. However, because the grid is aging there are many lines that were built before environmental permitting was meaningfully required and any significant upgrade to the existing transmission line, including reconductoring, could lead to new environmental permitting reviews. These new permitting requirements eliminate a significant benefit of reconductoring, which is the time saved compared to building a new line.

49 ISO-NE, "VELCO's Asset Condition Project: K42 Transmission Line Replacement," January 2022, https://www.iso-ne.com/static-assets/documents/2022/01/velco_asset_condition_project_k42_transmission_line_replacement.pdf.

- **In 2024, the U.S. Department of Energy (DOE) approved a new National Environmental Policy Act (NEPA) Categorical Exclusion** for all reconductoring and rebuild projects that are subject to DOE permitting under NEPA, which allows those projects to avoid having to complete a detailed environmental study because the type of action is unlikely to result in significant environmental impacts.[50]
- Depending on an individual state's permitting laws, legislation may be required to bring the state more in-line with these changes. **For example, California's AB 3246, a 2024 bill, streamlines permitting specifically for reconductoring projects that use HPCs** by eliminating the requirement for an official PUC vote to approve the project.[51]
- **In Utah, SB 191, as introduced in 2024, initially included a provision to accelerate permitting** for projects deploying HPCs.[52]

Encourage or Require the Creation of Utility Working Groups to Study and Share Lessons Learned on HPCs.

- **The New York Public Utilities Commission established the Advanced Technologies Working Group (ATWG) in 2020 to initially evaluate dynamic line ratings, power flow controls, and energy storage.**[53] In 2024, the commission issued a new order directing the ATWG to consider a broader range of technologies beyond its original three and allows stakeholders to submit advanced technology proposals, which could include HPCs.[54]
- **In 2022, the Maine Legislature passed a bill requiring an "Integrated Grid Planning Process."** The process (Case Number 2022-00322) brings together the PUC, utilities, and interested parties with the goal for the commission to develop a planning directive for the utilities. The process has included discussion on advanced transmission technologies.[55]
- **The Colorado PUC has similarly opened a docket (Proceeding 23M-0472E) seeking input on how utilities currently consider HPCs** within their transmission planning.[56]

50 U.S. Department of Energy, "DOE NEPA Categorical Exclusion Rulemaking (2024)," accessed September 2024, https://www.energy.gov/nepa/doe-nepa-categorical-exclusion-rulemaking-2024.

51 Assemblymember Garcia, California State Assembly, A.B. 3246, February 2024, https://leginfo.legislature.ca.gov/faces/billHistoryClient.xhtml?bill_id=202320240AB3246.

52 S.B. 191.

53 New York Department of Public Service, Case Number 20-E-0197, accessed September 2024, https://documents.dps.ny.gov/public/MatterManagement/CaseMaster.aspx?MatterCaseNo=20-E-0197.

54 New York Department of Public Service, Case Number 20-E-0197, "Order Establishing Procedures for the Advanced Transmission Technologies Working Group, January 2024, https://documents.dps.ny.gov/public/Common/ViewDoc.aspx?DocRefId=%7BB0E0228D-0000-C413-8A45-E2317EA6E16D%7D.

55 Maine Public Utilities Commission, Case Number 2022-00322, accessed September 2024, https://mpuc-cms.maine.gov/CQM.Public.WebUI/Common/CaseMaster.aspx?CaseNumber=2022-00322.

56 Colorado Public Utility Commission, Proceeding Number 23M-0472E, Decision No. C23-0640, September 22, 2023, https://www.dora.state.co.us/pls/efi/EFI_Search_UI.Show_Decision?p_session_id=&p_dec=30338.

Appendix

Federal Funding Opportunities

This section and the accompanying tables are adapted from the 2024 DOE Pathways to Commercial Liftoff: Innovative Grid Deployment report. The funding programs and technical assistance resources below include opportunities focused on supporting the deployment of advanced transmission technologies. These programs are largely funded by the Bipartisan Infrastructure Law.

