TRANSMISSION EXPANSION VIA OPTIMIZATION OF EXISTING SYSTEM AND RIGHTS-OF-WAY

COLORADO
ELECTRIC TRANSMISSION AUTHORITY

Masters of
the Environment

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ACRONYMS

AAR	Ambient Adjusted Ratings
AC	Alternating current
ACCC	Aluminum Conductor Carbon Core
ACSR	Aluminum Conductor Steel Reinforced
ACSS	Aluminum Conductor Steel Supported
AECC	Aluminum Encapsulated Carbon Core
APFC	Advanced Power Flow Controller
AR	Advanced Reconductoring
ARPA-E	Advanced Research Projects Agency-Energy
ATT	Advanced Transmission Technology
CETA	Colorado Electric Transmission Authority
DLR	Dynamic Line Rating
DOE	Department of Energy
DOT	Department of Transportation
EPRI	Electric Power Research Institute
EV	Electric Vehicle
FACTS	Flexible Alternating Current Transmission Systems
FERC	Federal Energy Regulatory Commission
GET	Grid Enhancing Technology
GW	Gigawatt
HVDC	High Voltage Direct Current
kV	Kilovolt
MW	Megawatt
NWA	Non-Wires Alternative
PBR	Performance Based Ratemaking
PFC	Power Flow Controllers
PPL	Pennsylvania Power and Light Electric Utilities
PUC	Public Utilities Commission
ROW	Right-of-way
SATA	Storage as a Transmission Asset
SeaLR	Seasonal Line Ratings
SLR	Static Line Ratings
TCA	Topology Control Algorithm
TO	Topology Optimization
TW	Terawatts
TSO	Transmission System Operators
VPP	Virtual Power Plant

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EXECUTIVE SUMMARY

Introduction

Today's existing transmission system is outdated and growing too slowly, resulting in significant challenges as it is unable to keep up with growing power demands and clean energy goals.[1] Significant growth in rates of electrification, clean energy integration, manufacturing, data processing, and population size have driven the need for increased transmission capacity.[2] Specifically for Colorado, CETA's Transmission Study report highlights that transmission capacity will need to double by 2045, stemming from an equal increase in electric load during that time.[3]

Despite this urgent need, recent transmission expansion efforts have been inefficient and, in some areas, nonexistent, as capacity in the U.S. has only grown by 1% per year over the last decade.[4] Traditionally, transmission expansion efforts have focused on constructing new lines on greenfield sites, yet this is no easy feat as stakeholder conflicts, high costs, and extensive siting and permitting processes often result in significant time delays.[5] While it is undeniable that these prolonged projects are needed in the long run, multiple alternative solutions that provide grid

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[1] Americans for a Clean Energy Grid, "State Policies to Advance Transmission Modernization and Expansion," September 2024, 2, https://cleanenergygrid.org/wp-content/uploads/2024/09/ACEG_State-Policies-to-Advance-Transmission.pdf.; Jake Gentle and Ethan Huffman, "Transmission Optimization with Grid-Enhancing Technologies Overview," Idaho National Laboratory, 2022, 1 https://inl.gov/content/uploads/2023/07/Transmission-Optimization-with-Grid-Enhancing-Technologies.pdf.; Katie Mulvaney, Katie Siegner, Chaz Teplin, and Sarah Toth, "GETting Interconnected in PJM: Grid-Enhancing Technologies (GETs) Can Increase the Speed and Scale of New Entry from PJM's Queue," RMI, February 2024, 8, https://rmi.org/wp-content/uploads/dlm_uploads/2024/02/GETs_insight_brief_v3.pdf.

[2] "Clean Energy Resources to Meet Data Center Electricity Demand," U.S. Department of Energy Office of Policy, August 12, 2024, https://www.energy.gov/policy/articles/clean-energy-resources-meet-data-center-electricity-demand.

[3] "Transmission Expansion Study for Colorado," Colorado Electric Transmission Authority, Gridworks, and Energy Strategies, August 26, 2024. https://static1.squarespace.com/static/6390da3a799a023d4be2c27e/t/66cd302f7f033d21278703c7/1724723258053/CO+PUC+-+CETA+Tx+Study+Briefing+-+240823.pdf.

[4] Americans for a Clean Energy Grid, "State Policies to Advance Transmission Modernization and Expansion," 2.; Emilia Chojkiewicz, Umed Paliwal, Nikit Abhyankar, Casey Baker, Ric O'Connell, Duncan Callaway, and Amol Phadke. "2035 and Beyond Report: Reconductoring With Advanced Conductors Can Accelerate the Rapid Transmission Expansion Required For a Clean Grid," GridLab, April 2024, 2, https://www.2035report.com/wp-content/uploads/2024/04/GridLab_2035-Reconductoring-Technical-Report.pdf.

[5] Catherine Clifford, "Why It's so Hard to Build New Electrical Transmission Lines in the U.S.," CNBC, February 21, 2023, https://www.cnbc.com/2023/02/21/why-its-so-hard-to-build-new-electrical-transmission-lines-in-the-us.html.; Kelsey Murlless and Shane Londagin, "Unlocking Our Power Grid's Potential," Third Way, May 22, 2024, https://www.thirdway.org/memo/unlocking-our-power-grids-potential.; "National Transmission Needs Study," Washington, DC, United States: U.S. Department of Energy, October 2023, https://www.energy.gov/sites/default/files/2023-12/National%20Transmission%20Needs%20Study%20-%20Final_2023.12.1.pdf.

stress relief and capacity increases are available.[6] These solutions, which include the use of existing rights-of-way (ROW), grid-enhancing technologies (GETs), and advanced reconductoring (AR), are ultimately complementary to the construction of new transmission as they can address grid challenges in the near term while longer projects are being completed.[7]

Purpose

The purpose of this Capstone Project is to investigate the use of existing ROWs, GETs, and AR to enhance and speed up transmission expansion within Colorado. Through a literature review and interviews with industry professionals, this report aims to provide a comprehensive overview of the solutions at hand. While these solutions can be implemented much quicker and for lower costs than traditional greenfield transmission expansion, they are not yet scaled or considered as a go-to option. This report concludes eight with recommendations for CETA to consider to help Colorado make better use of its existing ROWs to make a larger, more resilient, and cleaner grid.

Solutions Researched

The Use of Existing ROWs

Existing Transmission

- Existing transmission ROWs refer to land with pre-existing transmission infrastructure and permits; in certain instances, it is possible to co-locate additional infrastructure within the same corridor.

Highway

- Co-locating transmission within highway corridors provides transmission projects with a direct route to nearby population centers with high electricity demands. Both linear routes and proximity to population centers can decrease project capital expenditures.[8]

Railroads

- Lines are often buried underground in railroad ROWs. Undergrounding brings many benefits, such as reduced landowner and stakeholder conflicts, avoided

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[6] "Dynamic Line Rating," Washington, DC, United States: U.S. Department of Energy, June 2019, 3, https://www.energy.gov/oe/articles/dynamic-line-rating-report-congress-june-2019; Murlless and Londagin, "Unlocking Our Power Grid's Potential."

[7] T. Bruce Tsuchida and Rob Gramlich, "Improving Transmission Operation with Advanced Technologies: A Review of Deployment Experience and Analysis of Incentives," The Brattle Group, June 24, 2019, 2-6, https://www.brattle.com/wp-content/uploads/2021/05/16634_improving_transmission_operating_with_advanced_technologies.pdf.

[8] Randy Satterfield, Randy and Matthew Prorok, CU MENV Capstone Project Interview with NextGen Highways, July 9, 2024.

land and ecosystem disturbance, increased reliability and resilience, reduced aesthetic impacts, and enhanced safety.[9]

The Implementation of GETs

Dynamic Line Ratings (DLRs)

- DLRs use software and sensors to continually calculate line ratings based on real-time operations and environmental conditions, including ambient temperature, wind speed and direction, and solar radiation.[10] DLRs almost always have higher carrying capacities than current methods because these methods fail to account for the impact of real-time environmental and operational conditions on a line's capacity.[11]

Advanced Power Flow Controllers (APFCs)

- Power Flow Controllers (PFCs) are used to control how power flows by physically rerouting power away from overload lines and pushing or pulling it to underutilized lines within the transmission network.[12] Today's APFC technologies offer notable advantages over traditional PFC as they can be dynamically controlled in a quick and responsive manner, and they can provide dynamic services such as transient stability improvement and oscillation damping.[13]

Topology Optimization (TO)

- TO manages congestion by reconfiguring the transmission system to redirect power around congested or overloaded transmission elements.[14] New TO software relies on topology control algorithms (TCAs) to quickly identify and

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[9] Jeff St. John, "How Transmission along Railroads and Highways Could Break Open Clean Energy Growth," Canary Media, April 26, 2021, https://www.canarymedia.com/articles/transmission/how-transmission-along-railroads-and-highways-could-break-open-clean-energy-growth.; "Resilience," SOO Green HVDC Link, accessed December 17, 2024, https://soogreen.com/resilience/.

[10] "Smarter use of the dynamic grid: accessing transmission headroom through GETs deployment," AES Corporation, April 2024, 6, https://www.aes.com/sites/aes.com/files/2024-04/Smarter-Use-of-the-Dynamic-Grid-Whitepaper.pdf.; "Grid-Enhancing Technologies: A Case Study on Ratepayer Impact," Washington, DC, United States: U.S. Department of Energy, February 2022, 6, https://www.energy.gov/sites/default/files/2022-04/Grid%20Enhancing%20Technologies%20-%20A%20Case%20Study%20on%20Ratepayer%20Impact%20-%20February%202022%20CLEAN%20as%20of%20032322.pdf; Srishti Slaria, Molly Robertson, and Karen Palmer, "Expanding the Possibilities: When and Where Can Grid-Enhancing Technologies, Distributed Energy Resources, and Microgrids Support the Grid of the Future?" Resources for the Future, September 2023, 2-3, https://media.rff.org/documents/Report_23-13.pdf.

[11] "Innovative Landscape Brief: Dynamic Line Rating," International Renewable Energy Agency, 2020, 7, https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2020/Jul/IRENA_Dynamic_line_rating_2020.pdf.; "Grid-Enhancing Technologies: A Case Study on Ratepayer Impact," 75.

[12] "Technology Solutions," WATT Coalition, October 14, 2017. https://watt-transmission.org/page-4/.

[13] "Advanced Power Flow Control (APFC)," Electric Power Research Institute (EPRI), June 2024. 1. https://restservice.epri.com/publicdownload/000000003002030548/0/Product.

[14] J. Caspary, D. Bowman, K. Dial, R. Schoppe, Z. Sharp, C. Cates, J. Tanner, P. A. Ruiz, X. Li, and T. B. Tsuchida. "Application of Topology Optimization in Real-Time Operations," CIGRE United States, 2019, 1, https://cigre-usnc.org/wp-content/uploads/2019/10/4B_3.pdf.

evaluate one or more beneficial reconfigurations that take advantage of the transmission network's flexibility and meshed nature to reduce constraints while meeting reliability criteria.[15]

Advanced Reconductoring

Reconductoring with Carbon Core Advanced Conductors (AC)

- Reconductoring is the process of replacing old existing wires with new ones that offer more capacity. Using old conductor technology, such as aluminum conductor steel reinforced (ACSR) or aluminum conductor steel supported (ACSS), will require tower retrofits, which significantly increase capital expenditure for a reconductoring project.[16] However, newer technology using carbon core conductors results in stronger, lighter wires with significantly reduced risk of line sag, which allows a reconductoring project to add capacity without tower retrofit and ultimately results in lower project costs.[17]

Recommendations

Recommendation 1: Consideration of Advanced Transmission Technologies (ATTs)[18]

CETA should consider ATTs for all its transmission projects and planning studies and call on the Colorado Public Utilities Commission to require utilities to consider ATTs. CETA should also consider asking the state legislature for funding for CETA to incorporate ATT potential into future Transmission Studies. Benefits from implementation include:

- Insight into the application and benefits of ATTs
- Increased renewable interconnection and reduced retail electricity rates
- Improved planning procedures, grid resiliency, and reliability

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[15]Pablo A. Ruiz, "Transmission Topology Optimization," August 21, 2017, 3, https://www.brattle.com/wp-content/uploads/2017/10/7204_transmission_topology_optimization.pdf.; Slaria et al., "Expanding the Possibilities: When and Where Can Grid-Enhancing Technologies, Distributed Energy Resources, and Microgrids Support the Grid of the Future?" 7.; "Transmission Topology Optimization," EPRI, June 19, 2024, https://www.epri.com/research/products/000000003002030549.

[16]AMP Coalition and Grid Strategies, "Unlocking the Grid: A Playbook on High Performance Conductors for State and Regional Regulators and Policymakers," American Council on Renewable Energy (ACORE), October 2024, 2-6, https://acore.org/wp-content/uploads/2024/10/Unlocking-the-Grid-A-Playbook-on-High-Performance-Conductors-for-State-and-Regional-Regulators-and-Policymakers.pdf.

[17]"TS Conductor Raises $60 Million from Industry-Leading Investors to Expand US Production of High-Capacity Power Lines," PRWeb, July 31, 2024, https://www.prweb.com/releases/ts-conductor-raises-60-million-from-industry-leading-investors-to-expand-us-production-of-high-capacity-power-lines-302207238.html.

[18] *Note: The terms grid enhancing technologies (GETs) and advanced transmission technologies (ATTs) will be used frequently throughout this report. Each of these terms refers to a broad suite of technologies. The technologies listed under each umbrella term here are not the all-encompassing list of technologies that can be considered GETs or ATTs. Within the context of this report, GETs include dynamic line rating (DLR), topology optimization (TO), and advanced power flow controllers (APFCs), while ATTs include GETS and advanced conductors (AC).*

Recommendation 2: Priority Siting Order for New Lines

CETA should advocate for the state legislature to enact a bill similar to Wisconsin Act 89 (2003) to set a priority order for siting new electric transmission facilities: 1. Existing utility corridors; 2. Highway and railroad corridors; 3. New corridors.[19] Benefits from implementation include:

- Significantly shorter time required for permitting
- Significant cost savings related to permitting
- Fewer landowner and stakeholder conflicts

Recommendation 3: CETA-Supported Demonstrations of ATTs

CETA should request funding from the state legislature to support CETA-run pilot projects that investigate the incorporation of ATTs into Colorado's electricity grid in order to demonstrate their benefits. Benefits from implementation include:

- Demonstrate the feasibility of these technologies in Colorado
- Increase utility willingness in implementing GETs and completing advanced reconductoring projects
- Pioneer Colorado's deployment of these technologies

Recommendation 4: Public Education and Transmission Workshops

CETA should promote public education materials and opportunities for consumers, utilities, and transmission owners in partnership with organizations prioritizing the use of existing ROW (i.e., NextGen Highways, National Audubon Society, and The Nature Conservancy). Benefits from implementation include:

- Increase public knowledge and support for the use of existing ROW and ATTs
- Facilitate strategic partnerships

Recommendation 5: Shared Savings Cost Model & Performance Based Ratemaking (PBR)

CETA should advocate at the Colorado PUC and state legislature to establish ways to properly incentivize the deployment of GETs (DLR, TO, and APFC), including a shared savings cost model for utilities. Benefits from implementation include:

- Align utilities with the ratepayer requirement of "just and reasonable" rates
- Establish financial incentives to promote utility-scale GETs deployment

Recommendation 6: "Maximum Net Benefits" Framework

CETA should advocate for the Colorado PUC and state utilities to adopt a planning and project evaluation framework that promotes the adoption of ATTs in Colorado. In

[19] "Keys to Siting and Building Transmission in Highway Rights-of-Way," NextGen Highways, November 2022, 2, https://nextgenhighways.org/wp-content/uploads/2023/01/NGH_Keys-to-Siting-Building-Transmission-Highway-ROW.pdf.

order to do this, CETA should call on the PUC and utilities to adopt a "maximum net benefits" framework in their decision-making processes.[20] Benefits from implementation include:

- Replace the current "least cost" framework that hinders the adoption of ATTs by prioritizing technologies that have lower initial capital expenditure costs rather than those providing maximum net benefits[21]
- Deliver valuable benefits to Colorado and ratepayers

Recommendation 7: Data Sharing of Existing Transmission Infrastructure

CETA should recommend that the Colorado PUC direct utilities to compile data on their transmission infrastructure in Colorado (age, type, location, and manufacturer), and then submit all data for CETA to compile to create a GIS map and run a cost-benefit analysis on reconductoring older lines. Benefits from implementation include:

- Better data for CETA's Transmission Study
- Better insights when deciding whether or not to reconductor lines with advanced conductors
- Enable the creation of schedules for replacing existing infrastructure

Recommendation 8: Non-Wires Alternatives (NWAs)

CETA should research and consider other NWA solutions, specifically how they could be incorporated within future transmission planning. NWAs include a multitude of technologies that can defer or eliminate the need for traditional and costly "wires-and-poles" infrastructure in specific locations while also saving ratepayers money.[22]

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[20] "Recommended Actions for State Regulators to Unlock Transmission Capacity through the Deployment of ATTs," AMP Coalition and WATT Coalition, August 2024, 2, https://watt-transmission.org/wp-content/uploads/2024/08/WATT-and-AMP-Recommended-Priorities-for-State-Regulators-to-Unlock-Transmission-Capacity.pdf.

