ENERGY STRATEGIES

Integrating High-Performance Conductors in Long-Term Transmission Planning

Insights and Best Practices from the Connected West Study

1. Introduction

Transmission planning methods are evolving to keep pace with a rapidly changing power system. Emerging technologies, public policy goals, and growing system constraints are exposing the limits of traditional approaches. In response, planners are adopting longer time horizons, incorporating scenario-based analysis, new transmission solutions, and evaluating a wider range of transmission benefits—all while grounding their work in the physical realities of grid infrastructure.

In May 2024, the Federal Energy Regulatory Commission (FERC) issued Order No. 1920, formalizing many of these evolving practices. It establishes a new regional transmission planning framework for FERC-jurisdictional providers that includes a 20-year planning horizon, multiple future scenarios, a broader benefit assessment, and explicit consideration of **Advanced Transmission Technologies (ATTs).** ATTs—including **High-Performance Conductors (HPCs)**, dynamic line ratings, and power flow control devices—offer an evolving suite of tools to enhance existing infrastructure. While these tools are becoming more common in industry, they are often underutilized in transmission planning processes.

In September 2024, Energy Strategies released the **Connected West** study, a 20-year transmission analysis focused on infrastructure needs in a decarbonized Western U.S. grid. The study aligned with many Order 1920 requirements, including a 20-year study horizon, a multi-value benefit assessment, and explicit modeling of HPCs. In executing this study, our team developed new modeling techniques and refined prior practices.

This paper distills key lessons from that work, particularly around modeling High-Performance Conductors in long-range transmission plans. Our goal is to support stakeholders in implementing Order 1920 and building a transmission system that underpins a reliable, clean, and affordable energy future.

2. Connected West as a Model for Multi-Value Planning

In September 2024, Energy Strategies released the *Connected West* study—a 20-year transmission planning analysis focused on identifying infrastructure needs for a decarbonized Western U.S. power system. [1] Commissioned by Gridworks and GridLab, the study was not designed to comply with FERC Order No. 1920, but its methodology aligned with many of the Order's core planning elements, including a long-term planning horizon, structured benefit-cost analysis, and consideration of Advanced Transmission Technologies.

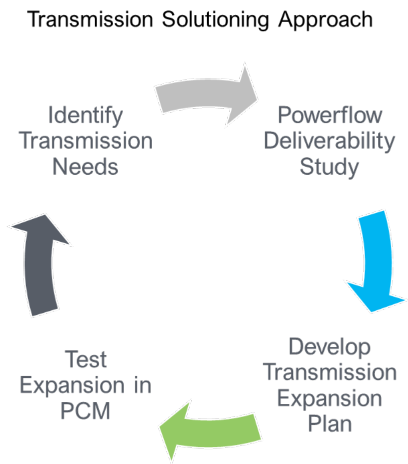
[1] Connected West Report: https://gridworks.org/wp-content/uploads/2024/09/Connected-West-Final-Report-240918.pdf

Although Connected West evaluated only a single scenario, the study's technical approach and findings may offer meaningful insights for planners, advocates, and regulators now working to implement Order 1920. This section summarizes the study's methods and distills key lessons relevant to the consideration of High-Performance Conductors in long-range transmission planning.

Study Scenario and Approach

Connected West centered on a 2045 decarbonized resource buildout, incorporating generation and siting assumptions consistent with the Power of Place–West study. [2] That resource portfolio, informed by land-use, permitting, and policy constraints, was embedded in a production cost model built upon WECC's 2032 Anchor Data Set. [3] This formed a single scenario reflecting ambitious but plausible assumptions about Western grid decarbonization in 2045.

Figure 1: Iterative modeling framework in the Connected West study.



The study used an iterative modeling framework shown in *Figure 1*. Generation, loads, and transmission plans were added to a nodal modeling platform, a production cost model identified transmission congestion and curtailment patterns, which informed a set of candidate transmission upgrades, which were tested for feasibility and reliability through AC power flow simulations. While not intended to result in a fully optimized grid expansion plan, the approach provided practical insight into the performance of distinct transmission strategies under a common future. It also helped to demonstrate the value transmission could provide in this future.