This is not an exhaustive list of all DOE funding programs. Additional resources on grid funding and technical assistance programs include:

- Grid and Transmission Program Conductor: Summary of the DOE's Grid Deployment Office (GDO)'s transmission and grid resilience financing programs, as well as other existing DOE transmission and grid programs.
- Public Sector Funding & Technical Assistance Programs: Additional information on a variety of technical assistance opportunities for states and local governments.

DOE Grid-Related Funding and Technical Assistance Resources (Not Exhaustive)[57]

Category	Program	Description
Direct Support	Grid Resilience and Innovation Partnerships (GRIP) Program	$10.5B in grant funding for grid investments, including for advanced grid solutions and applications.
	Grid Resilience State and Tribal Formula Grants	$2.3B in formula grants for grid resilience against extreme weather. There is funding available for all states, territories, and federally recognized Indian tribes, including Alaska Native Regional Corporations and Alaska Native Village Corporations. This funding can be claimed to then subaward to entities that will invest in projects that reduce the likelihood and consequence of disruptive events caused by extreme weather, wildfires, and other natural disasters.
	Energy Improvements in Rural and Remote Areas	$1B in funding to improve the resilience, reliability, and affordability of rural energy systems.
Loans and Financing Programs	Transmission Facilitation Program	$2.5B in commercial support for qualified transmission projects through tools such as capacity contracts, public-private partnerships, and loans.
	Transmission Facility Financing Program	$2B in to cover the costs of direct loans for transmission facilities in National Interest Electric Transmission Corridors.
	Innovative Energy Loan Program (1703)	Loan guarantees to support clean energy deployment of innovative or significantly improved technologies, including advanced grid solutions.
	Energy Infrastructure Reinvestment Loan Program (1706)	Loan guarantees for projects that retool, repower, repurpose, or replace Energy Infrastructure that has ceased operations, including for advanced grid solutions.
	Tribal Energy Finance Program (TEFP)	Offers loan guarantees exclusively to support federally recognized tribes, including Alaska Native village or village corporations, or a Tribal Energy Development Organization that is wholly or substantially owned by a federally recognized Indian tribe or Alaska Native Corporation. Financing is available for a broad range of energy technologies, including advanced grid solutions.
	Empowering Rural America Program **USDA program*	$9.7B in loans available for rural electric co-ops through U.S. Department of Agriculture's Rural Utilities Service.

57 Text and tables adapted from DOE Pathways to Commercial Liftoff: Innovative Grid Deployment report.

Category	Program	Description
Technical Assistance	Grid Resilience Assistance	Technical and other assistance that supports state, Indian tribe, territory, and industry needs to support grid resilience, including—if requested— support for advanced technologies.
	State Technical Assistance Program	Provides high-impact technical assistance and resources for state regulators and policymakers through a variety of support options, including—if requested—support for advanced grid solutions.
	Indian Energy Technical Assistance	Provides technical assistance and resources specifically for federally recognized Indian Tribes, including Alaska Native regional corporations and village corporations, and Tribal entities.
Tax Credits	48C Advanced Energy Project Credit	Provides an investment tax credit of up to 30% for qualifying projects placed in service within four years. The Inflation Reduction Act provided $10B to be competitively allocated to selected applicants; manufacturing for "electric grid modernization equipment or components" qualifies under IRS guidance for 48C.
Other Deployment Related Programs	National Interest Electric Transmission Corridors (NIETC)	Special designation that enables certain DOE financing and the Federal Energy Regulatory Commission to use permitting tools to spur construction of transmission projects within a NIETC.
	Puerto Rico Grid Modernization and Recovery Project	Technical assistance program provided to Puerto Rico energy system stakeholders with tools, training, and modeling support to enable planning and operation of the electric system with greater resilience against further disruptions.
	Clean Energy Innovator Fellowship	Funds recent graduates and energy professionals to support public utility commissions, co-ops, Puerto Rican energy associations, tribal utilities, and other grid operators.