[21] Jay Caspary and Jesse Schneider, "Advanced Conductors on Existing Transmission Corridors to Accelerate Low Cost Decarbonization," Grid Strategies, March 2022, https://acore.org/wp-content/uploads/2022/03/Advanced_Conductors_to_Accelerate_Grid_Decarbonization.pdf.; "Recommended Actions for State Regulators to Unlock Transmission Capacity through the Deployment of ATTs," 2.

[22] Mark Dyson, Jason Prince, Lauren Shwisberg, and Jeff Waller, "The Non-Wires Solutions Implementation Playbook," RMI, December 2018, 6, https://rmi.org/wp-content/uploads/2018/12/rmi-non-wires-solutions-playbook-report-2018.pdf.; *Note: this is not within the scope of this project, but these are solutions we find compelling for CETA's further consideration.*

1. INTRODUCTION

Transmission is the backbone of the energy grid as it ensures electricity is affordably, reliably, and resiliently delivered from generation to demand.[23] Yet, today's existing transmission system is outdated and growing too slowly, resulting in significant challenges as it is not able to keep up with growing power demands and clean energy goals.[24] Significant growth in rates of electrification, clean energy integration, manufacturing, data processing, and population size have driven the need for increased transmission capacity.[25] Multiple credible studies have identified an unprecedented need for transmission buildout in order to maintain grid reliability and resiliency, meet energy demands, and integrate over 2 TW of available clean energy generation currently stuck in interconnection queues.[26] Both the U.S. Department of Energy (DOE) and the Massachusetts Institute of Technology have estimated that the nation needs to double or even triple current transmission capacity in the next 10 to 20 years.[27] Specifically for Colorado, CETA's Transmission Study report highlights that transmission capacity will need to double by 2045, stemming from an equal increase in electric load during that time.[28]

Despite this urgent need, recent transmission expansion efforts have been inefficient and, in some areas, nonexistent, as capacity in the U.S. has only grown by 1% per year over the last decade.[29] Traditionally, transmission expansion efforts have focused on the construction of new lines on greenfield sites, yet this is no easy feat as stakeholder conflicts, high costs, and extensive siting and permitting processes often result in significant time delays.[30] Generally, it takes between five and fifteen

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[23] Americans for a Clean Energy Grid, "State Policies to Advance Transmission Modernization and Expansion," 2.; "Advanced Transmission Technologies," Washington, DC, United States: U.S. Department of Energy, December 2020, i, https://www.energy.gov/sites/prod/files/2021/02/f82/Advanced%20Transmission%20Technologies%20Report%20-%20final%20as%20of%2012.3%20-%20FOR%20PUBLIC.pdf.
[24] "State Policies to Advance Transmission Modernization and Expansion," 2.; Gentle and Huffman, "Transmission Optimization with Grid-Enhancing Technologies Overview," 1.; Mulvaney et al., "GETting Interconnected in PJM: Grid-Enhancing Technologies (GETs) Can Increase the Speed and Scale of New Entry from PJM's Queue," 8.
[25] "Clean Energy Resources to Meet Data Center Electricity Demand."
[26] T. Bruce Tsuchida, Linquan Bai, Jadon M. Grove, and The Brattle Group, "Building a Better Grid: How Grid Enhancing Technologies Complement Transmission Buildouts," The Brattle Group, April 20, 2023, 3, https://www.brattle.com/wp-content/uploads/2023/04/Building-a-Better-Grid-How-Grid-Enhancing-Technologies-Complement-Transmission-Buildouts.pdf.; "National Transmission Needs Study," vi-vii.; Chojkiewicz et al.,"2035 and Beyond Report: Reconductoring With Advanced Conductors Can Accelerate the Rapid Transmission Expansion Required For a Clean Grid," 2.
[27] Tsuchida et al., "Building a Better Grid: How Grid Enhancing Technologies Complement Transmission Buildouts,"8.
[28] "Transmission Expansion Study for Colorado."
[29] Americans for a Clean Energy Grid, "State Policies to Advance Transmission Modernization and Expansion," 2.; Chojkiewicz et al.,"2035 and Beyond Report: Reconductoring With Advanced Conductors Can Accelerate the Rapid Transmission Expansion Required For a Clean Grid," 2.
[30] Clifford, "Why It's so Hard to Build New Electrical Transmission Lines in the U.S."; Murlless and Londagin, "Unlocking Our Power Grid's Potential."; "National Transmission Needs Study," vii.

years to develop transmission on new greenfields.[31] While it is undeniable that these prolonged projects are needed in the long run, multiple alternative solutions that provide grid stress relief and capacity increases are available.[32] These solutions, which include the use of existing rights-of-way (ROW), grid-enhancing technologies (GETs), and advanced reconductoring (AR), are ultimately complementary to the construction of new transmission as they can address grid challenges in the near term while longer projects are being completed.[33]

The purpose of this Capstone Project is to investigate the use of existing ROWs, GETs, and AR to enhance and speed up transmission expansion within Colorado. Through a literature review and interviews with industry professionals, this report aims to provide a comprehensive overview of the solutions at hand. Expanding upon these solutions, this report concludes with a series of recommendations for CETA to consider in order to better incorporate these solutions and technologies into future transmission planning and development. Implementing these solutions would ensure Colorado is equipped with the tools necessary to meet its clean energy goals and ensure grid reliability and resiliency in the short- and long-term.

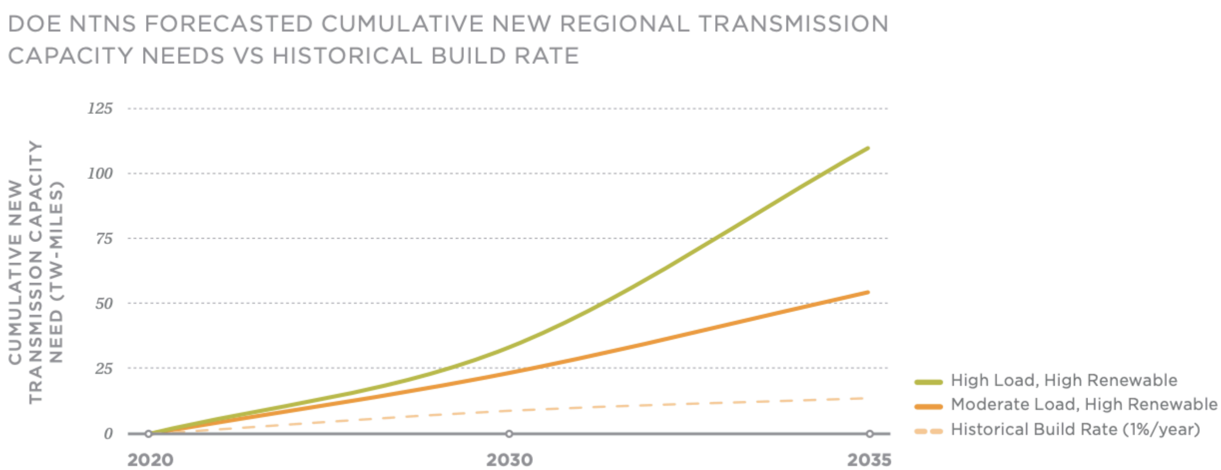
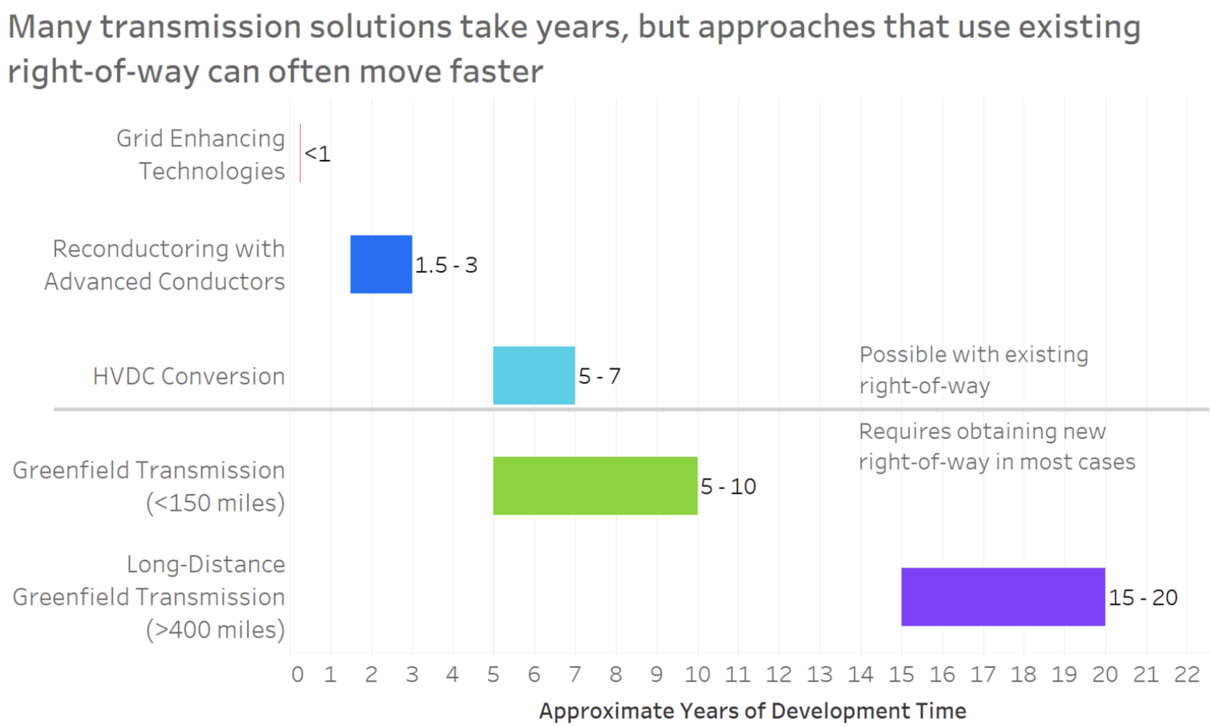


FIGURE 1: *Transmission Capacity Needs vs. Historical Build Rate.* The U.S. DOE 2023 National Transmission Needs Study compared forecasted regional capacity expansion needs to the historical growth rate (1% per year). The DOE estimates that transmission capacity must increase by 60% to 125% by 2035 to meet federal energy goals.[34]

[31] Chojkiewicz et al.,"2035 and Beyond Report: Reconductoring With Advanced Conductors Can Accelerate the Rapid Transmission Expansion Required For a Clean Grid," 2.
[32] "Dynamic Line Rating," 3.; Murlless and Londagin, "Unlocking Our Power Grid's Potential."
[33]Tsuchida and Gramlich, "Improving Transmission Operation with Advanced Technologies: A Review of Deployment Experience and Analysis of Incentives," 2-6.
[34] David Paolella, "Both/And—We Should Boost Existing Transmission Today and Build New Lines for Tomorrow," Breakthrough Energy US Policy, April 9, 2024.
https://www.breakthroughenergy.org/newsroom/articles/reconductoring/.



Sources: E. Chojkiewicz, U. Paliwal, N. Abhyankar, C. Baker, R. O'Connell, D. Callaway, A. Phadke, "Reconductoring Reconductoring with advanced conductors can accelerate the rapid transmission expansion required for a clean grid", (GridLab, 2024); Cembalest, "Eye on the Market 14th Annual Edition," (J.P. Morgan, 2024).

FIGURE 2: *Transmission Solution Development Timelines.* Obtaining new ROW for new transmission lines takes many years. In the meantime, transmission capacity can be quickly expanded by upgrading lines on existing ROWs.[35]

2. EXISTING RIGHTS-OF-WAY

2.1 Introduction to Rights-of-Way

"Transmission congestion and the long lag time it takes to permit and site new transmission infrastructure is one of the barriers to Colorado achieving its energy goals."[36]

– Randy Satterfield, *Executive Director, NextGen Highways*

Siting new transmission lines on existing ROWs, rather than greenfield sites, is an effective way to mitigate the permitting, siting, and stakeholder challenges typically faced when developing new transmission. By using previously disturbed and permitted land, transmission developers can minimize land conflicts and avoid delays in siting and permitting, subsequently saving money. As a result, local citizens and other stakeholders often prefer using existing corridors when available and

[35] Randy Satterfield and Matthew Prorok. CU MENV Capstone Project Interview with NextGen Highways, July 9, 2024.

[36] Drew Henry, "Colorado Coalition to Advocate for Building Transmission Along Highways," NextGen Highways, September 9, 2024, https://nextgenhighways.org/colorado/.

feasible.[37] Despite these benefits, the U.S. fails to optimize the use of its existing ROWs when compared to other developed countries.[38] Several different types of ROWs can be used for transmission siting. Figure 3 below presents the three types of ROWs most compelling for further use in Colorado – existing transmission, highways, and railroads – that should be considered before and prioritized over greenfield sites. Greenfield development should be the last option considered.

2.2 Existing Transmission

Existing transmission ROWs refer to land with pre-existing transmission infrastructure and permits; in certain instances, it is possible to co-locate additional infrastructure within the same corridor. Environmental NGOs, including National Audubon Society, support the use of existing transmission corridors to site new projects, as their use minimizes habitat and wildlife impact.[39] Avoiding controversy with environmentalists is another effective way to save time and money throughout the siting process. If a transmission developer or utility already owns the ROW permit, it could be the cheapest solution possible, as no new permits need to be acquired. Additionally, the visual impacts are mitigated if transmission infrastructure already exists in the corridor, reducing the likelihood of landowner pushback.[40] However, existing transmission ROWs are not a one-size-fits-all solution for siting as the proximity of adjacent lines can raise reliability concerns, particularly in relation to extreme weather events or environmental disasters that could put multiple lines out of service at once.[41]

2.3 Highways

Co-locating transmission within highway corridors provides transmission projects with a direct route to nearby population centers with high electricity demands. Both linear routes and proximity to population centers can decrease project capital expenditures.[42] Despite these benefits, the siting of new transmission in highway ROWs is often thwarted by existing policies at the state Departments of

[37]Nick Miller, "High Power Density on Existing Transmission ROW," Burns McDonnell, May 5, 2022, https://blog.burnsmcd.com/existing-corridor-considerations-in-transmission-line-route-selection.
[38] Miller, "High Power Density on Existing Transmission ROW," 2.
[39] Brook Bateman, Gary Moody, Jennifer Fuller, Taylor Lotem, Nat Seavy, Joanna Grand, Jon Belak, Garry George, Chad Wilsey, and Sarah Rose,"Birds and Transmission: Building the Grid Birds Need," National Audubon Society, 2023, 17, https://media.audubon.org/2024-10/Final_BirdsAndTransmission_Audubon2024.pdf.
[40] Joseph Donaldson, "Mitigating Visual Impacts of Utility-Scale Energy Projects," US Department of Agriculture Forest Service, accessed August 4, 2024, 238, https://www.fs.usda.gov/nrs/pubs/gtr/gtr-nrs-p-183papers/23-donaldson-VRS-gtr-p-183.pdf.
[41] Miller, "High Power Density on Existing Transmission ROW," 2.
[42] Randy Satterfield and Matthew Prorok. CU MENV Capstone Project Interview with NextGen Highways, July 9, 2024.