The single-scenario structure of the study meant that transmission need was directly influenced by the location of new resources and the magnitude of load growth in the 2045 Reference Case. Large-scale renewable development in remote areas—such as the Southwest, Pacific Northwest, and Intermountain West—created the need for new and expanded high-capacity transfer paths. The production cost model surfaced key congestion points, while AC power flow analysis refined those portfolios under physical grid constraints and tested solutions for reliable outcomes.

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[2] Power of Place—West Report: https://www.nature.org/content/dam/tnc/nature/en/documents/TNC_Power-of-Place-WEST-Executive_Summary_WEB-9.2.22.pdf

[3] WECC ADS Development Manual: https://www.wecc.org/system/files/documents/anchor_data_set/2024/ADS_Data_Development_and_Validation_Manual_6-30-2020_V3.0.pdf

Benefit Metrics and Cost Assumptions

The study applied a multi-value transmission framework to assess transmission portfolio performance, expanding beyond traditional reliability or economic measures. Quantified benefits included those listed in *Table 1*, below.

Table 1: Transmission Benefits Considered in Connected West

Benefit	Metric
Operational Savings	Reduction in system-wide production costs, including fuel and operational expenses, across the modeled timeframe.
Avoided Emissions	Monetized value of reduced carbon emissions, based on simulated emission reductions and forecasted carbon pricing.
Avoided Loss of Load	Value of improved reliability calculated using the reduction in loss-of-load events multiplied by a value of lost load.
Resource Adequacy	Additional effective capacity enabled by transmission, quantified as MWs of diversity and valued using avoided capacity cost.
Extreme Event Mitigation	Modeled benefit of reduced customer costs and unserved load under simulated extreme weather conditions.
Avoided Transmission Investment	Estimated cost of alternative transmission upgrades that would be required to maintain system reliability without the proposed portfolio.
Reduced Transmission Losses	Reduction in required generation capacity due to improved system efficiency and lower transmission losses.

These metrics were evaluated across three contrasting buildout strategies: an AC overlay, an HVDC overlay, and a targeted Advanced Conductor portfolio shown in *Figure 2*. The study also considered qualitative factors—such as permitting, wildfire exposure, and land-use compatibility—though these were not scored quantitatively.

Cost assumptions were drawn from widely adopted per-unit cost guides, including MTEP cost data and composite-core conductor specifications, with adjustments to reflect technology-specific, construction, and terrain-related factors. [4,5] While high-level, these cost estimates supported consistent, comparative analysis across transmission types and the resulting portfolios.

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[4] Transmission Cost Estimation Guide for MTEP24: https://cdn.misoenergy.org/20240501%20PSC%20Item%2004%20MISO%20Transmission%20Cost%20Estimation%20Guide%20for%20MTEP24632680.pdf

[5] HPC Conductor Specifications used in Connected West: https://ctcglobal.com/datasheets/?_vsrefdom=adwords&gad_source=1