Overview of Several DOE Grid Programs[58]

Recognizing the imperative to expand and modernize the grid, DOE has dozens of initiatives and funding programs to support the electric industry across grid research, development, demonstration, and deployment, including technology, regulatory and policy, and supply chain support**.**

The table below summarizes several of these efforts across the DOE focused on advancing grid outcomes—this is not an exhaustive list.

- Note: R&D = research and development; D&D = demonstration and deployment; Reg. & Policy = regulatory and policy. Column marks (X) indicate the primary focus areas for the program. Many programs are cross-cutting and may touch on multiple areas.

58 Text and tables adapted from DOE Pathways to Commercial Liftoff: Innovative Grid Deployment report.

Example DOE Grid-Related Programs Across Research, Development, Demonstration, and Deployment (RDD&D) Phases

Program	R&D	D&D	Reg. & Policy	Supply Chain
Grid Modernization Initiative (GMI) Crosscutting, multiyear program focused on RDD&D to ensure an affordable, resilient, flexible, secure, sustainable, equitable, and reliable grid. The GMI is organized into six strategic pillars: Devices and Integrated Systems; Operations; Planning; Markets, Policies, and Regulations; Resilient and Secure Systems; Flexible Generation and Load. GMI includes the Grid Modernization Lab Consortium, a partnership between DOE and the national laboratories. See the GMI Strategy 2020 for additional information (updated strategy document forthcoming in 2024).	X	X	X	X
Applied Grid Transformation Solutions (AGTS) Supports the validation and demonstration of new grid technology to support adoption and deployment, including scoping new and enhancing existing test beds in collaboration with national labs, academia, and industry.		X	X	X
Coordinated Interagency Transmission Authorizations and Permits Program (CITAP) Focuses on accelerating Federal environmental review and permitting processes for qualifying onshore electric transmission facilities. Consistent with the Fiscal Responsibility Act of 2023, the Program aims toward a better coordinated, more streamlined process that will set deadlines for Federal authorizations and permits for electric transmission on a two-year timeline while ensuring meaningful engagement with Tribes, local communities, and other stakeholders.			X	
Electricity Advisory Committee (EAC) Public-private group that advises DOE on grid modernization topics.			X	
Interconnection Innovation e-Xchange (i2X) Enables a simpler, faster, and fairer interconnection of clean energy resources by conducting four key activities: stakeholder engagement, data collection and analysis, strategic roadmap development, and technical assistance.			X	

Program	R&D	D&D	Reg. & Policy	Supply Chain
North American Energy Resilience Model (NAERM) Enables advanced modeling and analysis of the nation's energy infrastructure and interdependent systems. NAERM offers energy system planners, operators, and federal agency partners premier modeling and situational awareness capabilities to predict the consequences and evaluate mitigations and responses to natural hazards and malicious attacks.			X	
Resilient Distribution Systems (RDS) Develops transformative technologies, tools, and techniques to enable industry to modernize the distribution system, such as microgrids, dynamic controls and communications, electricity delivery systems, and sensors.	X	X	X	
Transmission Optimization with Grid-Enhancing Technologies (TOGETs) Based out of Idaho National Laboratory (INL), this program guides research to fill knowledge gaps of GETs, develops new modeling and simulation methodologies, and conducts a full-scale, multifaceted field exercise on INL's Power Grid Testbed.	X			
Transmission Reliability Program (TRR) Supports collaboration between the national labs, the electricity industry, and DOE to develop technologies that keep the nation's electric grid resilient and secure. Focus areas include: Advanced Applications R&D; Data Development for Transmission Systems; Human Factors, Visualization and Tool Modernization for Grid Ops; Transmission Measurement & Standards; and Grid-Enhancing Technologies.	X			
Transformer Resilience and Advanced Components (TRAC) Focuses on addressing challenges with large power transformers, Solid State Power Substations, high-voltage transmission, and other critical grid hardware components.	X			X