Transportation (DOT).[43] For example, many state DOTs explicitly prohibit the co-location of utility infrastructure on their ROWs, including those of highways.[44] Furthermore, state DOTs have raised concerns about the potential impacts of transmission infrastructure on worker safety, traffic, and future highway expansion efforts.[45]

Despite these obstacles, the siting of new transmission infrastructure in existing highway ROWs is a feasible solution in the U.S. that has already been successfully demonstrated. Colorado's largest utility, Xcel Energy, has experience with such projects as an owner of the Badger-Coulee line built on the Interstate 90-94 corridor in Minnesota and Wisconsin.[46] The organization NextGen Highways has pioneered and demonstrated successful use of existing highway corridors for new transmission lines for decades. At its core, NextGen Highways works to promote the construction of transmission infrastructure in existing public ROWs through the development of national and state-level coalitions.[47] Work is already well underway in Colorado, with a partnership of a Colorado Coalition between CETA and NextGen Highways.[48]

Using highway corridors to site new transmission lines would strengthen the grid, increase energy resiliency, reduce energy costs, enable more clean energy generation, enable more EV fast charging, and more.[49] Not only would it help Colorado meet its decarbonization goals much faster, but it would also result in cheaper electricity costs for ratepayers compared to more transmission on greenfield sites.

2.4 Railroads

The use of railroad ROW brings many benefits, such as reduced landowner conflict due to many reduced visual impacts as new lines are often placed underground.[50] Furthermore, projects in railroad ROWs receive greater support from local communities and environmentalists because the existing ROW's land has already been disturbed. As a result, the addition of a new line on a railway ROW

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[43] "Transmission in Highway ROW: Design Considerations," NextGen Highways, June 2023, 1, https://nextgenhighways.org/wp-content/uploads/2023/06/1-Transmission-in-Highway-ROW-DesignConsiderations-.pdf.
[44] Randy Satterfield and Matthew Prorok. CU MENV Capstone Project Interview with NextGen Highways, July 9, 2024.
[45] Satterfield, Randy, and Matthew Prorok.
[46] "Minnesota Takes Rare Step to Allow Power Lines alongside Highways," Canary Media, June 12, 2024, https://www.canarymedia.com/articles/transmission/minnesota-transmission-grid-power-lines-highway.
[47] "About Us," NextGen Highways, accessed December 17, 2024, https://nextgenhighways.org/about-us/.
[48] Henry, "Colorado Coalition to Advocate for Building Transmission Along Highways."
[49] "NextGen Highways: Co-Locating the Transport of Vehicles, Energy and Information," NGI Consulting. October 2021, 2, https://nextgenhighways.org/wp-content/uploads/2023/01/NextGen-Highways-Coalition.pdf.
[50] St. John, "How Transmission along Railroads and Highways Could Break Open Clean Energy Growth."

reduces the need for tree clearing and eliminates threats to sensitive species such as migratory birds, bats, and native plants.[51] National Audubon Society is particularly supportive of underground lines, as it reduces collision risk for birds.[52] In addition to environmental benefits, undergrounding lines increases their reliability and resilience during natural disasters, provides protection from tree branches and animals (which are a prevalent cause of outages), reduces the risk of electrocution, and avoids negative aesthetic impacts.[53] It is also important to note that undergrounding lines is not an easy task. In a 2014 report, Xcel Energy explains how underground transmission is noticeably more expensive in upfront capital costs.[54] However, grid planners are having to weigh the pros and cons of underground versus overhead lines, particularly as extreme weather becomes a larger threat to the grid.[55] One rural electric cooperative notes that it costs approximately three to five times more per foot to construct transmission underground and is more expensive to maintain long-term.[56] Extra caution must also be taken when digging or completing other construction nearby in order to prevent damage or electrocution.[57]

In some cases, it may be challenging to develop new transmission in existing railroad ROWs due to the fact that a corridor's geography significantly impacts its feasibility for use in transmission siting. For example, co-location may be difficult in parts of Colorado where railroads cross over or through mountains. Furthermore, power lines can threaten the safety of both railroad signaling and crew members.[58] Multiple mitigation measures are available, such as adding a counterpoise – also known as a mitigation wire – to minimize the effects of induction on railroad signaling, but the most common approach is to underground lines.[59]

Today, transmission projects have recently seen success along railroad corridors, particularly with the SOO Green HVDC Link, a 350-mile, 2,100 MW underground HVDC line running along railroads from North Central Iowa to Northern Illinois, which aims to reach commercial operation in 2027.[60] This project could

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[51] "Environmental Benefits," SOO Green HVDC Link, accessed December 17, 2024, https://v1q.db7.myftpupload.com/environmental-benefits/.
[52] Bateman et al.,"Birds and Transmission: Building the Grid Birds Need," 17.
[53] "Resilience."
[54]"Overhead vs. Underground: Information About Burying High-Voltage Transmission Lines," Xcel Energy, May 2014, 2, https://www.xcelenergy.com/staticfiles/xe/Corporate/Corporate%20PDFs/OverheadVsUnderground_FactSheet.pdf.
[55] "Underground vs. Overhead Power Lines," Lane Electric, accessed December 17, 2024, https://laneelectric.com/programs-services/underground-vs-overhead-power-lines/.
[56] "Underground vs. Overhead Power Lines."
[57] "Underground vs. Overhead Power Lines."
[58]Ryan Cisko, "The Effect of Transmission Lines on Railroads," T&D World, October 2018. https://www.tdworld.com/overhead-distribution/article/20971744/the-effect-of-transmission-lines-on-railroads.
[59]Cisko, "The Effect of Transmission Lines on Railroads."
[60] "About," SOO Green HVDC Link, accessed December 17, 2024, https://soogreen.com/about/.; Steve Frenkel, "SOO Green HVDC Link: Response to the Illinois Commerce Commission Notice of Inquiry Regarding the

enable more than 4 GW of renewable generation, as well as improve grid system reliability.[61]

2.5 Existing Rights-of-Way vs. Greenfields Summary

Below is a chart summarizing the benefits and considerations of using each type of existing ROW for transmission siting in contrast to the top row of greenfield siting.

	ROW Type	Benefits	Considerations	Examples
New	**Greenfield**	Potential for more direct routes and less infrastructure	- Permitting and siting processes can take very long time[62] - Transmission projects on greenfields usually take more than a decade to permit	Example with the TransWest Express project that took 15 years to secure approval[63]
Existing	**Existing Transmission**	- Avoids disturbing new land and habitat - Fewer agreements required with landowners (potential to save immense amount of money and time on permitting)[64]	- Reliability concerns (extreme weather could take out both lines) - Consider age of ROW and new	Xcel, Tri-State, and Black HIlls do consider this in transmission planning, as well as cost: "The positive impact to the environment of utilizing existing transmission corridors or upgrading existing facilities rather than constructing new ones"[65]
	Highway		- Concerns about safety and traffic during construction and limited potential to expand	- Successful application in WI since the early 2000s (Next Gen Highway work)[66]

Infrastructure Investment and Jobs Act," SOO Green HVDC Link ProjectCo., accessed July 27, 2024, https://icc.illinois.gov/api/web-management/documents/downloads/public/NOI/NOI%20SOO%20Green%20HVDC%20Initial%20Comments%2022-NOI-01.pdf.

[61] "SOO Green HVDC Link: Renewable Energy," SOO Green, accessed December 18, 2024, https://soogreen.com/renewable-energy/.

[62] "National Transmission Needs Study." Washington DC, United States: U.S. Department of Energy, October 2023, page 10. https://www.energy.gov/sites/default/files/2023-12/National%20Transmission%20Needs%20Study%20-%20Final_2023.12.1.pdf.

[63] Greg Brophy, "The TransWest Express Transmission Line Is a Win for Rural Communities. Why Did Approval Take 15 Years?" Utility Dive, May 16, 2023, https://www.utilitydive.com/news/transwest-express-transmission-permitting-reform-brophy/650342/.

[65] Xcel Energy, Tri-State Generation and Transmission Association, and Black Hills Energy, "10-Year Transmission Plan For the State of Colorado," February 2022, https://www.transmission.xcelenergy.com/staticfiles/microsites/Transmission/Files/2022%2010-Year%20Report,%20Rev%202.pdf.

[66] "Keys to Siting and Building Transmission in Highway Rights-of-Way," 1.

		- Great option if enough space existing for new line, or corridor is easy to widen with minimal time and money	lanes in future - Often requires the removal of prohibitive policy - Thorough planning required with state DOT	- Xcel has prior experience, as part owner of Badger Coulee transmission line (completed 2018)
	Railroad		- Corridor is not always wide enough, can require more permitting effort & money for expansion compared to other existing ROW - Additional planning required to mitigate impacts to railroad signaling - Not necessarily close to high load centers	SOO Green Line (from Mason City, IA to Chicago, IL) using undergrounded HVDC[67]

FIGURE 3: *Types of ROWs used in transmission.* This figure compares new greenfields to existing ROWs, including their types, benefits, considerations, and examples. Note that this list is not exhaustive, other ROWs could be included here (such as siting transmission along recreational trails, rivers or next to pipelines). However, we feel that existing transmission, highway, and railroad ROWs are more compelling for consideration within Colorado; these should be CETA's primary focus.

3. GRID ENHANCING TECHNOLOGIES

3.1 Introduction to Grid Enhancing Technologies

GETs are relatively simple hardware and/or software solutions that can be added to the existing grid to increase transmission capacity, efficiency, reliability, and to ensure the safety of power lines.[68] Compared to new lines, GETs can be implemented and deliver benefits in a shorter period of time for a lower cost.[69] While GETs can include a longer list of technologies, this report focuses on the three primary technologies: dynamic line ratings (DLR), advanced power flow controllers (APFCs), and topology optimization (TO) (Figure 4).

[64] Brian Martucci, "NextGen Highways Launches Effort to Build Transmission Lines along Public Right of Way in Minnesota," Utility Dive, February 20, 2024, https://www.utilitydive.com/news/highway-electric-transmission-infrastructure-siting/707922/.
[67] David Roberts, "Transmission Fortnight: Burying Power Lines Next to Rail & Roads to Make a National Transmission Grid," Volts Podcast, February 1, 2021, https://www.volts.wtf/p/transmission-fortnight-burying-power.
[68] "Unlocking Power: What Are Grid Enhancing Technologies?" WATT Coalition, accessed December 17, 2024, 1, https://watt-transmission.org/wp-content/uploads/2024/11/Unlocking-Power-What-are-Grid-Enhancing-Technologies.pdf.
[69] "Unlocking Power: What Are Grid Enhancing Technologies?" 1.

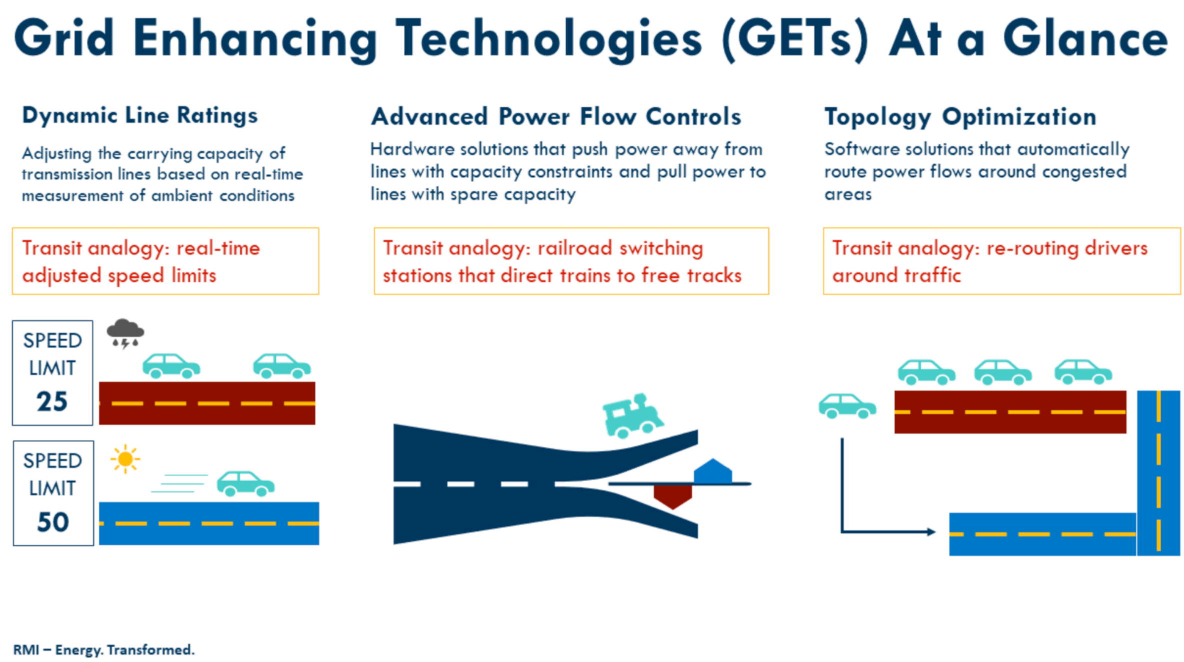


FIGURE 4: *GETs Transit Analogies.* Transit analogies have commonly been used to explain GETs, their functions, and their benefits. RMI published the above graphic to depict these analogies.[70]

Looking at the U.S. as a whole, Rob Gramlich argues that "less transmission development is planned [into the future], aging lines will soon be retired, and utility-scale renewables installed at remote locations will take up more system capacity," which will result in higher levels of congestion costing ratepayers $6 billion annually.[71] The WATT Coalition states that deploying GETs could reduce these costs by $2 billion.[72] The transmission system's aging infrastructure and lack of flexibility and awareness pose reliability and safety risks, particularly wildfire risks, which are of prominent concern in Colorado.[73] When a power line is overloaded, it can lead to line sagging as the wire overheats. Significant sagging may lead to short circuits, outages, and even wildfires (with a primary example being Colorado's 2021

[70] Russell Mendell, Mathias Einberger, and Katie Siegner, "FERC Could Slash Inflation and Double Renewables with These Grid Upgrades," RMI, July 7, 2022, https://rmi.org/ferc-could-slash-inflation-and-double-renewables-grid-upgrades/.
[71]Herman Trabish, "Smart Transmission: How FERC Can Spur Modernization of the Bulk Power System," Utility Dive, March 26, 2018, https://www.utilitydive.com/news/smart-transmission-how-ferc-can-spur-modernization-of-the-bulk-power-syste/519901/.
[72]Trabish, "Smart Transmission: How FERC Can Spur Modernization of the Bulk Power System."
[73]"The Challenges and Risks of Sagging Power Lines: An In-Depth Look at the Fairview Fire," EKN Engineering. December 28, 2023, https://www.eknengineering.com/blog/the-technical-challenges-and-risks-of-sagging-power-lines-an-in-depth-look-at-the-fairview-fire.

Marshall Fire).[74] GETs provide grid operators with the tools and insight to respond quickly and efficiently to outages and extreme weather conditions, such as high winds.[75] These upgrades can also provide insights and tools to avoid overburdening lines, thereby mitigating wildfire risk.

