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November 5, 2024

MEMORANDUM

TO: **Council Members**

FROM: **John Ollis, Manager of Planning and Analysis**

SUBJECT: **Transmission Landscape Update**

BACKGROUND:

Presenters: Paul Wetherbee, Advisor Regional Energy System Planning, Pacific Northwest National Laboratory; Matthew Tisdale, Executive Director, Gridworks; Jennifer Galaway, Senior Manager, Regional Transmission Development and Interconnection Services, Portland General Electric; Kyle Kohne, Manager of Transmission Planning, Bonneville Power Administration

Summary: This panel will include four presentations of recent and ongoing transmission planning efforts:

- Paul Wetherbee will present on the National Transmission Planning study, a recently completed effort seeking to inform regional and interregional transmission planning through the development of tools and methodologies and the identification of potential solutions.
- Matthew Tisdale will present the Connected West study, which focuses on identifying the “next generation” of transmission development for the West in a highly decarbonized and electrified economy, again with the goal of helping to inform other planning efforts.
- Jennifer Galaway will provide an update on the Western Transmission Expansion Coalition, also known as the WestTEC, which is embarking on a 20-year transmission study for the West.

Jennifer serves as one of the co-chairs of the WestTEC Assessment and Technical Taskforce (WATT) supporting this effort.

- Kyle Kohne will provide an update on Bonneville's Evolving Grid efforts, including an overview of recently announced transmission projects identified through its most recent cluster study.

Relevance: The resource strategy in the Council's power plan is to give priority to conservation and generation resources that are "cost-effective." To be "cost-effective" under the Northwest Power Act, a resource not only has to meet or reduce load at a cost less than other resources, it also has "to be reliable and available within the time it is needed." Section 3(4)(A)(i). One of the key pieces of a resource being deemed available is access to transmission. Understanding transmission availability is becoming an increasingly important element of the Council's power planning as load forecasts show potentially dramatic growth and policies and economics drive greater need for clean, renewable energy.

The analysis for the upcoming ninth power plan will explore resource development needs considering various transmission build sensitivities. Understanding the existing landscape of transmission planning and planned projects will provide important information as the Council scopes its scenario analysis and considers potential transmission resources to include in future modeling.

Workplan: A.3.3. Track markets efforts, including data-ahead market offerings and transmission planning, to inform Council analysis.

Background: This panel will highlight several different transmission planning efforts.

National Transmission Planning Study

The U.S. Department of Energy's (DOE) Grid Deployment Office led this effort, in partnership with the National Renewable Energy Laboratory (NREL) and the Pacific Northwest National Laboratory (PNNL). While the nation's transmission systems have served power system needs, increases in load growth, renewable energy generation, and extreme weather are driving the need to enhance the existing system. DOE launched this effort in March of 2022 with goals of seeking to identify potential transmission solutions that will inform transmission planning efforts and developing planning tools and methodologies that could support transmission planning, with a specific focus on interregional transmission. The study also explored strategies to maintain grid reliability as the power system transitions to increased amount of carbon free resources.

The modeling for this study included both zonal and nodal modeling. The zonal modeling supported long-term scenario analysis through 2050 exploring different transmission expansion availability, demand growth and emissions trajectories, and a range of sensitivities on technology costs and availability. The nodal modeling, which has a more granular look at the power system, provided a deep dive into reliability with a focus on the 2035 transmission portfolios. The study findings show that large scale transmission expansion, particularly interregional expansion, provides for the lowest cost system to meet future demand and reduce emissions, saving billions of dollars relative to a more limited build out. The study also shows that grid reliability can be maintained in a future low-carbon grid during times of the greatest stress by relying on coordinated interregional transmission utilization.

This study does not recommend any specific transmission lines or locations and is not meant to replace any existing regional or interregional planning process. Rather, DOE's goal was to highlight areas that might warrant future exploration in others' planning efforts and to provide tools to enhance those planning activities.

The full report and related tools are available on DOE's website: https://www.energy.gov/gdo/national-transmission-planning-study.

Connected West

Gridworks[1] and GridLab[2] commissioned Energy Strategies to conduct the Connected West study. The study seeks to identify the "next generation" of transmission investments needed to support a highly decarbonized and electrified economy. This is a 20-year planning study focused on the Western grid. The objectives were to serve as an informational resource to help stakeholders understand trade-offs with various strategies, identify high value corridors for future transmission, and put forward new methods and approaches that could serve as inputs into other processes, such as the WestTEC effort.