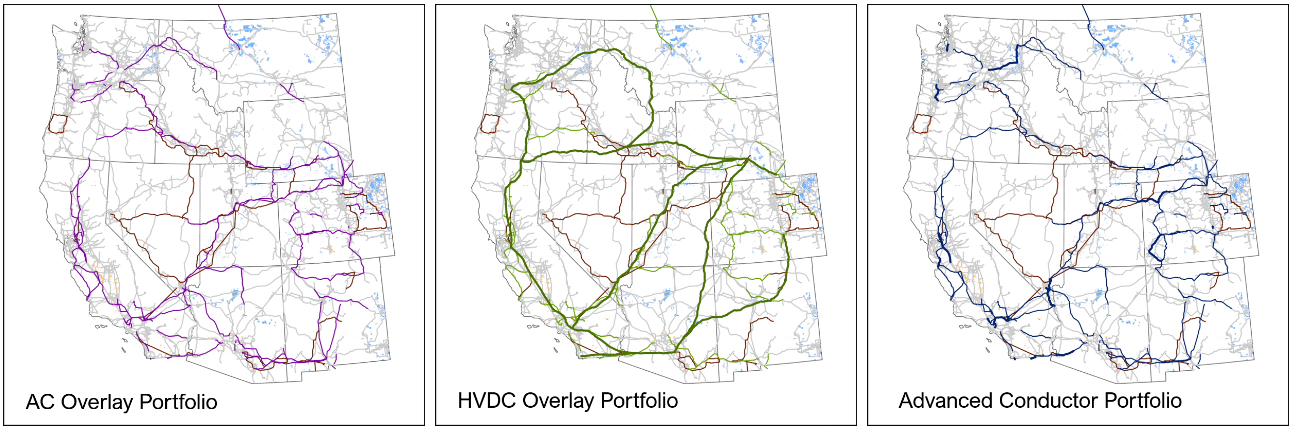

Figure 2: Connected West Transmission Portfolios

Addressable vs. Non-Addressable Renewable Curtailment

A notable insight from the study was the distinction between addressable and non-addressable renewable curtailment. As the team assessed transmission needs, it explored two concepts:

- "Addressable curtailment" referred to curtailment that occurred due to transmission congestion and could be mitigated with infrastructure upgrades like HPCs.
- "Non-addressable curtailment" was traced to issues like system-wide oversupply, operational constraints, or market dispatch dynamics that new transmission capacity alone cannot solve. These types of issues are less about transmission need and are more related to the nature of the resource portfolio.

This distinction is essential for identifying where new transmission can meaningfully reduce curtailment. Without it, planners risk pursuing costly infrastructure to solve problems rooted in operational or portfolio design issues—not transmission constraints.

GIS Methods in Long-Term Planning

In the Connected West study, GIS-based cost surfaces, shown in *Figure 3* and developed by Montara Mountain Energy, helped inform transmission routing decisions by capturing terrain, land use, and permitting sensitivities—adding practical realism to lines included in the resulting transmission portfolios. [6]

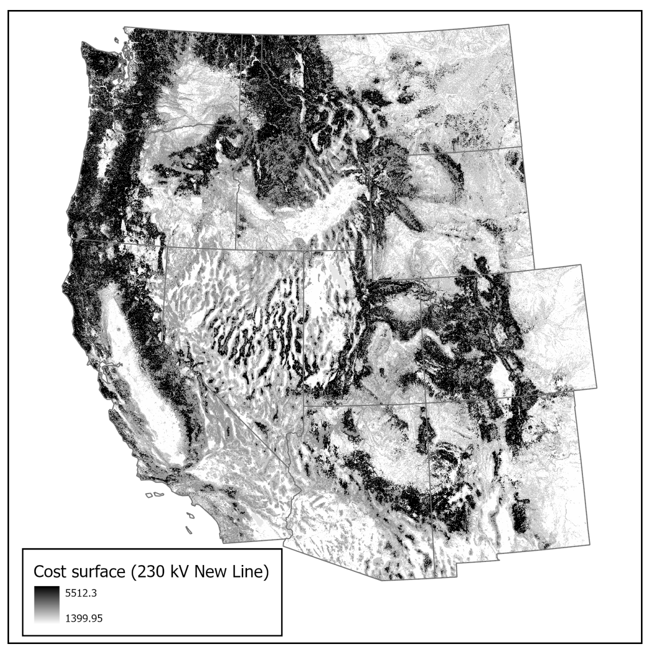

Figure 3: Transmission Cost Routing Surface from Connected West

[6] Montara Mountain Energy Website: https://www.montaraco.com/

These methods also support more nuanced decisions between solutions like ATTs and new builds by overlaying spatial data on infrastructure, right-of-way availability, and system needs. As transmission planning evolves, GIS offers a transparent and scalable way to link system modeling with siting feasibility—improving both stakeholder trust and decision quality.