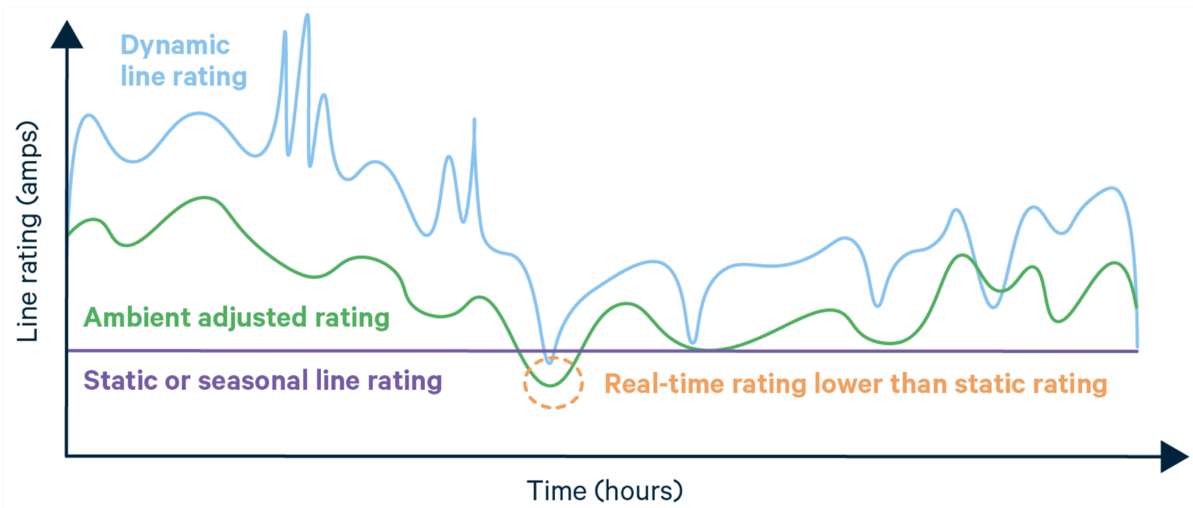
3.2 Dynamic Line Ratings

General Description

When transmission lines overheat, they become less efficient and are at increased risk of reliability issues and infrastructure damage.[76] To prevent this, transmission system operators (TSOs) use line ratings to ensure line safety as they set and enforce a line's maximum power-carrying capacity and operating temperature.[77] Traditionally, TSOs have relied on static line ratings (SLR) that assume constant, conservative environmental conditions, or seasonal line ratings (SeaLR) that adjust static environmental assumptions depending on the time of year.[78] More recently, TSOs have adopted ambient adjusted ratings (AAR), which determine thermal limits using weather models based on real-time air temperatures, in response to the 2021 Federal Energy Regulatory Commission's (FERC's) Order 881.[79] Despite their frequent use, SLR, SeaLR, and AAR unnecessarily restrict power flow as they frequently set ratings below a line's actual thermal capacity.[80]

[74]Westline Electrical Services. "Information On The Effect Of Weather Conditions On Power Lines," December 6, 2021. https://www.electricianinperth.com.au/blog/effect-of-weather-on-power-lines/.; The Challenges and Risks of Sagging Power Lines: An In-Depth Look at the Fairview Fire."
[75]"Grid Enhancing Technologies in Generator Interconnection," WATT Coalition, September 26, 2023, https://watt-transmission.org/grid-enhancing-technologies-in-generator-interconnection/.
[76] "Innovative Landscape Brief: Dynamic Line Rating," 6.; Dillon Kolkmann, "Managing Transmission Line Ratings," Washington, DC, United States: Federal Energy Regulatory Commission, August 2019, 1, https://www.ferc.gov/sites/default/files/2020-05/tran-line-ratings.pdf.
[77] Americans for a Clean Energy Grid, "Dynamic Line Ratings," August 2014, 1, https://cleanenergygrid.org/wp-content/uploads/2014/08/Dynamic-Line-Ratings.pdf. 1; "Improving Efficiency with Dynamic Line Ratings: Successes from New York Power Authority's Smart Grid Demonstration Project," Washington, DC, United States: U.S. Department of Energy, accessed April 15, 2024, 1-2, https://www.energy.gov/sites/prod/files/2017/01/f34/NYPA_Improving-Efficiency-Dynamic-Line-Ratings.pdf; T. Bruce Tsuchida, Stephanie Ross, and Adam Bigelow, "Unlocking the Queue with Grid-Enhancing Technologies: Case Study of the Southwest Power Pool," Brattle Group, February 1, 2021, 18, https://watt-transmission.org/wp-content/uploads/2021/02/Brattle__Unlocking-the-Queue-with-Grid-Enhancing-Technologies__Final-Report_Public-Version.pdf90.pdf.
[78] Slaria et al., "Expanding the Possibilities: When and Where Can Grid-Enhancing Technologies, Distributed Energy Resources, and Microgrids Support the Grid of the Future?" 2-3.; "Grid-Enhancing Technologies: A Case Study on Ratepayer Impact," 5.
[79]Ethan Howland, "FERC Advances Dynamic Line Rating Framework, plus 6 Other Takeaways from Its Open Meeting," Utility Dive, June 28, 2024, https://www.utilitydive.com/news/ferc-dynamic-line-rating-dlr-rosner-clements-miso-nerc/720136/.
[80] "Innovative Landscape Brief: Dynamic Line Rating," 6-7.; "Grid-Enhancing Technologies: A Case Study on Ratepayer Impact," 75.; "Smarter use of the dynamic grid: accessing transmission headroom through GETs deployment," 6.; "Improving Efficiency with Dynamic Line Ratings: Successes from New York Power Authority's Smart Grid Demonstration Project," 1.

In lieu of these methods, dynamic line rating (DLR) can provide more accurate line ratings and increase transmission capacity.[81] DLRs use software and sensors to continually calculate line ratings based on real-time operations and environmental conditions, including ambient temperature, wind speed and direction, and solar radiation.[82] Generally, a DLR system consists of sensors attached to or near transmission lines for monitoring environmental conditions and electric system operations, DLR software for data processing, and telecommunication systems.[83] Compared to current methods, DLRs almost always have higher carrying capacities than SLRs, SeaLRs, and AARs because these methods fail to account for the impact of real-time environmental and operational conditions on a line's capacity (Figure 5).[84] Although applicable in various situations, DLRs are particularly effective on older, lower-voltage, and/or overloaded lines.[85]



Source: US DOE, 2020, 8.

FIGURE 5: *Comparison of Different Types of Line Ratings.* When compared to SLRs (purple line), DLRs (light blue line) are much higher in almost all instances.[86]

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[81] "Grid-Enhancing Technologies: A Case Study on Ratepayer Impact," 69-70.
[82] "Smarter use of the dynamic grid: accessing transmission headroom through GETs deployment," 6..;"Grid-Enhancing Technologies: A Case Study on Ratepayer Impact," 6.;Slaria et al., "Expanding the Possibilities: When and Where Can Grid-Enhancing Technologies, Distributed Energy Resources, and Microgrids Support the Grid of the Future?" 2-3.
[83] Yu Hou, Wei Wang, Zheng Wei, Xiaojun Deng, Qiuhua Ji, Tong Wang, and Xinqin Ru, "Research and Application of Dynamic Line Rating Technology," *Energy Reports* 6 (December 2020): 717, https://doi.org/10.1016/j.egyr.2020.11.140.
[84] "Innovative Landscape Brief: Dynamic Line Rating," 7.;"Grid-Enhancing Technologies: A Case Study on Ratepayer Impact," 75.
[85] "Grid-Enhancing Technologies: A Case Study on Ratepayer Impact," 5.; Mulvaney et al.,"GETting Interconnected in PJM: Grid-Enhancing Technologies (GETs) Can Increase the Speed and Scale of New Entry from PJM's Queue," 13.; Slaria et al., "Expanding the Possibilities: When and Where Can Grid-Enhancing Technologies, Distributed Energy Resources, and Microgrids Support the Grid of the Future?" 4-5.
[86] Slaria et al., "Expanding the Possibilities: When and Where Can Grid-Enhancing Technologies, Distributed Energy Resources, and Microgrids Support the Grid of the Future?" 3.

Today, DLR technologies are considered mature by multiple major industry groups (i.e., ENTSO-E, Cigre, IEEE), and their deployment has been included in the grid development roadmaps of major utilities.[87] Domestically and internationally, numerous DLR systems have been deployed, all of which have benefitted transmission systems and their customers by increasing capacity and reducing congestion costs.[88] Multiple DLR systems and software have been developed and are commercially available today from companies such as WindSim Power, SmartWires, Ampacimon, Lindsey Systems, Enline Energy, Heimdall Power, and LineVision.

Economics

Although total implementation costs vary from project to project, the upfront costs of DLR installations include the costs of sensors (~$5,000 per line), DLR software (~$70,000 per line), telecommunication systems ($10,000 per line), and their installation, configuration, integration, data cleanup, and uplift costs (Figure 6).[89] While payback periods differ for every project, DLR deployments have demonstrated periods of less than two months.[90] Compared to other transmission capacity expansion and utilization options, DLRs are relatively inexpensive and economically feasible ways to increase the existing transmission system's efficiency and capacity.[91] The DOE supports such claims in its *2024 Pathways to Commercial Liftoff: Innovative Grid Deployment* report, which found that DLR systems can increase transmission capacity for less than 5% of the cost of rebuilding the same line, resulting in significant cost savings.[92]

The cost-effectiveness of DLR systems, in part, is attributed to the fact that they can be deployed on existing infrastructure.[93] Because they can be retrofitted to the transmission system without changing its structure, DLRs can increase line capacity and system efficiency without the need to take the line out of service or costly upgrades.[94] Furthermore, DLR systems can be easily and quickly installed, have a simple and standard method of use, maintain relatively high accuracy, and

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[87] "Dynamic Line Rating: Monitoring Real-Time Line Conditions to Amplify Electric Transmission Capacity with GridBoost Line Ratings," Ampacimon, accessed December 17, 2024, https://www.ampacimon.com/dynamic-line-rating/line-ratings.

[88] "Implementation of Dynamic Line Ratings," Federal Energy Regulatory Commission (FERC), Notice of Proposed Rulemaking, Federal Register, July 15, 2024, https://www.govinfo.gov/content/pkg/FR-2024-07-15/pdf/2024-14666.pdf.

[89] Louise White, Eshaan Agrawal, Angelena Bohman, Avi Gopstein, Charles Hua, Isabel Sepulveda, and Lucia Tian, "Pathways to Commercial Liftoff: Innovative Grid Deployment," U.S. Department of Energy, April 2024, 87, https://liftoff.energy.gov/wp-content/uploads/2024/05/Liftoff_Innovative-Grid-Deployment_Final_5.2-1.pdf.

[90] "Dynamic Line Rating," 14-15.

[91] Hou et al., "Research and Application of Dynamic Line Rating Technology," 716.; "Dynamic Line Rating," 14.

[92] White et al., "Pathways to Commercial Liftoff: Innovative Grid Deployment," 5.

[93] "Dynamic Line Rating Technology & Software," LineVision, Inc., accessed December 17, 2024, https://www.linevisioninc.com/technology#sensor.

[94] Hou et al., "Research and Application of Dynamic Line Rating Technology," 716.; "Dynamic Line Rating Technology & Software.";"Grid-Enhancing Technologies: A Case Study on Ratepayer Impact," 77.

deliver capacity benefits rapidly.[95] On average, DLR systems take one to three years to implement and an additional three to six months to fully scale operations and deliver line capacity improvements.[96] Compared to the 2+ and 10+ years it takes to reconductor or build a new line, DLRs can increase transmission capacity for a lower cost in less time.[97] Furthermore, DLRs also result in annual savings that include production costs, net imports, avoided curtailment, and congestion savings.[98]

System/ Sub-System	Type	CAPEX Valuation Parameter	CAPEX Scale Metric(s)
DLR Software	Asset	$70,000	Number of transmission lines
	Installation, Configuration, Integration	3x the license cost	
	Data cleanup and uplift	1x to 10x the license cost	
Sensors	Asset	$5,000	Number of transmission lines
	Installation, Configuration, Integration	1.5x the sensor cost per line	
Telecommunications	Asset	$10,000	Number of transmission lines
	Installation, Configuration, Integration	1.5x the telecommunications cost per line	

FIGURE 6: *DLR System Capital Costs.* Although system costs ultimately vary by project, the U.S. DOE estimated the capital expenditure for all parts of a DLR system in its Pathways to Commercial Liftoff Report.[99]

Capacity

On average, DLRs deliver capacity increases between 10% and 30%, with at least 10% increases provided 90% of the time.[100] When the system's climate and geography are favorable, DLRs can increase transmission line capacity between 30 and 50%.[101] This wide range of increases is due to the impact weather conditions

[95] Research and Application of Dynamic Line Rating Technology," 717.
[96] White et al., "Pathways to Commercial Liftoff: Innovative Grid Deployment,"5-22.; "Smarter use of the dynamic grid: accessing transmission headroom through GETs deployment," 11.
[97] "Smarter use of the dynamic grid: accessing transmission headroom through GETs deployment," 11.
[98] "Grid-Enhancing Technologies: A Case Study on Ratepayer Impact," ix.
[99]White et al., "Pathways to Commercial Liftoff: Innovative Grid Deployment,"87.
[100] "Pathways to Commercial Liftoff: Innovative Grid Deployment,"5.; "Unlock Power Line by Line: Dynamic Line Ratings," WATT Coalition, June 26, 2024, https://watt-transmission.org/about-dynamic-line-ratings/.
[101] "Unlock Power Line by Line: Dynamic Line Ratings."

have on a line's thermal capacity, thus its line rating.[102] For example, the likelihood of a line overheating and losing power tends to increase in hot weather.[103] Due to operating at higher temperatures, the ratings of lines in hot, windless areas are decreased to ensure safe power flows and to prevent overheating.[104] On the other hand, line ratings can be set higher in cold and windy weather conditions.[105] This is because these conditions cool lines, subsequently lowering their operating temperatures and increasing their power-carrying capacities.[106] As a result, lines in cold and windy weather conditions receive capacity increases significantly higher than those afforded to lines in hot and windless conditions. Because of this, DLRs can be particularly beneficial during extreme weather events.[107] For example, the value of DLR was demonstrated in 2018 when a 13 day cold snap triggered high electricity demands and fuel supply constraints that caused significant congestion in a large portion of the Northeast grid.[108] In response, ISO New England implemented DLRs to increase line carrying capacity, enabling alternative power plants to add more electricity to the grid to meet high loads and avoid congestion costs.[109]

Implementation Examples

1. *Pennsylvania Power & Light Electric Utilities in the PJM*

Initiated in 2020 by Pennsylvania Power and Light Electric Utilities (PPL) and facilitated by the PJM, PPL deployed DLRs on three historically congested lines in October of 2022.[110] The DLR vendor Ampacimon installed DLR systems on the two-circuit 230 kV Susquehanna-Harwood path and the 230 kV Juniata-Cumberland line.[111] The project cost significantly less than other solutions – $1 million compared to $20 million for reconductoring and $40-60 million for transmission rebuilds – and has increased normal line capacity by twenty percent and emergency

[102] "Dynamic Line Rating Activated by PPL Electric Utilities," PJM Inside Lines, October 24, 2022, https://insidelines.pjm.com/dynamic-line-rating-activated-by-ppl-electric-utilities/.
[103] "Dynamic Line Rating Activated by PPL Electric Utilities."
[104] "Innovative Landscape Brief: Dynamic Line Rating,"6.; "Dynamic Line Rating Activated by PPL Electric Utilities."
[105] "Innovative Landscape Brief: Dynamic Line Rating,"6.; "Dynamic Line Rating Activated by PPL Electric Utilities."
[106] "Smarter use of the dynamic grid: accessing transmission headroom through GETs deployment," 5.; Slaria et al., "Expanding the Possibilities: When and Where Can Grid-Enhancing Technologies, Distributed Energy Resources, and Microgrids Support the Grid of the Future?" 5.; "Dynamic Line Rating Activated by PPL Electric Utilities."
[107] "Dynamic Line Rating," 7.
[108] "Dynamic Line Rating," 7.
[109] "On the Road to Increased Transmission: Dynamic Line Ratings." NREL. May 16, 2024. https://www.nrel.gov/news/program/2024/on-the-road-to-increased-transmission-dynamic-line-ratings.html.; "Dynamic Line Rating," 7.; Tsuchida et al., "Building a Better Grid: How Grid Enhancing Technologies Complement Transmission Buildouts,"26.
[110] "Dynamic Line Rating Activated by PPL Electric Utilities."; White et al., "Pathways to Commercial Liftoff: Innovative Grid Deployment,"79.
[111] "Dynamic Line Rating Activated by PPL Electric Utilities."; Tsuchida et al., "Building a Better Grid: How Grid Enhancing Technologies Complement Transmission Buildouts,"14.

line capacity between 9% and 17% while creating $23.5 million in annual congestion cost savings.[112]

2. *National Grid and Line Vision in NYISO*

In 2022, National Grid Utilities and the DLR vendor Line Vision installed DLR systems in western upstate New York.[113] Experiencing growth in wind and solar generation, National Grid implemented DLRs on two double-circuit 30-mile 115kV lines located near two large wind farms to reduce the region's renewable energy curtailment.[114] Although National Grid plans to overhaul the corridor with higher-capacity lines eventually, the utility still decided to move forward with its DLR project due to the technology's easy implementation and immediate benefits.[115] In addition to avoiding the need to rebuild 26 miles of double-circuit transmission lines and saving consumers $46 million in construction costs, the entire project budget (~ $3.2 million) costs less than the average cost to rebuild a single mile of a 115 kV line in the region.[116] The project, along with five miles of circuit rebuilds, has been projected to reduce the area's wind energy curtailment by 350 MW and increase the corridor's overall capacity by 190 MW.[117] Increasing corridor capacity by over 30%, the added capacity to existing lines will be enough to power between 80,000 and 100,000 homes in the region.[118]

3. *Oncor Electric Delivery Company in ERCOT*

In 2013, the Texas transmission and distribution system operator Oncor Electric Delivery Company (Oncor) implemented DLR systems on eight transmission lines in Bell, Bosque, Falls, Hill, McLennan, and Williamson counties in Central Texas.[119] Funded under the DOE's Smart Grid Demonstration Program, Oncor installed and commissioned the DLR technology on five 345 kV and three 138 kV

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[112] "Building a Better Grid: How Grid Enhancing Technologies Complement Transmission Buildouts,"14.; White et al., "Pathways to Commercial Liftoff: Innovative Grid Deployment,"79.