This study leverages The Nature Conservancy's Power of Place: West report published in August 2022, which explores land use requirements and conservation impacts of achieving net-zero greenhouse gas emissions by 2050 across the eleven western states. The Connected West study uses the load forecast and resource builds from the high electrification scenario of the Power of Place: West analys. It also leveraged databases on land use and development sensitivities to inform potential transmission routing and the cost analysis. Because the Connected West study strived to identify the "next generation" of transmission investment, it assumed all the known planned and proposed upgrades were constructed.

The study identified a minimum of around 21,500 line miles of transmission needed to meet the loads and resources as projected by the study.[3] Of this, roughly 25% represents planned and proposed upgrades that were assumed in the study to be developed. The new "next generation" transmission identified significant potential for upgrades and expansions to existing corridors with the need for development of some new transmission corridors.

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[1] GridWorks is an organization whose "mission is to convene, educate and empower stakeholders working to decarbonize electricity grids"; https://gridworks.org/about-us/.

[2] GridLab, is an organization that coordinates a team of experts and independent consultants to provide modeling support and expert testimony in rate proceedings and hearings on energy policy; https://gridlab.org/mission-approach/.

[3] For context, the study assumed approximately 100,000 line miles of existing transmission.

- Upgrades/Expansions to Existing Corridors: This accounted for approximately 85% of the next generation transmission. This includes reconductoring upgrades, co-locating new lines, and advanced grid technologies such as high-capacity conductors. Leveraging these technologies minimized the need for new greenfield transmission.
- New Transmission Corridors: The remaining 15% was from new transmission corridors. The study identified critical areas for this new transmission development to include connections between Colorado and its neighbors, Arizona and New Mexico, Montana and the Mid-Columbia, and pathways inside of California.

As with the National Transmission Planning study, the Connected West results demonstrated net benefits from increased connectivity between regions, which allows for efficiencies across the system taking advantage of load and resource diversity. These results underscore the importance for planning and coordination across utilities and regions.

The full report is available here: https://gridworks.org/wp-content/uploads/2024/09/Connected-West-Final-Report-240918.pdf.

Western Transmission Expansion Coalition

The Western Transmission Expansion Coalition, also known as WestTEC, is a west-wide effort to develop an actionable transmission study. The WestTEC is coordinated by the Western Power Pool (WPP) and represents the planning footprints of NorthernGrid (the transmission planning organization covering our region), West Connect, California ISO, and future planning region of the Southwest Power Pool. By bringing together this larger footprint, WestTEC is embarking on the first of its kind interregional planning study. This initiative started to come together in 2023. In October of 2023, WPP released a concept paper outlining the goals and objectives of this effort, seeking feedback to help shape the work.[4] With a goal of expediency, the WestTEC quickly then transitioned into developing out the coalition and starting to scope the study.

One core element of WestTEC is working with a broad set of regional partners representing a range of industry expertise, States, and Tribes. The hope is that this broad coalition will provide for a strong foundation to support working collectively through some of the more challenging aspects of transmission development, such as cost allocation and permitting. The WestTEC has three workgroups:

- Steering Committee: This committee is the primary decision-making group of WestTEC and is responsible for providing direction to guide the technical taskforce and the Regional Engagement Committee.
- WestTEC Assessment Technical Task (WATT): This group is responsible for providing technical support, by informing the study scope and analytical approach and working with the contractor (Energy Strategies) throughout the analysis. John Ollis serves on the WATT for the Council.

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[4] The Council submitted comments in support of this effort, available here: https://nwcouncil.box.com/s/62ok7izmqqerpmauhbnewc9q0862s1ni.

- Regional Engagement Committee: This committee brings together a wide range of regional partners to serve as the primary engagement group. Representatives on this committee include consumer-owned utilities, public interest organizations, ratepayer advocacy organizations, independent transmission companies, independent power producers, industrial customer representatives, and Tribes.

The WestTEC completed its study plan in August of this year. The work includes both a 10-year and 20-year study. The 10-year study focuses on near-term gaps in interregional transmission, focusing on transmission solutions that could be realistically developed in the time horizon (e.g. grid enhancing technologies). The 20-year analysis will seek to identify transmission solutions to support efficient and reliable transfer of power from generation to load. In addition to considering interregional upgrades, the study will also address intraregional and interstate needs. The longer time horizon for this portion of the analysis allows for the study to consider advanced transmission solutions that are still being developed.