Initial Lessons for Planners and Stakeholders

The Connected West study was not intended to be a full compliance roadmap for FERC Order 1920, but it offers insights for entities preparing to implement long-range, multi-value transmission planning:

1. **Scenario design drives transmission outcomes.**
   Even a single, well-structured scenario can yield rich information—provided it reflects policy, siting, and resource development constraints. The study's outputs were highly sensitive to its geographic and operational inputs.

2. **But one scenario isn't enough.**
   Over a 20-year horizon, a wide range of uncertainties—policy, technology, load growth, fuel prices—make it critical to evaluate multiple possible futures. Planners should focus on investments that are robust across scenarios, not just optimal in one.

3. **Planning accuracy benefits from iterative refinement.**
   By cycling between production cost and power flow modeling, the study was able to produce transmission portfolios that addressed both economic and reliability needs, without claiming a "least-cost" solution. The number of iterations required between these two modeling platforms will depend on the geographic breadth and severity of issues that stem from the scenario being investigated.

4. **Multi-benefit frameworks require rigor and transparency.**
   Capturing multiple types of transmission benefits—like production cost savings, reliability, and capacity sharing—requires careful effort to avoid double-counting, properly account for uncertainty, and clearly defined methodologies. Accurately monetizing risk-driven benefits (e.g., extreme event mitigation) adds further complexity as their results can be volatile and heavily driven by practitioner assumptions. Clear documentation and accounting between benefit types are essential to maintain credibility.

5. **GETs were not suited for this study's horizon but may support long-term solutions.**
   While Grid Enhancing Technologies (GETs) offer flexible, low-cost options for unlocking additional grid capacity, the 20-year horizon and scale of need in Connected West exceeded their typical application. Many segments required major capacity increases that far surpassed what GETs can provide. However, this does not preclude their value in long-term planning. GETs are likely to play a supporting role—addressing near-term constraints, providing flexibility during construction, or enhancing performance of new infrastructure. Future studies with phased buildouts or shorter planning horizons may better capture their contributions.

6. **Geospatial analysis is essential for realistic transmission planning.**
   Long-range plans must reflect the physical, environmental, and jurisdictional landscape where projects will be built. In Connected West, GIS helped identify viable corridors, assess right-of-way constraints, and eliminate options hindered by terrain, land use, or permitting barriers. Integrating GIS early bridges the gap between conceptual modeling and real-world feasibility, especially in the West where long distances and complex siting challenges can significantly influence transmission pathways.

7. **Flexibility in assumptions is sometimes necessary.**
   Modeling results may occasionally conflict with practical expectations or known development trends. In Connected West, initial outputs showed a concentration of new wind capacity in one area that exceeded plausible siting and development patterns. Adjusting these assumptions produced results better aligned with real-world development patterns, enhancing the credibility and usefulness of the findings.

These lessons informed the study's exploration of advanced conductor deployment and shaped how infrastructure options were screened and evaluated. The following section builds on this foundation, focusing specifically on the opportunities and challenges associated with High-Performance Conductors in regional transmission planning.

3. High-Performance Conductors in Transmission Plans

High-Performance Conductors are advanced conductors that use composite cores or novel materials to increase performance compared to traditional steel core lines, with increased carrying capacity, reduced thermal sag, and higher efficiency. In long-range transmission planning, HPCs can be deployed in three primary contexts: reconductoring existing lines, rebuilding within existing rights-of-way, and constructing new corridors. Each approach presents different design constraints, land use requirements, and technical planning tradeoffs.

Deployment Options

In **reconductoring applications**, HPCs replace conventional conductors on existing towers and structures. This approach offers a fast, relatively low-impact way to boost capacity where thermal constraints are the limiting factor. Because towers and rights-of-way remain in place, reconductoring typically avoids major permitting hurdles and environmental review (and can be completed relatively quickly). However, it is limited by the strength, spacing, and voltage class of the original infrastructure. HPC reconductoring is most effective when capacity needs are within roughly two times the original line rating, segment lengths are under 50–70 miles, and the corridor is part of a well-networked grid that can manage contingencies.