[113] "Pathways to Commercial Liftoff: Innovative Grid Deployment,"79.; "Building a Better Grid: How Grid Enhancing Technologies Complement Transmission Buildouts,"14.

[114] "Building a Better Grid: How Grid Enhancing Technologies Complement Transmission Buildouts,"14.; "Pathways to Commercial Liftoff: Innovative Grid Deployment,"79.

[115]"Pathways to Commercial Liftoff: Innovative Grid Deployment,"79.

[116] "Building a Better Grid: How Grid Enhancing Technologies Complement Transmission Buildouts,"14.; Abby Sherman, "WATT Coalition Global Deployments of Grid-Enhancing Technologies," Tableau, March 22, 2023, https://public.tableau.com/app/profile/abby.sherman/viz/WATTCoalitionGlobalDeploymentsofGrid-EnhancingTechnologies/Dashboard1.

[117] "Building a Better Grid: How Grid Enhancing Technologies Complement Transmission Buildouts,"14.;White et al., "Pathways to Commercial Liftoff: Innovative Grid Deployment,"79.

[118] Sherman, "WATT Coalition Global Deployments of Grid-Enhancing Technologies."; "National Grid and LineVision Deploy Largest Dynamic Line Rating Project in the United States," PR Newswire, October 20, 2022, https://www.prnewswire.com/news-releases/national-grid-and-linevision-deploy-largest-dynamic-line-rating-project-in-the-united-states-301653906.html.

[119] "Innovative Landscape Brief: Dynamic Line Rating,"15.;"Oncor Electric Delivery Smart Grid Program Final Report: Dynamic Line Rating," Oncor Electric Delivery Company, 2013, 3, https://digital.library.unt.edu/ark:/67531/metadc867255/m2/1/high_res_d/1111102.pdf.

transmission lines used for daily operations and wholesale market transactions.[120] With an installation cost of $4.833 million and saving $20 million from congestion reductions, the DLR systems successfully mitigated congestion, avoided transmission upgrades, and increased line capacities for several 345 kV and 138 kV lines.[121] Additionally, the project validated that DLR increases capacity as the real-time capacity of the 138 kV and 345 kV lines increased between 8% and 12% and 6% and 14%, respectively, for 83% to 90% of the time.[122] Ultimately, the study found DLR systems to be highly reliable and accurate as they provide 24/7 functionality and measure average conductor temperatures accurately within one to two degrees Celsius.[123]

3.3 Advanced Power Flow Controllers

Background – Power Flow Controllers

Generally, TSOs have little control over how power flows along the grid as it flows based on the laws of physics and on network impedance.[124] Power Flow Controllers (PFC) are used to control how power flows by physically rerouting power away from overload lines, and pushing or pulling it towards underutilized lines within the transmission network.[125] PFC technologies are not new to the transmission industry, with series reactors and series capacitors first being deployed in the 1920s, and the emergence of Flexible Alternating Current Transmission Systems (FACTS) in the 1980s.[126]

General Description

Advanced Power Flow Controllers (APFCs) are a group of FACTS that are voltage-agnostic and modular in design, which enables faster deployment options that offer flexibility in both size and ability to be relocated elsewhere on the grid when needed.[127] In contrast, previous FACTS technologies required custom designs, series injection transformers, water cooling across a high-voltage gradient, circuit breaker bypass protection, and considerable substation space, which significantly

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120 "Innovative Landscape Brief: Dynamic Line Rating," 15.

121 "Innovative Landscape Brief: Dynamic Line Rating," 15.; "Advanced Transmission Technologies," 35.; Tsuchida and Gramlich,"Improving Transmission Operation with Advanced Technologies: A Review of Deployment Experience and Analysis of Incentives," 7.

122 "Innovative Landscape Brief: Dynamic Line Rating," 15.; "Oncor Electric Delivery Smart Grid Program Final Report: Dynamic Line Rating," 2.

123 Tsuchida and Gramlich,"Improving Transmission Operation with Advanced Technologies: A Review of Deployment Experience and Analysis of Incentives," 7.

124 "Grid-Enhancing Technologies: A Case Study on Ratepayer Impact,"7.

125 "Technology Solutions."

126 "SmartValve™ - Advanced Power Flow Control," Smart Wires Inc., accessed December 17, 2024, https://www.smartwires.com/smartvalve/.

127 "Advanced Power Flow Control (APFC)," 1.

increased solution costs and deployment timelines.[128] Today's APFC technologies offer notable advantages over traditional PFC as they can be dynamically controlled in a quick and responsive manner, and they have the ability to provide dynamic services such as transient stability improvement and oscillation damping.[129] Additionally, these technologies do not rely on electrochemical components and, therefore, have continuous control with no limitations on the number of operations. The Electric Power Research Institute (EPRI) lists several benefits of the use of APFC, including congestion reduction, operational resilience, system stress alleviation, mitigation of unscheduled flows, enforcement of contractual flows, dynamic stability enhancement, renewable energy integration, adaptive expansion solutions, maintenance and construction mitigation, and synergy with other GETs.[130]

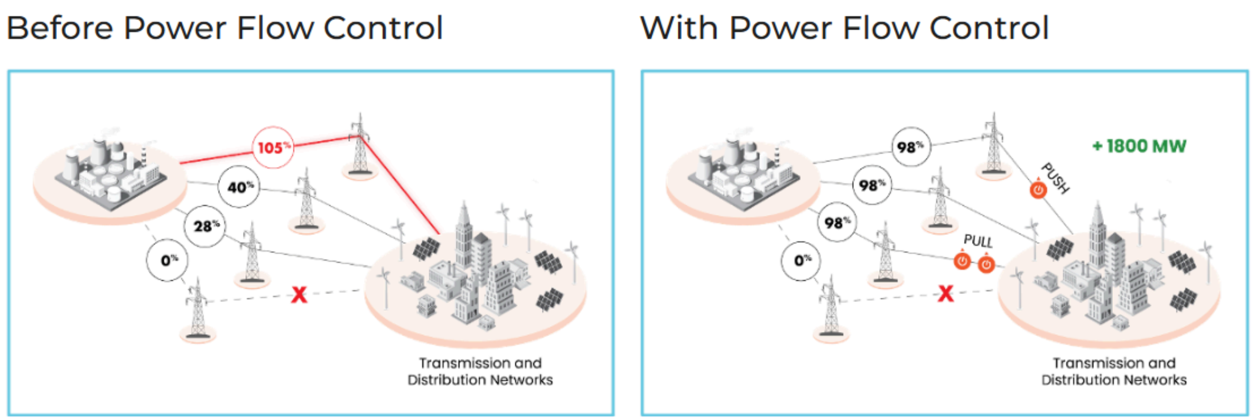

FIGURE 7: *Before and After APFC.* Before APFC (on the left side), some lines may be overloaded, which pose serious risks associated with lines overheating and sagging. On the other hand, most other lines are very underloaded, and could be transmitting more power. With APFC (on the right side), the software and hardware technologies work together to physically pull power away from the overloaded line, and push it onto the lines with available capacity in order to spread the power out evenly. This results in zero lines being overused and at risk of overheating and sagging, as well as significantly more power flowing through the grid as a whole.[131]

Although PFCs and FACTS are mature technologies, there have only been a handful of APFC deployments in the U.S., with no notable deployments within Colorado or the WestConnect planning region.[132] Regardless, APFC technologies are commercially available and have been deployed in various systems around the world. Western Europe and South America have demonstrated more deployments than the

[128] "SmartValve^{TM} - Advanced Power Flow Control."
[129] "Advanced Power Flow Control (APFC)," 1.
[130] "Advanced Power Flow Control (APFC)," 2.
[131] "What Are GETs?" WATT Coalition, June 17, 2021, https://watt-transmission.org/what-are-grid-enhancing-technologies/
[132] "WATT: Working for Advanced Transmission Technologies," WATT Coalition, accessed December 17, 2024, https://watt-transmission.org/.

U.S., particularly the U.K. and Colombia.[133] Smartwires' SmartValve technology is the predominant player in the APFC market.[134] Smart Wires cites eight successful case studies on its website with deployments across Northern England, Colombia, New York, Slovenia, Lithuania, Australia, Canada, etc.[135]

Economics

Generally, PFCs may see payback within about one to four years (solely based on uncurtailed renewable energy generation), depending on technology, whereas traditional upgrades often require approximately 15 years for payback on capital cost.[136] It's important to note that if multiple GETs technologies are used in tandem and require a new substation, this payback may take slightly longer (closer to seven years), but is still a significantly shorter payback than traditional upgrades, and often can be deployed much more quickly.[137] It's also important to note that APFC is notably cheaper, and can be deployed and redeployed much more easily due to its modular nature.[138] Although total implementation costs vary from project to project, the upfront costs of APFC installations include asset expenditures (about $210,000 per line), installation, configuration, and integration costs (about $140,000 per line), and the cost of AFP systems (about $5,000,000 fixed cost)(Figure 8).[139]

Furthermore, APFC saves ratepayers money by reducing grid congestion and allowing low-cost generation to come online sooner. There is an example in Colombia where APFC saved more than $70 million over three and a half years by mitigating outages and avoiding redispatch, while the annual cost of the APFC devices were less than $14 million over that period.[140]

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[133] "WATT: Working for Advanced Transmission Technologies."
[134] "SmartValve™ - Advanced Power Flow Control."
[135] "Case Studies," Smart Wires Inc., accessed December 17, 2024, https://www.smartwires.com/case-studies/.
[136] "Grid-Enhancing Technologies: A Case Study on Ratepayer Impact,"61.
[137] "Grid-Enhancing Technologies: A Case Study on Ratepayer Impact,"61.
[138] "Unlock Power by Redistributing Energy: Advanced Power Flow Control," WATT Coalition, accessed December 17, 2024, 13, https://watt-transmission.org/wp-content/uploads/2024/11/Unlocking-Power-by-Redistributing-Energy-Advanced-Power-Flow-Control.pdf.
[139] White et al., "Pathways to Commercial Liftoff: Innovative Grid Deployment,"87.
[140] "Unlock Power by Redistributing Energy: Advanced Power Flow Control," 13.

System/ Sub-System	Type	CAPEX Valuation Parameter	CAPEX Scale Metric(s)
Equipment	Asset	$210,000	Number of transmission lines
	Installation, Configuration, Integration	$140,000	Number of transmission lines
	AFP Systems	$5,000,000	Fixed Cost for System

FIGURE 8: *APFC System Capital Costs.* Although system costs ultimately vary by project, the U.S. DOE estimated the capital expenditure for all parts of an APFC system in its Pathways to Commercial Liftoff Report. [141]

Capacity

By spreading out the power flow in a more efficient manner and allowing underloaded lines to carry more power and relieve the burden from overloaded lines, the implementation of APFCs may result in increased transmission capacity. An RMI report from 2024 cites an analysis conducted by Quanta Technologies that modeled scenarios where PFCs could be applied in the PJM region.[142] The cost of reconductoring/rebuilding lines was estimated to be five and a half times more expensive than implementing PFCs for the same capacity increase.[143] The study also found that within five states studied (IN, OH, VA, PA, IL), GETs, including PFCs, could enable 6.6 GW of queued solar, wind, and storage generation to connect to the grid much quicker and much cheaper.[144] But, it is important to note that the PJM region has been cited as one of the most congested grid regions in the country, and these studies may not yield the same results should they be done in Colorado and the West.

Implementation Examples

1. *National Grid and Smart Wires Project*

National Grid Electricity Transmission, U.K., partnered with Smart Wires on a project back in 2020. SmartValves were the chosen solution to address grid congestion in the region that limits the interconnection of renewable generation.[145] An update on the project in May 2021 describes the installation of 48 SmartValves

[141]"Pathways to Commercial Liftoff: Innovative Grid Deployment,"87.
[142] Mulvaney et al., "GETting Interconnected in PJM: Grid-Enhancing Technologies (GETs) Can Increase the Speed and Scale of New Entry from PJM's Queue,"6.
[143] "GETting Interconnected in PJM: Grid-Enhancing Technologies (GETs) Can Increase the Speed and Scale of New Entry from PJM's Queue,"6.
[144] "GETting Interconnected in PJM: Grid-Enhancing Technologies (GETs) Can Increase the Speed and Scale of New Entry from PJM's Queue,"6.
[145]"Working Smarter to Get to Net Zero,"National Grid, May 10, 2021, https://www.nationalgrid.com/stories/journey-to-net-zero-stories/working-smarter-get-net-zero.

across five circuits and three substations, that would unlock 1.5 GW of electric capacity, enough to power one million homes with renewable energy.[146] A case study update from May 2024 highlights how the project has unlocked over 2 GW of capacity and is estimated to deliver over £400 million of savings for U.K. ratepayers through its first seven years.[147]

3.4 Topology Optimization

General Description

The traditional approach to real-time congestion management is redispatch generation, which is when TSOs request to adjust the amount of electricity power plants are generating and injecting into the transmission grid.[148] A complementary approach is topology optimization (TO), which manages congestion by reconfiguring the transmission system to redirect power around congested or overloaded transmission elements.[149] TO is not new as it has been a viable alternative to other congestion management techniques for years.[150] In the past, system operators have used TO reconfigurations on an ad-hoc basis for reliability and remedial applications.[151] Yet the flexibility of the transmission network remains underutilized as reconfigurations are manually identified based on previous experience or a set of fixed procedures, making the current reconfiguration process extremely time-consuming to create and evaluate.[152]

Recently, the development of software to identify reconfigurations has allowed TO to gain momentum as a practical alternative to the traditional, manual process as the software makes the task of reconfiguration identification effortless.[153] New TO software relies on topology control algorithms (TCAs) to quickly identify and evaluate one or more beneficial reconfigurations that take advantage of the