Their current timeline anticipates completion of the 10-year study in September 2025 and the 20-year study in November 2026, with a final report to be published in the first quarter of 2027. This timing aligns with the Council's current Ninth Power Plan timeline, with a goal to start scenario modeling in the third quarter of 2025, which would allow leveraging insights from the 10-year study to inform potential transmission resources. The Council's final plan is currently anticipated to be completed by the end of 2026. Staff is staying connected to the WestTEC efforts, primarily through engagement in the WATT, to both inform and learn from this transmission planning effort.

More information on the WestTEC is available here: https://www.westernpowerpool.org/about/programs/western-transmission-expansion-coalition.

Bonneville's Evolving Grid

Bonneville operates and maintains roughly 75% of the region's transmission system, and therefore plays a critical role in transmission planning for the region. Bonneville developed significant amounts of transmission capacity in the 1960s, 1970s, and some into the 1980s, and the region was able to grow into that capacity. The recent transition to clean generation and load growth from electrification and industry has driven a need for expanded transmission capacity. Bonneville has experienced exponential growth in its various service request queues from generation interconnection, transmission service requests to move power from one point to another, and line and load requests from customers. Bonneville's established its strategic Evolving Grid effort to identify critical new projects and address policy needs.

Bonneville announced a first set of projects (Evolving Grid 1.0) in 2023. Many of these projects are intended to address congestion issues in the Portland area and help get power from generation on the east side of the region across the Cascades to the load centers in the west. Bonneville also identified several projects for generation and load connections in central Oregon. These projects are in various stages of scoping, design, and construction, with planned completion dates between 2025 and 2030.

In October 2024, Bonneville announced its second set of projects (Evolving Grid 2.0). This includes 13 new projects that continue to address challenge of getting power across the Cascades and the congestion in load centers like Portland.

More information on Bonneville Transmission's Evolving Grid efforts is available here: https://www.bpa.gov/energy-and-services/transmission/business-model.

Pacific Northwest
NATIONAL LABORATORY

NREL
NATIONAL RENEWABLE ENERGY LABORATORY

U.S. DEPARTMENT OF
ENERGY

National Transmission Planning (NTP) Study:

Northwest Power and Conservation Council

Paul Wetherbee (PNNL)

November 14, 2024

NOTICE

This presentation includes preliminary results and should not be cited or distributed

Study objectives

- **Identify potential transmission solutions** that will provide broad-scale benefits to electric customers under a wide range of potential futures
- **Inform planning processes** for regional and interregional transmission
- **Identify interregional and national strategies** to maintain grid reliability as the grid transitions, including to a reliance on low- and zero-carbon energy resources
- Develop new national **grid-scale planning tools and methods** that can be used by industry, especially when planning for interregional transmission capacity needs

Broad Stakeholder Engagement

Public Input

Existing Convenor Groups

Technical Review Committee

Tribal Outreach

NESCOE
New England States Committee on Electricity

NARUC
National Association of Regulatory Utility Commissioners

NASEO
National Association of State Energy Officials

OMS

WESTERN

NATIONAL GOVERNORS ASSOCIATION

EIPC
Eastern Interconnection Planning Collaborative

UNIVERSITY OF MICHIGAN

Southeastern Regional TRANSMISSION PLANNING

CEBA

EPRI ELECTRIC POWER RESEARCH INSTITUTE

Bonneville POWER ADMINISTRATION

Organization of PJM States, Inc.

TVA TENNESSEE VALLEY AUTHORITY

THE Brattle GROUP

MISO misoenergy.org

SPP Southwest Power Pool

WILDLIFE

EPRI ELECTRIC POWER RESEARCH INSTITUTE

AMERICAN CLEAN POWER

NEI NUCLEAR ENERGY INSTITUTE

MISO misoenergy.org

California ISO

ISO new england

DEQ MONTANA ENERGY OFFICE

OREGON DEPARTMENT OF ENERGY

Xcel Energy

TVA TENNESSEE VALLEY AUTHORITY

eia

SMART WIRES

ESIG ENERGY SYSTEMS INTEGRATION GROUP

PACIFICORP

US Army Corps of Engineers

Penn Law

The Nature Conservancy

LS POWER

New York ISO Independent System Operator

ercot

APEX CLEAN ENERGY

pjm

Southern Company

NEW YORK STATE OF OPPORTUNITY. Public Service Commission

eia

NEW YORK STATE OF OPPORTUNITY. NYSERDA

NRDC NATURAL RESOURCES DEFENSE COUNCIL

COLUMBIA UNIVERSITY

OCETI SAKOWIN POWER

Many others…

GDO GRID DEPLOYMENT OFFICE

Technical Review Committee (TRC)