As a rough screening method, engineers may compare existing conductor weight to that of a similar HPC to estimate potential capacity gains without major structural upgrades. While not a substitute for detailed analysis, it can help scope HPC opportunities in early planning.

In **rebuilds within existing corridors**, planners replace towers and structures while retaining the original right-of-way. This allows for increased voltage levels, expanded span lengths, and bundled conductor configurations—providing higher capacity than reconductoring alone. HPCs in this context can reduce the number of required circuits, limit visual or environmental impact, and support future-ready designs where right-of-way constraints persist.

When **creating new corridors,** HPCs offer planners maximum design flexibility. Their higher ampacity can reduce the size or number of lines required to meet a given capacity target, potentially lowering land acquisition needs and environmental impact. In these cases, HPCs are not just a tool for squeezing more capacity out of existing corridors, they can enable more efficient expansion of the grid itself.

Technical Tradeoffs

Despite their advantages, HPCs come with important tradeoffs. They do not address all system limitations, particularly when voltage stability, dynamic performance, or reactive power losses are the binding constraints. Their high current-carrying capability can increase reactive losses over long distances, and beyond roughly 150 miles, even extensive reactive compensation may not enable additional real power transfer compared to conventional conductors.

In reconductoring applications, benefits are further limited by the structural capacity of existing towers to support increased tension, weight, or thermal loading. And in less networked parts of the grid, adding significant capacity to a single corridor without sufficient parallel paths can increase contingency exposure and create new vulnerabilities, limiting the effective value of an HPC upgrade.

From an operational standpoint, HPCs may require updated installation techniques, specialized hardware, and enhanced monitoring to ensure long-term performance. Reconductoring also involves extended outages and careful construction planning, which may not be feasible in heavily loaded corridors without temporary reinforcements. These considerations underscore the need to align HPC deployment with system needs, network strength, and logistical feasibility.

Cost Considerations

HPCs carry higher capital costs than conventional conductors, driven by more expensive materials and potentially higher installation costs. While the per-mile premium can be significant, its impact on total project cost is often limited, as conductors make up only part of overall transmission spending. Their cost-effectiveness depends on factors like voltage class, terrain, structure design, and whether the project involves reconductoring or new construction.

Connected West Implementation

The Connected West study applied a simplified, portfolio-level approach to incorporating HPCs. The objective was not to engineer each line in detail, but to explore how advanced conductors could influence transmission buildout needs in a long-term planning context. While no real-world plan would rely on a single technology, using HPCs as a consistent design proxy allowed the study to test their potential impact and better understand their practical boundaries.

The effort to develop the HPC portfolio began by developing an AC Overlay portfolio based on conventional AC conductor technology. This included identifying HPC solutions via all three deployment options: reconductoring existing lines, rebuilds within existing corridors, and creating new corridors. From this portfolio – which met the economic and reliability needs of the grid – select segments were identified as candidates for HPC deployment in a "post-hoc" manner. Approximately 4,700 miles of AC lines, about one-third of the total transmission portfolio—were ultimately replaced with HPC upgrades. Most of these were short segments under 50 miles, located along paths where thermal limits were the primary constraint and the surrounding network was able to support the increased capacity of the HPC. For longer segments, HPCs were used selectively in cases where sectionalization and reactive support could reasonably address system performance concerns.

These replacements assumed that existing rights-of-way could support HPC upgrades, but no structural or detail corridor analysis was conducted to confirm feasibility. This approach was intended to test directional impacts, not to prescribe individual project designs.

Notably, the total cost of the Advanced Conductor portfolio was higher than the conventional AC portfolio. This was not due to the intrinsic cost of HPCs, but rather a reflection of the fact that their placement and selection were not fully optimized. Detailed iteration on HPC deployment and co-optimization with other system reinforcements (e.g., HPC plus HVDC solutions) was beyond the scope of the study. Even so, the exercise offered valuable insight into where and how HPCs might be applied—and highlighted the importance of refining future modeling workflows to better capture their potential.