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146"Working Smarter to Get to Net Zero."
147 "Northern England Projects: Unlocking Boundary Capacity to Accelerate Renewable Integration," Smart Wires.
148 Caspary et al.,"Application of Topology Optimization in Real-Time Operations,"3.; "Redispatch," 50hertz, accessed December 18, 2024, https://www.50hertz.com/en/Grid/Systemcontrol/Redispatch.
149 "Application of Topology Optimization in Real-Time Operations,"1.
150 Tsuchida and Rob Gramlich, "Improving Transmission Operation with Advanced Technologies: A Review of Deployment Experience and Analysis of Incentives,"12.
151 Caspary et al.,"Application of Topology Optimization in Real-Time Operations,"3.; "Transmission Topology Optimization," 7.
152 "Transmission Topology Optimization," 7.; "Transmission Topology Optimization,"2.; Tsuchida and Rob Gramlich, "Improving Transmission Operation with Advanced Technologies: A Review of Deployment Experience and Analysis of Incentives,"12.; Evgeniy A. Goldis, Xiaoguang Li, Michael C. Caramanis, Bhavana Keshavamurthy, Mahendra Patel, Aleksandr M. Rudkevich, and Pablo A. Ruiz, "Applicability of Topology Control Algorithms (TCA) to a Real-Size Power System," Newton Energy, 2018, 1, https://newton-energy.com/wp-content/uploads/2018/05/pjmresults_allerton.pdf.
153 "Grid-Enhancing Technologies: A Case Study on Ratepayer Impact," 88.;Tsuchida, Stephanie Ross, and Adam Bigelow, "Unlocking the Queue with Grid-Enhancing Technologies: Case Study of the Southwest Power Pool,"4.; Slaria et al.,"Expanding the Possibilities: When and Where Can Grid-Enhancing Technologies, Distributed Energy Resources, and Microgrids Support the Grid of the Future?" 7. "Transmission Topology Optimization," 8.

transmission network's flexibility and meshed nature to reduce constraints while meeting reliability criteria.[154] TCAs quickly search for and find reconfigurations, in ten seconds to two minutes on average, and then implement them by opening or closing circuit breakers to redirect power flows.[155] Ultimately, TO software benefits TSOs and the grid's efficiency by systematically and automatically evaluating the transmission system's current state, identifying potential switching options, and then presetting preventive or corrective solutions to mitigate abnormal conditions and contingency events.[156]

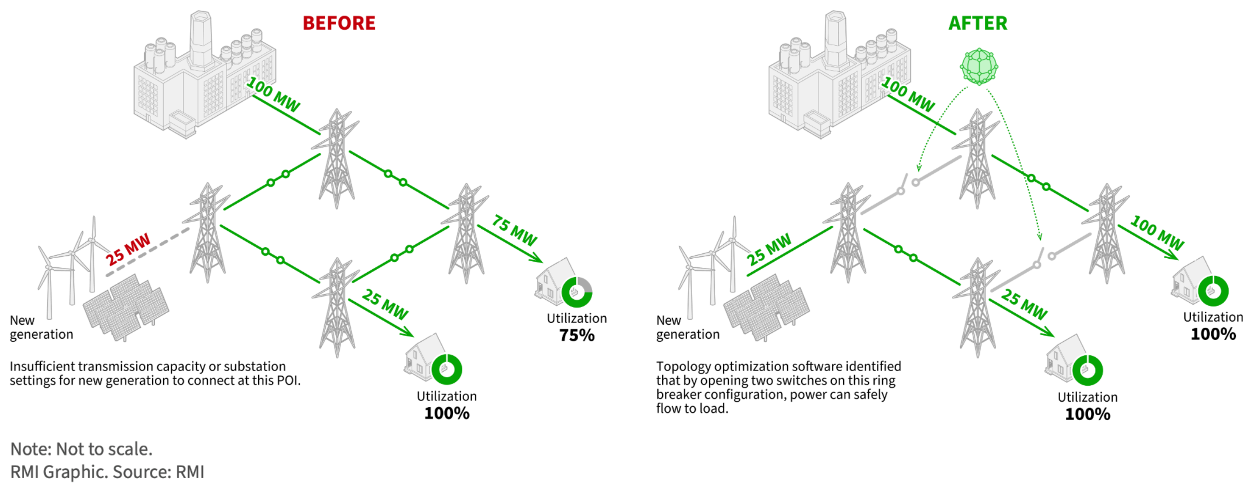

FIGURE 9: *TO can enable new generator interconnection.* This figure demonstrates how TO can be used to connect new energy generation sources to the grid. Before, there was not sufficient transmission capacity available to connect the new generation to the grid. Once TO is applied, the software is able to find two reconfigurations that allows the new generation to be connected while also safely delivering power to load.[157]

TO is widely applicable in the U.S. as it has been found to be economically viable to implement the technology on 90% of the transmission system due to TO's

[154] "Transmission Topology Optimization," 3.; "Expanding the Possibilities: When and Where Can Grid-Enhancing Technologies, Distributed Energy Resources, and Microgrids Support the Grid of the Future?" 7.

[155] Pablo A. Ruiz and Johannes Pfeifenberger, "Congestion Mitigation with Topology Optimization: Case Studies and a Path Toward Implementation," Presented at the Organization of MISO States and Midwestern Governors Association's Americas Smartland Discussion Webinar, June 1, 2021, 6, https://www.brattle.com/wp-content/uploads/2021/08/Congestion-Mitigation-with-Topology-Optimization-Case-Studies-and-a-Path-Toward-Implementation.pdf.; "Grid-Enhancing Technologies: A Case Study on Ratepayer Impact,"8.; Slaria et al., "Expanding the Possibilities: When and Where Can Grid-Enhancing Technologies, Distributed Energy Resources, and Microgrids Support the Grid of the Future?" 7.; Tsuchida et al., "Unlocking the Queue with Grid-Enhancing Technologies: Case Study of the Southwest Power Pool,"4.

[156] "Advanced Transmission Technologies," 11-12.; Tsuchida and Gramlich, "Improving Transmission Operation with Advanced Technologies: A Review of Deployment Experience and Analysis of Incentives,"12.; Caspary et al.,"Application of Topology Optimization in Real-Time Operations,"2.; Mulvaney et al., "GETting Interconnected in PJM: Grid-Enhancing Technologies (GETs) Can Increase the Speed and Scale of New Entry from PJM's Queue," 15.

[157] "GETting Interconnected in PJM: Grid-Enhancing Technologies (GETs) Can Increase the Speed and Scale of New Entry from PJM's Queue," 15.

low cost and broad viability.[158] Despite its feasibility and potential to be used on the current distribution system, TO has not yet been widely deployed, although its adoption is expected to grow in the future.[159] Globally, few TO software products have been developed, but one U.S. company, NewGrid, is leading the way.[160] In 2016, as part of an Advanced Research Projects Agency-Energy (ARPA-E) project, NewGrid developed its NewGrid Router, the first production-grade TO software made commercially available.[161] Today, NewGrid's Router has been used in multiple TO studies and deployments in the U.S. and U.K.[162]

Economics

TO systems are able to successfully operate with existing transmission systems and software because the necessary circuit breaker switching infrastructure is already in place.[163] Able to leverage existing infrastructure and communications hardware, TO software can be easily integrated into existing systems and quickly deployed for low costs.[164] It typically takes one to three years for a TO system to be deployed and another three to six months to make the system operational.[165] Because TO is a software application that does not require the installation of new hardware, it is commonly associated with implementation costs lower than those of other solutions.[166] Generally speaking, TO systems have a capital expenditure of $1,500,000 with additional data uplift and feeder equipment costs, although their payback periods vary for each deployment (Figure 10).[167]

Compared to new lines and other transmission solutions, TO systems provide significant production cost savings as they reduce congestion, avoid transmission upgrades, and prevent system violations. More specifically, early research demonstrated the potential for TO systems to provide up to 25% in production cost

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[158] White et al., "Pathways to Commercial Liftoff: Innovative Grid Deployment," 83.
[159] "Pathways to Commercial Liftoff: Innovative Grid Deployment," 13.
[160] "Advanced Transmission Technologies,"36.
[161] "Advanced Transmission Technologies,"36.
[162] Sherman, "WATT Coalition Global Deployments of Grid-Enhancing Technologies."; "Process to Support Congestion Cost Reconfigurations in the MISO Footprint," n.d., https://cdn.misoenergy.org/20221020%20RSC%20Item%2008%20Congestion%20Cost%20Reconfiguration%20Process%20Redline626713.pdf.
[163] Ruiz, "Transmission Topology Optimization," 8.; Slaria, Molly Robertson, and Karen Palmer, "Expanding the Possibilities: When and Where Can Grid-Enhancing Technologies, Distributed Energy Resources, and Microgrids Support the Grid of the Future?" 7.
[164] "Advanced Transmission Technologies," 13.; Pablo A. Ruiz, German Lorenzon, Paola Caro, and Mitchell Myhre, "Congestion Mitigation with Grid-Enhancing Technologies," Presented at the ESIG 2022 Fall Technical Workshop, Minneapolis, MN, October 25, 2022, 7, https://www.brattle.com/wp-content/uploads/2022/10/Congestion-Mitigation-with-Grid-Enhancing-Technologies.pdf.
[165] White et al., "Pathways to Commercial Liftoff: Innovative Grid Deployment," 22.
[166] "Advanced Transmission Technologies," 13.; Tsuchida and Gramlich, "Improving Transmission Operation with Advanced Technologies: A Review of Deployment Experience and Analysis of Incentives," 12.
[167] White et al., "Pathways to Commercial Liftoff: Innovative Grid Deployment," 87.

savings and between 25% and 50% congestion cost reductions.[168] The cost of TO operations is minuscule in comparison to the millions of dollars of potential savings.[169] Because TO systems work to reroute power flow around overloaded lines, their most significant savings are often seen through congestion cost reductions.[170] For example, in the summer of 2021 MISO's Rochester – Wabaco line congestion cost over $57 million, yet had reconfigurations been used, congestion costs would have been cut by roughly two-thirds.[171] The reconfigurations would have resulted in over $38 million in congestion cost savings and an additional 25% of throughput.[172] Furthermore, TO can defer the need for certain upgrades by increasing lines' long-term value and effectively addressing reliability issues.[173] For example, one study on TO systems found that they can reduce the frequency of system violations by at least 75% for no additional cost.[174]

System/ Sub-System	Type	CAPEX Valuation Parameter	CAPEX Scale Metric(s)
System	NTO System	$1,500,000	Licence Cost
	Data uplift	2x the license cost	
Equipment	Equipment	5,000	Number of Feeders

FIGURE 10: *TO System Capital Costs.* Although system costs ultimately vary by project, the U.S. DOE estimated the capital expenditure for all parts of a TO system in its Pathways to Commercial Liftoff Report.[175]

168 "Advanced Transmission Technologies," 12.; "WATT Coalition Resources on Grid Enhancing Technologies," WATT Coalition, accessed December 17, 2024, https://www.icc.illinois.gov/docket/P2024-0088/documents/356796/files/625245.pdf.
169 Pablo A. Ruiz, Paola Caro Ochoa, Mitchell Myhre, Rodica Donaldson, and Xiaoguang Li, "Congestion & Overload Mitigation With Transmission Reconfigurations: Experience in MISO and SPP," Washington, DC, United States: New Grid, Alliant Energy, EDF Renewables, June 23, 2022, 4, https://watt-transmission.org/wp-content/uploads/2022/06/Topology-Optimization_Ruiz_FERC_20220623_FINAL.pdf.; Tsuchida et al., "Building a Better Grid: How Grid Enhancing Technologies Complement Transmission Buildouts," 14.; Slaria et al., "Expanding the Possibilities: When and Where Can Grid-Enhancing Technologies, Distributed Energy Resources, and Microgrids Support the Grid of the Future?" 8.
170 Murlless and Londagin, "Unlocking Our Power Grid's Potential."
171 Ruiz et al., "Congestion & Overload Mitigation With Transmission Reconfigurations: Experience in MISO and SPP," 13.; "Transmission Topology Optimization," New Grid, accessed May 20, 2024, 5, https://arpa-e.energy.gov/sites/default/files/NewGrid.pdf.
172 "Congestion & Overload Mitigation With Transmission Reconfigurations: Experience in MISO and SPP," 13.; "Transmission Topology Optimization," 5.
173 Slaria, Molly Robertson, and Karen Palmer, "Expanding the Possibilities: When and Where Can Grid-Enhancing Technologies, Distributed Energy Resources, and Microgrids Support the Grid of the Future?" 9.; "Smarter use of the dynamic grid: accessing transmission headroom through GETs deployment," 4.
174 "Advanced Transmission Technologies,"13.
175 White et al., "Pathways to Commercial Liftoff: Innovative Grid Deployment," 87.

Capacity

Although their main focus is to reduce congestion, TO systems are also able to provide capacity increases by evenly distributing power flow on the grid.[176] Global TO research and demonstrations have illustrated these benefits as TO systems have been found to increase capacity by as much as 50% although between ten and twenty percent increases are the average.[177] For example, through an ARPA-E TCA project in collaboration with the PJM, NewGrid found that TO reconfigurations are feasible, reliable, and can typically provide capacity increase between 5% and 10% during highly congested conditions.[178]

Implementation Examples

1. *MISO Reconfigurations*

In 2021, NewGrid developed TO reconfiguration solutions to alleviate some of the most heavily binding constraints in MISO North.[179] NewGrid requested reconfigurations for three lines facing significant congestion and constraints, which included the Chub Lake 345/115 kV line, the Lime Creek – Barton 161 kV line, and the Raun – Tekamah 161 kV line.[180] The Chub Lake 345/115 kV line experienced severe congestion from February to October 2021 as a result of the outage of the Helena to Scott Co 345 kV line due to its rebuild.[181] During the first three months this constraint was binding for more than 260 hours and resulted in an additional $13 million in congestion costs.[182] Additionally, the Lime Creek – Barton 161 kV line was previously identified as a standing constraint by MISO, and the Raun – Tekamah 161 kV was constrained by the outage of Raun – Ft. Calhoun 345 kV in February to March 2022.[183] Following the implementation of NewGrid's reconfigurations by MISO in 2022, throughput was reliably increased between 10% and 56% for the three lines.[184]

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[176] "Grid-Enhancing Technologies: A Case Study on Ratepayer Impact," 8.; Tsuchida and Gramlich, "Improving Transmission Operation with Advanced Technologies: A Review of Deployment Experience and Analysis of Incentives," 12.;Matt Vulpis, "Through Topology Optimization, NewGrid Routing Software Is Reducing Congestion Costs By 50%," The Frontier Hub, June 22, 2023, https://www.industrial-innovation.com/through-topology-optimization-newgrid-routing-software-is-reducing-congestion-costs-by-50/.

[177] John Carey. "'Grid-Enhancing Technologies' Can Squeeze a Lot More Power from the Existing Electric Grid," *Proceedings of the National Academy of Sciences of the United States of America* 121, no. 4: e2322803121, accessed December 17, 2024, https://doi.org/10.1073/pnas.2322803121.

[178] "Transmission Topology Optimization."; Ruiz, "Transmission Topology Optimization."

[179] Ruiz et al., "Congestion & Overload Mitigation With Transmission Reconfigurations: Experience in MISO and SPP," 14.; Tsuchida et al., "Building a Better Grid: How Grid Enhancing Technologies Complement Transmission Buildouts," 18.

[180] "Congestion & Overload Mitigation With Transmission Reconfigurations: Experience in MISO and SPP," 14.

[181] Tsuchida et al., "Building a Better Grid: How Grid Enhancing Technologies Complement Transmission Buildouts," 18.

[182] "Building a Better Grid: How Grid Enhancing Technologies Complement Transmission Buildouts," 18.

[183] Tsuchida et al., "Building a Better Grid: How Grid Enhancing Technologies Complement Transmission Buildouts," 13.; Ruiz et al., "Congestion & Overload Mitigation With Transmission Reconfigurations: Experience in MISO and SPP," 14.