- Thank you to all TRC members
  - **Four** public meetings
  - **Three** plenary TRC meetings
  - **Six** Modeling Subcommittee meetings
  - **Four** Government Subcommittee meetings
  - **Two** Land Use and Environmental Exclusions subcommittee meetings
  - **Four** rounds of regional meetings
  - **Two** sets of office hours

Source: Unsplash

Final Report Organization

- **Executive Summary** - high-level findings and next steps for how to build on the analysis.
- **Chapter 1: Introduction –** background, context and study design; modeling and scenario framework.
- **Chapter 2: Long-Term U.S. Transmission Planning Scenarios** - methods for capacity expansion and resource adequacy, key findings from the scenario analysis and economic analysis, and High Opportunity Transmission interface analysis.
- **Chapter 3: Transmission Portfolios and Operations for 2035 Scenarios** - methods for translating zonal scenarios to nodal-network-level models, network transmission plans for a subset of the scenarios, and key findings from transmission planning and production cost modeling
- **Chapter 4: AC Power Flow Analysis for 2035 Scenarios** - methods for translating from zonal and nodal production cost models to alternating current (AC) power flow models and describes contingency analysis for a subset of scenarios.
- **Chapter 5: Stress Analysis for 2035 Scenarios** - how the future transmission expansions perform under stress tests.
- **Chapter 6: Conclusions** - high-level findings and study limitations across the six chapters.

Companion Reports

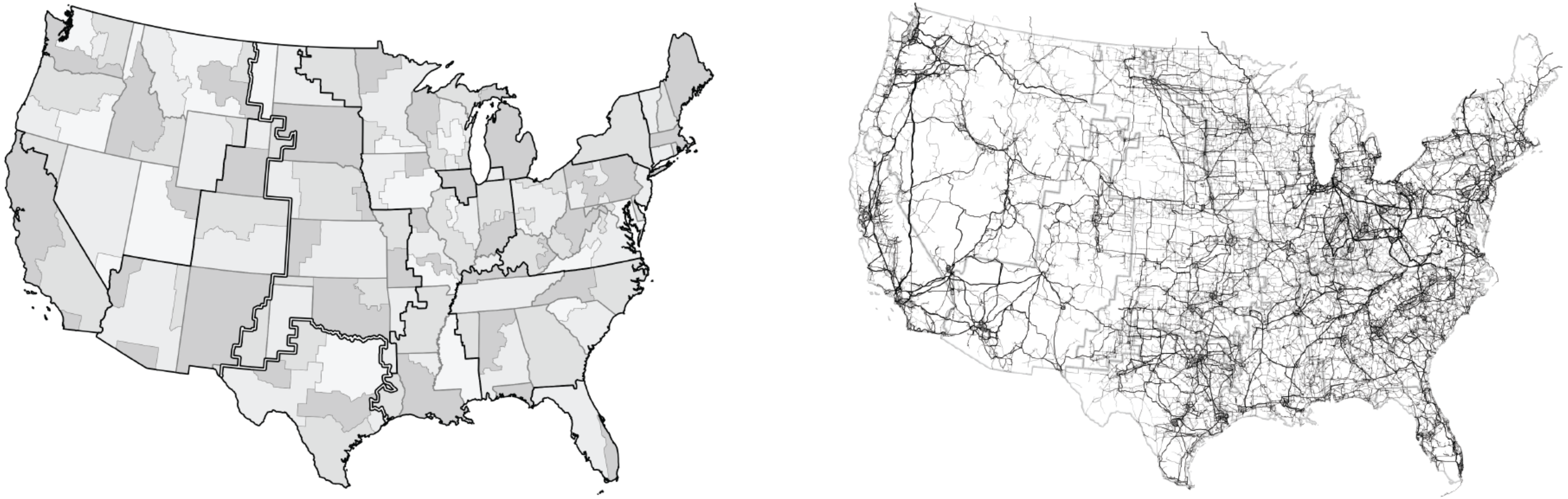
- **Interregional Renewable Energy Zones (March 2024)** connects the NTP Study scenarios to ground-level regulatory and financial decision making—specifically focusing on the potential of interregional renewable energy zones.
- **Barriers and Opportunities to Realize the System Value of Interregional Transmission (June 2024)** examines issues that prevent existing transmission facilities from delivering maximum potential value and offers a suite of options that power system stakeholders can pursue to overcome those challenges between non-market or a mix of market and non-market areas, and between market areas.
- **Western Interconnection Baseline Study (September 2024)** uses production cost modeling to compare a 2030 industry planning case of the Western Interconnection to a high renewables case with additional planned future transmission projects based on best available data.
- Forthcoming: **Regulatory Pathways to Interregional Transmission (December 2024)**