4. Conclusions and Recommendations

Transmission planning is growing more complex as system needs expand, technologies evolve, and expectations for long-term coordination increase. FERC Order 1920 raises the bar for scenario-based, multi-value planning and explicitly calls for the consideration of Advanced Transmission Technologies like High-Performance Conductors (HPCs). While not a one-size-fits-all solution, HPCs can play a critical role—particularly in constrained corridors or where new rights-of-way are limited.

The Connected West study illustrates how many elements of Order 1920 can be applied in practice. By incorporating a 20-year horizon, structured benefit-cost analysis, and evaluation of HPCs, the study yielded insights into where advanced conductors can add value—and where their limitations must be considered. Based on our experiences, we offer the following recommendations for planners assessing HPCs in future studies:

1. Use conventional portfolios as a benchmark for advanced solutions.
Starting with a viable AC solution built from conventional technologies creates a strong reference point. This allows planners to test Advanced Transmission Technologies as targeted enhancements that clarify their value, tradeoffs, and risks within an "all of the above, where appropriate" planning framework. Skipping straight to advanced solutions risks overlooking what constitutes an acceptable or cost-effective outcome.

2. Apply preliminary screens to scope potential HPC upgrades
Not all transmission segments are well-suited for HPC deployment. Effective candidates are typically thermally constrained, under ~50–70 miles in length and located in well-networked areas that can support increased capacity without introducing new contingency vulnerabilities. In reconductoring applications, engineers may use simple checks—such as comparing the weight of existing conductors with HPC alternatives—to estimate potential capacity increases without major structural upgrades. While not a substitute for engineering analysis, these heuristics help identify promising opportunities and guide early planning efforts

3. Follow initial HPC screening with detailed project analysis
High-Performance Conductors offer valuable flexibility, but their benefits depend heavily on line-specific factors like structure design, line length, voltage class, thermal limits, and system context. Detailed engineering assessments remain the only reliable way to determine whether HPCs are the most effective solution. Broad assumptions or generic screening criteria are useful starting points but should not replace project-level analysis.

Components of a Next-Generation Planning Framework

The Connected West study used a streamlined approach to integrate HPCs by substituting them into an existing AC buildout. While this yielded valuable insights, it was not an optimized solution or the only viable approach. A next-generation transmission planning framework would improve upon this by incorporating more data, modeling precision, and co-optimization capabilities.

Key components might include:

- **Joint Optimization of Technologies** – Simultaneously evaluate HPCs, conventional conductors, HVDC, and GETs to identify the most cost-effective and operable combinations, rather than layering solutions after-the-fact. Currently, this is a manual process requiring iteration and engineering heuristics. The solution space for transmission planning is incredibly large, non-linear, and non-convex. This prevents the use of common system optimization practices that are used in other steps of the planning process like Capacity Expansion or Production Cost Modeling.

- **Structure and Corridor Feasibility** – Incorporate physical design criteria (e.g., structure strength, clearance, and sag) into screening tools to better assess viability of reconductoring projects. Often planners do not have access to these details. Transmission entities could expedite and improve decision-making in this domain by creating GIS-capable databases of structure age, health, material, etc.

- **Voltage and Stability-Aware Screening** – Embed voltage margin, contingency exposure, and reactive power limits into candidate evaluation to better reflect non-thermal constraints.

- **Staged Buildout and Interim-Year Planning** – Model system needs over multiple time steps (e.g., every 5 years) to better identify near-term actions, including temporary solutions such as GETs.

- **Multi-Value and Multi-Metric Evaluation** – Quantify a range of benefits (e.g., production cost savings, emissions reduction, reliability improvement) across candidate portfolios to support tradeoff analysis and stakeholder alignment.

While Connected West helped demonstrate the potential of HPCs in a long-range context, these enhancements represent the analytical depth needed to fully unlock the value of advanced technologies in future planning cycles.