[184] (EPRI TO 3)

The Chub Lake 345/115 kV reconfiguration increased the area's throughput by 56% and resulted in estimated regional market cost savings of $40 million during the nine-month period it was implemented.[185] The Lime Creek-Barton 161 kV reconfiguration, which would have been binding for more than 220 hours without the reconfiguration, increased the area's throughput by up to 12% and had a mitigation rate of over 50%.[186] Lastly, the Raun – Tekamah 161 kV reconfiguration increased throughput by up to 16% and reduced the constraint's binding frequency by 60%. [187]

2. *SPP Study and Pilot*

Initiated in 2018, NewGrid, The Brattle Group, and SPP conducted a study and pilot to evaluate the application and impacts of TO on the SPP's system and its congestion.[188] The study evaluated 20 historical snapshots of the real-time operations of the SPP system, all of which were picked by SPP, that represented various complex system conditions with severe congestion and at least one constraint.[189] TO software was used to identify reconfiguration options, later validated as feasible by SPP in the Energy Management System (EMS), for each snapshot while simultaneously maintaining generation dispatch and meeting operating criteria.[190] The TO software identified reconfigurations that aligned with SPP's criteria for 19 of the 20 historical snapshots (95%), all of which provided 31% flow relief to the constraints of interest.[191] Preferred reconfigurations, based on more stringent criteria defined by SPP, were also found for 14 of the 20 historical snapshots (70%) that provided, on average, 26% flow relief.[192] Additionally, it was shown that TO reconfigurations could result in real-time market cost savings that range between 2% and 5% of initial congestion costs.[193] The study's results concluded that if TO software was fully deployed SPP's would have annual congestion cost savings between $18 million and $44 million.[194]

Following the study, SPP conducted a pilot from July to December 2018 that used NewGrid's Router TO tool to investigate the effectiveness of TO software in

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[185]Ruiz et al., "Congestion & Overload Mitigation With Transmission Reconfigurations: Experience in MISO and SPP," 14.; Tsuchida et al., "Building a Better Grid: How Grid Enhancing Technologies Complement Transmission Buildouts," 18.
[186]Ruiz et al., "Congestion & Overload Mitigation With Transmission Reconfigurations: Experience in MISO and SPP," 14.; Tsuchida et al., "Building a Better Grid: How Grid Enhancing Technologies Complement Transmission Buildouts," 13.
[187] Ruiz et al., "Congestion & Overload Mitigation With Transmission Reconfigurations: Experience in MISO and SPP," 14.
[188] Caspary et al.,"Application of Topology Optimization in Real-Time Operations,"2-4.
[189] "Application of Topology Optimization in Real-Time Operations,"2-4.
[190] "Application of Topology Optimization in Real-Time Operations,"4.
[191]"Application of Topology Optimization in Real-Time Operations,"5.
[192] "Application of Topology Optimization in Real-Time Operations,"5.
[193] Tsuchida and Gramlich, "Improving Transmission Operation with Advanced Technologies: A Review of Deployment Experience and Analysis of Incentives,"13.; "Advanced Transmission Technologies," 37.
[194] "Improving Transmission Operation with Advanced Technologies: A Review of Deployment Experience and Analysis of Incentives,"13.; Caspary et al.,"Application of Topology Optimization in Real-Time Operations,"2.

managing congestion during real-time operations.[195] The pilot used TO software to identify reconfiguration solutions for previously observed transmission overloads, several of which were used to develop new operating guides.[196] The pilot analyzed 100 congested constraints from real-time operations and found preferred solutions for 55 of them. Notably, two of the preferred solutions were implemented in real-time operations.[197] In one instance, the TO software quickly detected a pre-contingency mitigation plan that was able to reduce the flow constraint by more than 20% and completely eliminated post-contingency overloads.[198]

4. Advanced Reconductoring

4.1 Reconductoring

General Description

Reconductoring is the act of replacing existing transmission line cables, also known as conductors, with cables of higher capacity.[199] This replacement process can be deployed three to five times faster than most greenfield transmission projects as they enhance existing transmission infrastructure rather than having to plan, permit, and build new lines and towers in new ROWs.[200] Reconducting with traditional lines includes retrofitting towers to accommodate larger wires that are being implemented; however, raising these towers is still cheaper than the permitting needed to build on new greenfield sites.[201] Reconductoring helps provide near-term capacity solutions to strengthen the grid, while other long-term transmission projects are constructed.[202] For this reason, reconductoring has become an increasingly popular and feasible way to optimize the existing transmission system and increase its capacity. In order to meet growing capacity needs, however, significant investment in reconductoring must occur. According to CETA's transmission study, Colorado will need to reconductor at least 4,036 miles of

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[195] "Application of Topology Optimization in Real-Time Operations,"2-6.
[196] "Advanced Transmission Technologies," 13.
[197] Caspary et al.,"Application of Topology Optimization in Real-Time Operations,"2-6.
[198] "Advanced Transmission Technologies,"13, 37.; Ruiz and Caspary, "SPP Transmission Topology Optimization Pilot: Efficient Congestion Management and Overload Mitigation Through System Reconfigurations," 10.
[199] Silvio Marcacci. "Reconductoring Could Help Solve America's Looming Grid Crisis," Forbes Energy, September 24, 2024, https://www.forbes.com/sites/energyinnovation/2024/04/09/reconductoring-could-help-solve-americas-looming-grid-problems/.
[200] Chojkiewicz et al.,"2035 and Beyond Report: Reconductoring With Advanced Conductors Can Accelerate the Rapid Transmission Expansion Required For a Clean Grid," 2.
[201] Lucas Penido Monteiro and Dan Ryall, CU MENV Capstone Project Interview with TS Conductor, October 14, 2024.
[202] Chojkiewicz et al.,"2035 and Beyond Report: Reconductoring With Advanced Conductors Can Accelerate the Rapid Transmission Expansion Required For a Clean Grid," ii.

transmission to accommodate a high load growth scenario.[203] This expansion investment would result in cost estimations well over $1 billion.[204]

Advanced Reconductoring

Traditionally, the U.S. has used aluminum conductor steel reinforced (ACSR) and aluminum conductor steel supported (ACSS) conductors as the primary solutions for transmission build-out. This is because utilities and transmission developers are familiar with these technologies, making them an easy, go-to solution.[205] These conductors are also often favored due to their low cost on a per-foot-of-wire basis.[206] Yet, these traditional conductors also bring their own challenges. For example, they often result in line sag that increases the risk of reliability and resilience failure, like in 2003, when a sagging line that made contact with a tree resulted in extensive blackouts throughout the U.S. and Canada.[207] The resulting blackouts resulted in eleven deaths and economic costs of $6 billion.[208]

In place of traditional methods, support is growing for advanced reconductoring (AR) to increase the existing transmission system's capacity. More specifically, AR refers to reconductoring projects that use advanced conductors (ACs), which are modern conductor technologies that provide better performance than traditional conductors.[209] These ACs are often characterized by higher capacities, enhanced efficiency, and reduced thermal sag.[210]

By replacing existing lines with new and more efficient conductors, AR is able to deliver significant capacity increases. Typically, AR projects cost less than half the price of new transmission lines while offering comparable capacity increases.[211] Additionally, these projects can double or triple the transmission capacity of overburdened and sagging lines without having to retrofit the existing system or raise existing towers. [212] With electricity demand increasing, the broad-scale application of AR can help meet near-term capacity needs and fill gaps while

[203] "Transmission Expansion Study for Colorado."
[204] "Transmission Expansion Study for Colorado."
[205] Caspary and Schneider, "Advanced Conductors on Existing Transmission Corridors to Accelerate Low Cost Decarbonization," 6.
[206] Lucas Penido Monteiro and Dan Ryall, CU MENV Capstone Project Interview with TS Conductor, October 14, 2024.
[207] David Kramer, "Advanced Conductors Could Double Power Flows on the Grid," Physics Today, June 2024, https://pubs.aip.org/physicstoday/article/77/6/21/3294388/Advanced-conductors-could-double-power-flows-on.
[208] Kramer, "Advanced Conductors Could Double Power Flows on the Grid."
[209] AMP Coalition and Grid Strategies, "Unlocking the Grid: A Playbook on High Performance Conductors for State and Regional Regulators and Policymakers," 1.
[210] "Unlocking the Grid: A Playbook on High Performance Conductors for State and Regional Regulators and Policymakers," 1.
[211] Chojkiewicz et al.,"2035 and Beyond Report: Reconductoring With Advanced Conductors Can Accelerate the Rapid Transmission Expansion Required For a Clean Grid," 3.
[212] "TS Conductor Raises $60 Million from Industry-Leading Investors to Expand US Production of High-Capacity Power Lines."

long-term solutions are completed.[213] For example, one study in the U.S. demonstrated that relying on AR, rather than greenfield expansion alone, could meet growing capacity needs while enabling savings of over $400 billion by 2050.[214]

4.2 Advanced Conductors (Carbon Core)

Technology & Market

ACs are composed of carbon composite cores wrapped in trapezoidal strands of fully annealed aluminum.[215] Compared to traditional wires that use steel, carbon core conductors are stronger, lighter, and experience less thermal expansion – about one-tenth of what traditional lines experience.[216] As a result, ACs have significantly reduced risks of line sag that overall benefit their efficiency, reliability, and resilience.[217] Additionally, these characteristics enable ACs to increase transmission capacity while avoiding the need to retrofit towers, ultimately resulting in lower project costs.[218] In many cases, ACs offer two to five times greater capacity than ACSR wires while simultaneously improving efficiency with reduced line losses.[219]

On a foot-by-foot basis, AC wires are about twice as expensive as traditional ACSR wires, however, conductor costs are only a fraction of total project expenditures.[220] However, the majority of total project capital expenditure comes from construction and the price of steel towers that have been engineered at various heights to mitigate line sag risk.[221] When using AC, these costs are significantly reduced as their low risk of line sag reduces the need for as many or as tall of towers.[222] With this in mind, ACs can offer a competitive advantage despite the fact that the conductors alone cost more than ACSR or ACSS.[223] Furthermore, their reduced need for tower upgrades and installations ultimately reduces both the land

[213]Chojkiewicz et al.,"2035 and Beyond Report: Reconductoring With Advanced Conductors Can Accelerate the Rapid Transmission Expansion Required For a Clean Grid," 5.
[214]"2035 and Beyond Report: Reconductoring With Advanced Conductors Can Accelerate the Rapid Transmission Expansion Required For a Clean Grid," 7.
[215] AMP Coalition and Grid Strategies, "Unlocking the Grid: A Playbook on High Performance Conductors for State and Regional Regulators and Policymakers," 2.
[216]Kramer, "Advanced Conductors Could Double Power Flows on the Grid."
[217]Kramer, "Advanced Conductors Could Double Power Flows on the Grid."
[218]"TS Conductor Raises $60 Million from Industry-Leading Investors to Expand US Production of High-Capacity Power Lines."
[219]AMP Coalition and Grid Strategies, "Unlocking the Grid: A Playbook on High Performance Conductors for State and Regional Regulators and Policymakers," 2-6.
[220] Lucas Penido Monteiro and Dan Ryall, CU MENV Capstone Project Interview with TS Conductor, October 14, 2024.
[221] "What Is Sag in Overhead Power Transmission Lines?"
[222]Kramer, "Advanced Conductors Could Double Power Flows on the Grid."
[223]"How Composite Core Conductors Reduce the Costs of Transmission Projects," Utility Dive, April 18, 2022, https://www.utilitydive.com/spons/how-composite-core-conductors-reduce-the-costs-of-transmission-projects/621481/.

impacts and project timelines of AC projects.[224] To date, ACs have been deployed in over 60 countries across five continents.[225] There are a number of companies each with their own proprietary advanced conductor technology, including CTC Global, Southwire, 3M, TS Conductor, and Prysmian.[226]

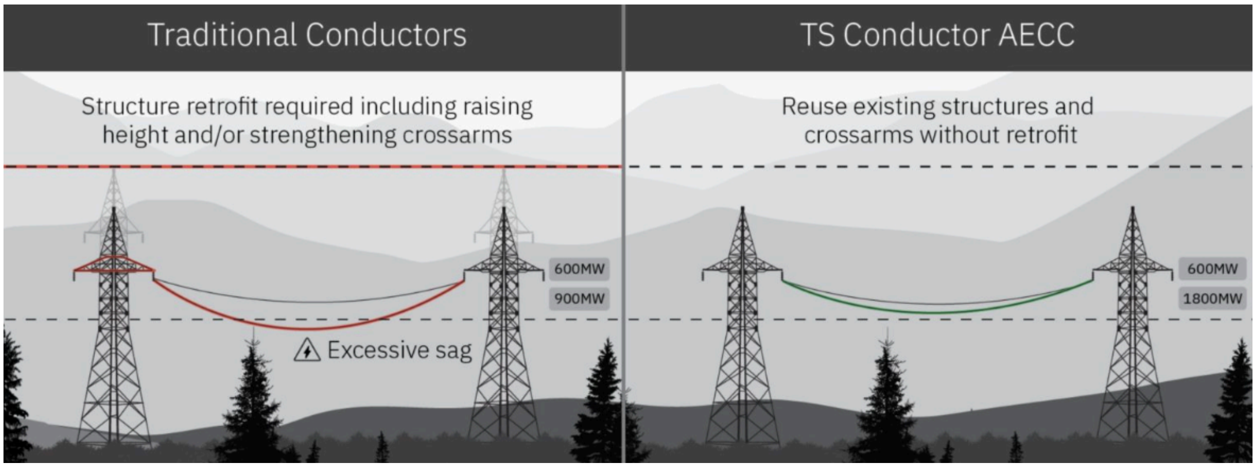

FIGURE 11: *Reconductoring with Traditional Conductors vs. Advanced Conductors.* Tower cost savings potential by using advanced conductors (avoiding tower retrofits).[227]

TS Conductor

TS Conductor is an emerging company in the AC marketplace that has successfully mitigated or solved many of the challenges that earlier ACs faced. For example, TS Conductor has been able to reduce its conductor's vulnerability to natural disasters by engineering its conductors to ensure longevity and durability.[228] Its Aluminum Encapsulated Carbon Core (AECC) provides three times the capacity

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224 AMP Coalition and Grid Strategies, "Unlocking the Grid: A Playbook on High Performance Conductors for State and Regional Regulators and Policymakers," 6.
225 AMP Coalition and Grid Strategies, "Unlocking the Grid: A Playbook on High Performance Conductors for State and Regional Regulators and Policymakers," 2.
226"Advanced Conductor Scan Report," Idaho National Laboratory, December 2023, 26, https://inl.gov/content/uploads/2024/10/23-50856_R12a_-AdvConductorsScanProjectReportCompressed.pdf.; "ACCC® Conductor," CTC Global, accessed December 17, 2024, https://ctcglobal.com/accc-conductor/.; "C7® OVERHEAD CONDUCTOR," Southwire, accessed November 22, 2024, https://overheadtransmission.southwire.com/wp-content/uploads/2017/06/1904_C7-Brochure_IMPERIAL_WEB_SPREADS.pdf.; "3M™ Aluminum Conductor Composite Reinforced (ACCR) High-Capacity Transmission Conductor," 3M, accessed June 17th, 2024, https://www.google.com/url?q=https://multimedia.3m.com/mws/media/478270O/3mtm-accr-high-capacity-transmission-conductor.pdf&sa=D&source=docs&ust=1734479039811076&usg=AOvVaw1Fkx-CCG_pJIDxe7fIEU7G.; "Product Details," TS Conductor, accessed December 17, 2024. https://tsconductor.com/product-details/.; "TransPowr® ACCC® /TW Bare Overhead Conductor," Prysmian, June 2018, https://na.prysmian.com/sites/na.prysmian.com/files/media/documents/TransPowr%C2%AE%20ACCC%C2%AE-TW%20Bare%20Overhead%20Conductor%20%28Canada%29.pdf.
227 "Lower Project Costs."
228 "Product Details."

of ACSR and reduces line losses by 50%.[229] One great benefit of its conductor is that its implementation process is identical to that of ACSR, meaning that linemen aren't required to learn new skills or use new equipment, ultimately increasing their willingness to use TS Conductor.[230]

	Pure Wire Comparison	Whole Project Lifecycle		
	Traditional Lines	**Rewiring due to Aging Infrastructure**	**Reconductoring to Allow for More Capacity**	**New Transmission Lines or Complete Rebuild**
Finance	**Higher Initial Cost:** Approximately 2x–3x the price per foot **Increased Capacity:** Up to 3x the ampacity **Reduced Line Losses:** Efficiency is 96% instead of 92%. **Extended Conductor Lifespan:** longer lifespan due to increased durability and efficiency, further offsetting the initial investment	**Often Ideal for Aging Infrastructure (but not guaranteed)** **Reduced Maintenance Needs & Costs** **Extended Lifespan**	**Up to 40% CAPEX Reduction** due to elimination of need for structural retrofits **Example (MDU):** 40% reduction in CAPEX and a project timeline cut from 15 months to just 3 months	**Fewer Towers Required > Cost Savings for Labor & Permitting** due to high strength and low thermal sag **Lower Tower Heights Required**, further saving construction and material cost **Up to 20% CAPEX Savings** **Example (Basin Electric Project):** Reduced the required number of towers by 15% and decreased tower height by 10 feet, resulting in significant CAPEX savings and a shortened project timeline
Project Timeline		**Shorter Lead Times – Accelerated Project Timelines**	**Reduced Project Timelines** (by several months)	**Reduced Project Timelines** (by several months–years)

229 "Product Details."; Lucas Penido Monteiro and Dan Ryall, CU MENV Capstone Project Interview with TS Conductor, October 14, 2024.
230 "Product Details."