Report Timeline

- Report was released October 3, 2024
- Final public webinar October 16, 2024
- National labs meeting individually with RTOs/ISOs and transmission-owning utilities in the next few months to discuss results and potential next steps
  - Key insights
  - Technical results
  - Data
  - Tools and methods

Study Methods & Scenarios

Multimodel analysis for a low-cost, reliable transmission system of the future



Zonal Resolution
Long-Term Scenarios through 2050

- Capacity Expansion
- Economic Analysis
- Resource Adequacy

Nodal Resolution
2035 Transmission Portfolios

- Production Cost
- Power Flow
- Stress Analysis

Scenarios:

Transmission Frameworks

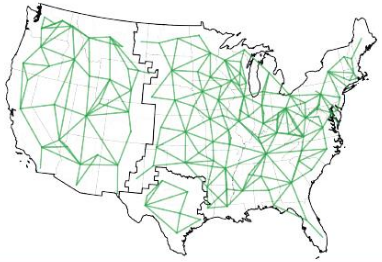
Reference Transmission Framework

Limited (Lim)

- No new interregional transmission
- Total annual transmission expansion limited to recent observed maximum

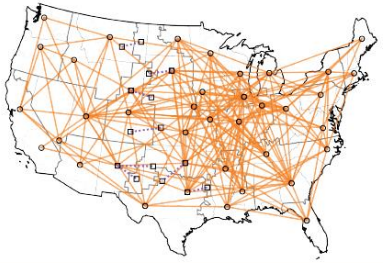
Accelerated Transmission Framework

Alternating Current (AC)



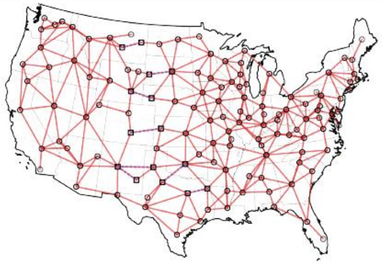
- Expansion allowed within interconnections
- No new DC connections

Point-to-Point (P2P)



- Expansion allowed across the country
- Includes long-distance point-to-point HVDC options

Multi-Terminal (MT)



- Expansion allowed across the country
- Includes multi-terminal HVDC options between neighboring zones

Scenarios:

Transmission
×
Demand
×
Emissions
Targets

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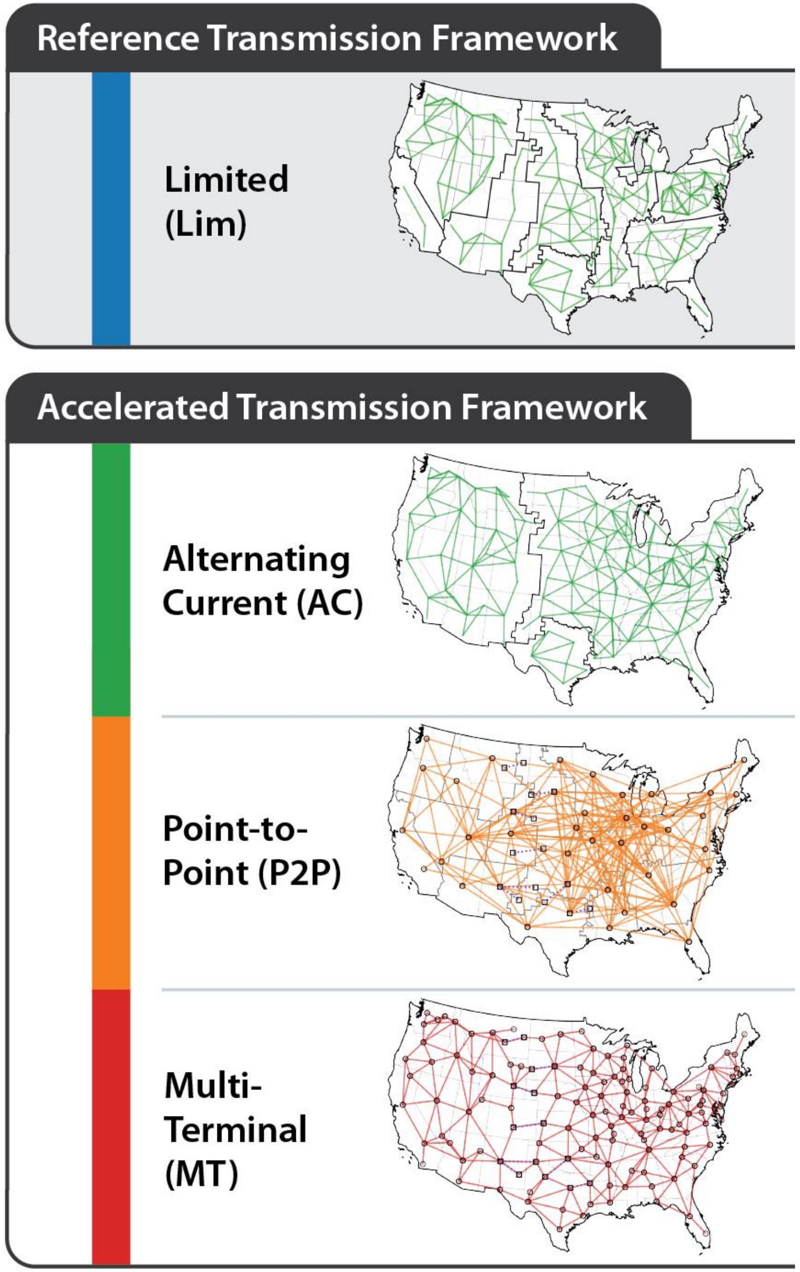
36 core
scenarios



Reference Transmission Framework

Limited (Lim)

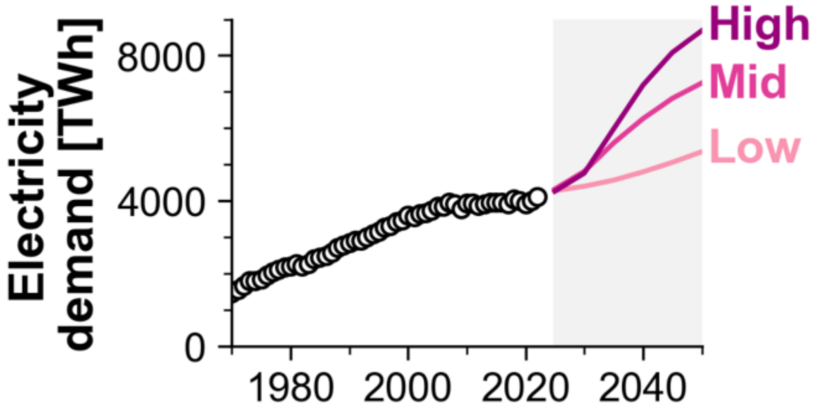
Accelerated Transmission Framework

Alternating Current (AC)

Point-to-Point (P2P)

Multi-Terminal (MT)

× 3 Demand Growth



× 3 Emissions Targets

- Current policies
- 90% CO_2 reduction by 2035
- 100% by 2035

Goal is to understand role of transmission across many possible futures

6 principal findings (+22 supporting key takeaways)

1. Transmission expansion under current policies
2. Benefits of transmission
3. Amount of transmission expansion
4. Grid reliability
5. Promising interregional transmission
6. Advancements in planning approaches

90% emissions reductions by 2035

Executive Summary

Current Policies definition

- Includes legislated energy policies as of **June 2023**
  - State renewable portfolio and clean energy standards
  - Inflation Reduction Act

- Excludes
  - Newer policies (e.g., Clean Air Act section 111 rules, newer state policies)
  - Non-binding state targets
  - Corporate voluntary targets