Unlocking the Grid: High Performance Conductors and Case Studies

Carbon and Composite Core Conductors

American Electric Power (AEP) West reconductoring in the Texas Lower Rio Grand Valley (2011): AEP West, a Texas utility, was experiencing significant load growth and chose to reconductor approximately 240 miles of aging traditional conductors with HPCs, **doubling line capacity and saving customers $15 million annually through a 30% reduction in line losses.** AEP was told by Electric Reliability Council of Texas the line was not going to be able to be taken out of service for the time needed to rebuild the line to a bigger size. Instead, the project was completed using energized reconductoring, which kept the corridor in service throughout the process, avoiding permitting delays or outages.[59]

Montana-Dakota Utilities Reconductoring Project in Montana (2021): Montana-Dakota Utilities, a utility serving North Dakota, South Dakota, Montana and Wyoming, selected a project for reconductoring with HPCs that reused the existing transmission structures **resulting in a 40% cost savings** compared to rebuilding with the best available alternative enhanced steel core conductor (ACSS). In addition, the HPC was the only technical solution available able to manage 1.5 inches of ice. The project increased the capacity of the line by 50%, saved $1.8 million from the original budget, and was implemented in 3 months instead of the 15 months originally planned, an 80% reduction in construction time.[60]

Southern California Edison Reconductoring of Big Creek Corridor (2016): Southern California Edison, a utility serving southern California, chose to reconductor a transmission line with HPCs, **doubling corridor capacity and saving customers $85 million** and reduce construction time by approximately 30 months in comparison to building a larger ACSR project to deliver the same capacity. The lower-sag due to the carbon core of the HPC also helped the transmission line avoid damage during a 2020 wildfire.[61]

Superconductors

Chicago Superconductor Project (2020): Commonwealth Edison (ComEd) energized the first commercial superconductor project in Chicago in 2020. The project was designated by FERC as a transmission asset and was approved for cost recovery. The project connects two substations in the city, increasing reliability and avoiding additional land acquisition and disturbance of existing infrastructure. ComEd plans to expand the project to connect additional substations.[62]

Munich SuperLink (2019): Once complete, the Munich SuperLink project will be the longest superconducting project in the world at 12 km. The project will connect Munich's grid to the larger transmission system, partially by using existing conduits, some as small as 150 mm, to minimize construction disruptions or additional corridor acquisitions. The superconductor is planned as a 110 kV line that can deliver 500 MW, a roughly 67% capacity increase over conventional conductors, despite the very small corridor needs.[63]

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59 CTC Global, "American Electric Power Doubles Capacity, Saves Time and Money," accessed September 2024, https://ctcglobal.com/aep-reconductor-project/.

60 Montana-Dakota Utilities, "Montana-Dakota Utilities believes it is the first in North America to deploy aluminum-encapsulated carbon fiber conductor, March 2021, https://www.montana-dakota.com/montana-dakota-utilities-first-in-north-america-to-deploy-carbon-fiber-conductor/.

61 CTC Global, "SCE Uses ACCC® Conductor to Mitigate Sag and Increase Capacity," March 2021, https://ctcglobal.com/sce-uses-accc-conductor-to-mitigate-sag-and-increase-capacity/.

62 M. Ross, "Utility applications and experience with resilient electric grid systems utilizing high temperature superconductor wires in Chicago," Science Direct Physica C: Superconductivity and its Applications, Volume 614, November 2023, https://doi.org/10.1016/j.physc.2023.1354374.

63 Transformer Magazine, "The Munich Superlink Project," 2021, https://ivsupra.de/wp-content/uploads/2021/05/Transformer-Magazine_SuperLink-140521.pdf.

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2. U.S. Department of Energy, "Pathways to Commercial Liftoff: Innovative Grid Deployment," April 2024, https://liftoff.energy.gov/innovative-grid-deployment/.
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8. Frank Merschel and Mathias Noe, "The AmpaCity Project," T&D World, December 2013, https://www.tdworld.com/overhead-distribution/article/20964180/the-ampacity-project.