Other	**No Special Installation Tools or Training Needed** **Protection Against Galvanic Corrosion** ensuring long-lasting performance **Reduced Aeolian Vibrations and Galloping** extending the conductor and infrastructure lifespan **Very Low Sag Risk**	**FERC 1920 Compliance and Future-Proofing** **Low Thermal Sag for Enhanced Wildfire Prevention** ensuring resilient, long-term performance in fire-prone areas **Integrated Optical Fiber for Real-Time Monitoring and Fire Prevention (Launching 2026):** optical fiber to be included by 2026, enabling dynamic line rating (DLR)

FIGURE 12: *New Projects and Reconductoring: TS Conductor vs. Traditional Wires.*
TS Conductor versus traditional technology - pure wire comparison, rewiring, reconductoring, and new transmission/rebuild projects.[231]

4.3 Advanced Reconductoring Implementation Examples

Texas

The 2016 Lower Rio Grande Valley project was one of the first prominent AR projects in the U.S., where a 345kV line's capacity was doubled using CTC Global's aluminum conductor composite core (ACCC) conductor.[232] At the time, this Lower Rio Grande Valley line was the longest reconductoring project in the world.[233] The local utility, American Electric Power, did consider conventional solutions, but it ultimately determined that it would not solve the urgent need quickly enough.[234]

Belgium

Beginning in 2009, Belgium was the first country to start utilizing ACs in Europe with ACCCs from CTC Global.[235] Its TSO, Elia, began by targeting overburdened lines with high temperature low sag conductors.[236] Ultimately, these projects were chosen because they required less than half the time and costs of a traditional greenfield project.[237] These capacity upgrades doubled the load capacity

[231] Lucas Penido Monteiro and Dan Ryall, CU MENV Capstone Project Interview with TS Conductor, October 14, 2024.
[232]Chojkiewicz et al.,"2035 and Beyond Report: Reconductoring With Advanced Conductors Can Accelerate the Rapid Transmission Expansion Required For a Clean Grid," 23.
[233]"2035 and Beyond Report: Reconductoring With Advanced Conductors Can Accelerate the Rapid Transmission Expansion Required For a Clean Grid," 23.
[234]"2035 and Beyond Report: Reconductoring With Advanced Conductors Can Accelerate the Rapid Transmission Expansion Required For a Clean Grid," 23.
[235]"2035 and Beyond Report: Reconductoring With Advanced Conductors Can Accelerate the Rapid Transmission Expansion Required For a Clean Grid," 42.
[236]"2035 and Beyond Report: Reconductoring With Advanced Conductors Can Accelerate the Rapid Transmission Expansion Required For a Clean Grid," 42.
[237]"2035 and Beyond Report: Reconductoring With Advanced Conductors Can Accelerate the Rapid Transmission Expansion Required For a Clean Grid," 42.

from 2,000A to 4,000-5,000A, enabling the installation of more renewable energy with lower lead times than building new transmission on greenfield sites.[238]

North Dakota

Another advanced reconductoring project was completed by Montana-Dakota Utilities in March 2021 in Heskett, North Dakota, including a 65-mile, 230 kV line. [239] This project targeted the aging infrastructure of a 60 year-old line in order to accommodate additional interconnection for renewable generation projects.[240] TS Conductor was used for 11 miles of the project in order to avoid high capital expenditures required to increase tower heights to accommodate higher levels of sag associated with ACSS conductors.[241] This project was completed one year ahead of schedule and reported 40% savings on construction while increasing ampacity by 78%.[242]

[238] "2035 and Beyond Report: Reconductoring With Advanced Conductors Can Accelerate the Rapid Transmission Expansion Required For a Clean Grid," 42.
[239] "2035 and Beyond Report: Reconductoring With Advanced Conductors Can Accelerate the Rapid Transmission Expansion Required For a Clean Grid," 42.
[240] "2035 and Beyond Report: Reconductoring With Advanced Conductors Can Accelerate the Rapid Transmission Expansion Required For a Clean Grid," 42.
[241] "2035 and Beyond Report: Reconductoring With Advanced Conductors Can Accelerate the Rapid Transmission Expansion Required For a Clean Grid," 42.
[242] "2035 and Beyond Report: Reconductoring With Advanced Conductors Can Accelerate the Rapid Transmission Expansion Required For a Clean Grid," 42.

5. Summary Chart of Solutions Researched

				Evaluation Metrics						
	Solution	Transit Analogy	Reliability & Resiliency	Guaranteed Capacity Increase	Deployment Cost	Deployment Timeline	Payback Period	Outages Required for Deployment	Relative # U.S. Deployment	Relative # Global Deployment
Traditional Development: New Lines	Greenfield	Building a new highway with older materials	Increases grid capacity; Provides more routes to be taken	Yes	Very High	1 Decade+	Multiple decades	No	High	High
	Existing ROW	Adding a new lanes to a highway	Increases grid capacity; Provides more routes to be taken	Yes	High	Several Years	Multiple decades	No	Medium-High	Medium-High
Grid Enhancing Technologies (GETs)	Dynamic Line Rating	Adjusting speed limits based on road conditions	Prevents line overuse leading to sagging; Often increases line's power rating; Reduces congestion; Operational flexibility during extreme weather (i.e., cold & windy)	No	Low	Months	Months	No	Low	Low
	Topology Optimization	Google Maps or Waze, using software to find the most efficient route	Prevents line overuse leading to sagging; Reduces congestion; Flexibility minimizes system overloads, violations & outages	No	Low	1.5-3 Years	Nearly immediate	No	Very Low	Very Low
	Advanced Power Flow Controllers	Railroad switching station, directing trains to free tracks	Prevents line overuse leading to sagging; Reduces congestion; Decreases risk during severe weather & natural disasters (i.e. wildfires, high winds)	No	Low	1 Year	1-5 years	Yes, briefly	Low	Low
Advanced Conductors (AC)	New Lines with AC (existing ROW)	Building a new double-decker highway (2x the lanes on same land)	Guaranteed & accessible capacity increases; Decreases risk of conductor sagging & overheating	Yes	Medium-High	Several Years	Multiple decades	No	Low	Medium
	Reconductoring with AC	Resurfacing lanes so that cars can go 2x as fast	Guaranteed & accessible capacity increases; Decreases risk of conductor sagging & overheating	Yes	Medium	1.5-3 Years	Several years	Yes	Low	Medium

FIGURE 13: *Summary Chart: Existing ROW siting & ATT Projects vs. Greenfield Projects.* Summary of all solutions researched compared to greenfield transmission projects (top); existing ROW siting, GETs (DLR, TO, APFC), Advanced Conductors (new builds and reconductoring).[243]

[243]Mendell et al.,"FERC Could Slash Inflation and Double Renewables with These Grid Upgrades."; AMP Coalition and Grid Strategies, "Unlocking the Grid: A Playbook on High Performance Conductors for State and Regional Regulators and Policymakers.'; ; Mike O'Boyle, Casey Baker, and Michelle Solomon, "Supporting Advanced Conductor Deployment: Barriers and Policy Solutions," Energy Innovation & GridLab, April 9, 2024, 2, https://www.2035report.com/wp-content/uploads/2024/04/Supporting-Advanced-Conductor-Deployment-Barriers-and-Policy-Solutions.pdf.; John Engel, "'Low-Hanging Fruit': Inside the U.S.' Largest Grid-Enhancing Tech Deployment," POWERGRID International, May 13, 2024, https://www.power-grid.com/td/transmission/low-hanging-fruit-inside-the-u-s-largest-grid-enhancing-tech-deployment/.; David Roberts, "One Easy Way to Boost the Grid: Upgrade the Power Lines," Volts Podcast, January 31, 2024, https://www.volts.wtf/p/one-easy-way-to-boost-the-grid-upgrade.; "What Are GETs?";

6. Recommendations for CETA

Category	Number	Title
Policy	1	Consideration of Advanced Transmission Technologies (ATTs)
Policy	2	Priority Siting Order for New Lines
Studies and Demonstrations	3	CETA-Supported Demonstrations of ATTs
Education	4	Public Education and Transmission Workshops
Financial	5	Shared Savings Cost Model & Performance Based Ratemaking (PBR)
Financial	6	"Maximum Net Benefits" Framework
Other	7	Data Sharing of Existing Transmission Infrastructure
Other	8	Non-Wires Alternatives (NWAs)

FIGURE 14: ***Summary of Final Recommendations.*** This chart lists all eight of our final recommendations to CETA, listed with their respective category, number, and title.

Recommendation 1: Consideration of Advanced Transmission Technologies (ATTs)

CETA should consider ATTs for all its transmission projects and planning studies. In addition, CETA should:

- Call on the Colorado Public Utilities Commission to require utilities to consider ATTs and to provide reasoning when these technologies cannot or should not be used
- Consider asking the state legislature to require utilities to consider ATTs
- Consider asking the state legislature for funding for CETA to incorporate ATT potential into future Transmission Studies

Benefits from implementation:

- Insight into the application and benefits of ATTs
- Increased renewable interconnection and reduced retail electricity rates
- Improved planning procedures
- Increased grid resiliency and reliability

Recommendation 2: Priority Siting Order for New Lines

CETA should advocate for the state legislature to enact a bill similar to Wisconsin Act 89 (2003) to set a priority order for siting new electric transmission facilities: 1. Existing utility corridors; 2. Highway and railroad corridors; 3. New corridors.[244] In addition, CETA should:

- Publicly support this kind of act on its website
- Continue its work and relationship with NextGen Highways in order to establish partnership with Colorado's Department of Transportation, state legislature, and transmission developers

Benefits from implementation:

- Significantly shorter time required for permitting
- Significant cost savings related to permitting
- Fewer landowner and stakeholder conflicts

Recommendation 3: CETA-Supported Demonstrations of ATTs

CETA should work to deploy ATTs in Colorado and demonstrate their benefits. In order to do this, CETA should:

- Request funding from the state legislature to support CETA-run pilot projects that investigate the incorporation of ATTs into Colorado's electricity grid
- Collaborate with suppliers of these technologies in order to efficiently deploy projects

Benefits from implementation:

- Demonstrate the feasibility of these technologies in Colorado
- Increase utility willingness in implementing GETs and completing advanced reconductoring projects
- Pioneer Colorado's deployment of these technologies

Recommendation 4: Public Education and Transmission Workshops

CETA should promote public education materials and opportunities for consumers, utilities, and transmission owners in partnership with organizations prioritizing the use of existing ROW (i.e., NextGen Highways, National Audubon Society, and The Nature Conservancy). In support of this initiative, CETA should:

- Host and organize annual workshops to educate on and promote the use of existing ROWs and ATTs in Colorado
- Invite these groups to present at workshops: NextGen Highways, National Audubon Society, The Nature Conservancy, and members of other organizations who have successfully implemented ATTs

[244] "Keys to Siting and Building Transmission in Highway Rights-of-Way."

- Create a new website page with information related to past, present, and future workshop topics, including CETA's own research and studies

Benefits from implementation:

- Increase public knowledge and support for the use of existing ROW and ATTs
- Facilitate strategic partnerships

Recommendation 5: Shared Savings Cost Model & Performance Based Ratemaking (PBR)

CETA should advocate at the Colorado PUC and state legislature to establish ways to properly incentivize the deployment of GETs (DLR, TO, and APFC), including a shared savings cost model for utilities. In addition, CETA should:

- Call on PUC to propose a shared savings cost model
- Consider partnering with the WATT Coalition, which has previously studied and advocated for this savings model

Benefits from implementation:

- Align utilities with the ratepayer requirement of "just and reasonable" rates
- Establish financial incentives to promote utility-scale GETs deployment

Recommendation 6: "Maximum Net Benefits" Framework

CETA should advocate for the Colorado PUC and state utilities to adopt a planning and project evaluation framework that promotes the adoption of ATTs in Colorado. In order to do this, CETA should:

- Call on the PUC and utilities to adopt a "maximum net benefits" framework in their decision-making processes[245]

Benefits from implementation:

- Replace the current "least-cost" framework that hinders the adoption of ATTs by prioritizing technologies that have lower initial capital expenditure costs rather than those providing maximum net benefits[246]
- Deliver valuable benefits to Colorado and ratepayers

Recommendation 7: Data Sharing of Existing Transmission Infrastructure

CETA should recommend that the Colorado PUC direct utilities to compile data on their transmission infrastructure in Colorado that includes the age, type, location,

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[245] "Recommended Actions for State Regulators to Unlock Transmission Capacity through the Deployment of ATTs," 2.
[246] Caspary and Schneider, "Advanced Conductors on Existing Transmission Corridors to Accelerate Low Cost Decarbonization."; "Recommended Actions for State Regulators to Unlock Transmission Capacity through the Deployment of ATTs," 2.

and manufacturer of any existing infrastructure and then submit all data to CETA. Once all data is collected, CETA should:

- Create a GIS map of all infrastructure with associated information
- Make capacity and costs publicly available, or make it information that can be applied for
- Organize a cost-benefit analysis on reconductoring older lines

Benefits from implementation:

- Better data for CETA's Transmission Study
- Better insights when deciding whether to or not to reconductor lines with advanced conductors
- Enable the creation of schedules for replacing existing infrastructure

Recommendation 8: Non-Wires Alternatives (NWAs)

CETA should research and consider other NWA solutions, specifically how they could be incorporated within future transmission planning. NWAs include a multitude of technologies that can defer or eliminate the need for traditional, costly "wires-and-poles" infrastructure in specific locations while also saving ratepayers money.[247] Please note, this is not within the scope of this project, but these are solutions we find compelling for CETA's further consideration. In addition, CETA should:

- Propose a future capstone project with CU Boulder graduate student to research the potential of other NWAs within Colorado
- Once Virtual Power Plants (VPPs) become commercially successful and deployed at scale in Colorado, hire consultants to do a study to determine net benefits of VPPs, assigning a dollar value to avoided transmission costs
- Invite various companies developing or working with VPPs or Storage as a Transmission Asset (SATA) to present at future CETA board meetings
- Engage New Mexico's Renewable Energy Transmission Authority about its consideration of storage and SATA[248]

[247] Dyson et al.,"The Non-Wires Solutions Implementation Playbook."
[248] "New Mexico Renewable Energy Transmission and Storage Study," New Mexico Renewable Energy Transmission Authority, June 2020, 73, https://nmreta.com/wp-content/uploads/2020/10/NM_RETA_Transmission_Study_June2020v2.pdf.

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