Principal Finding

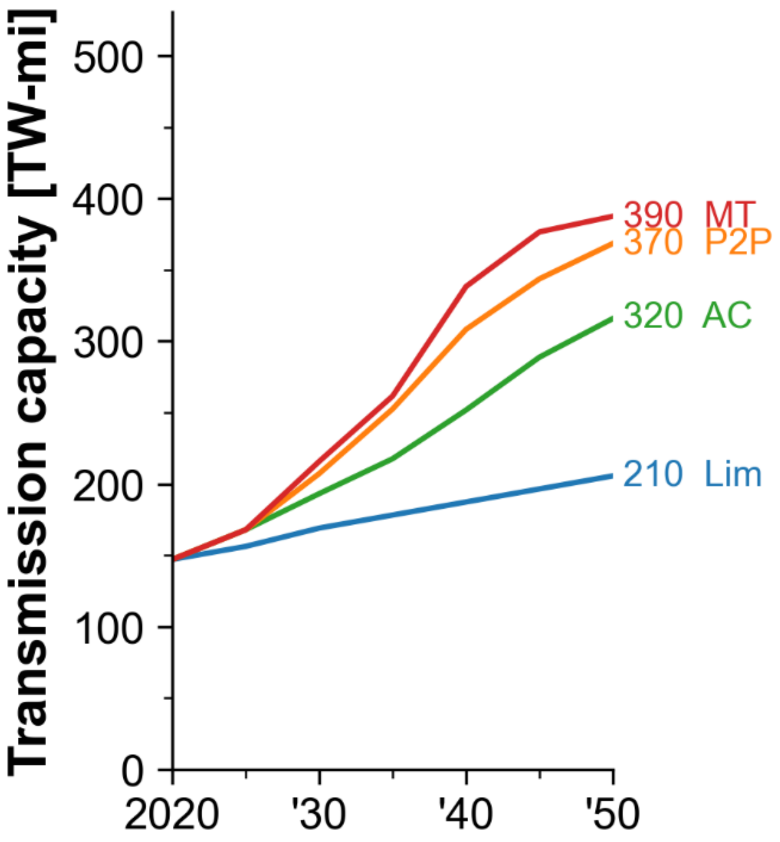
Under Current Policies…

The lowest-cost U.S. electricity system portfolios that meet future demand growth and reliability requirements include substantial expansion in transmission.

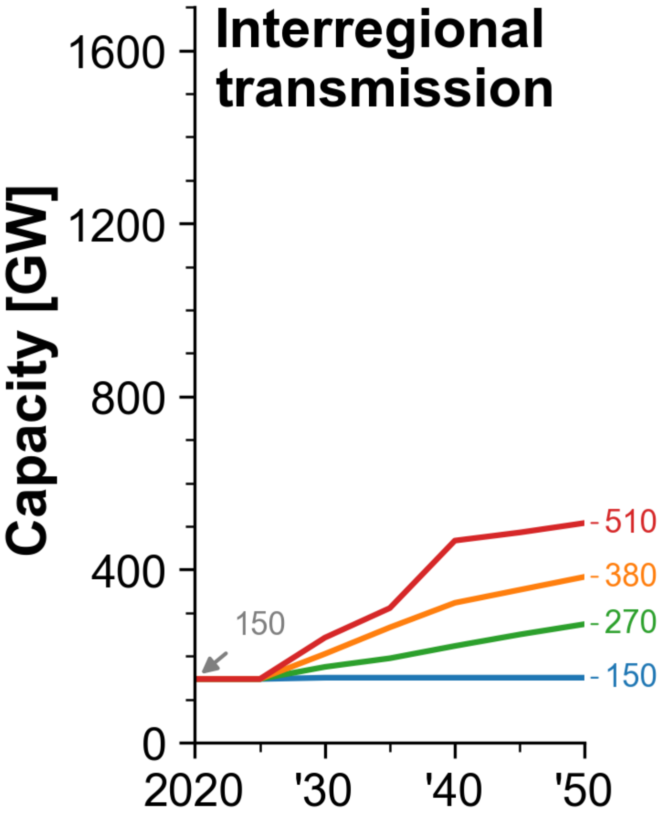
Under Current Policies

The total transmission system of the contiguous United States expands 1.7 to 2.1 times the size of the 2020 system by 2050 and interregional transmission grows 2.0 to 2.8 times.

Mid-demand



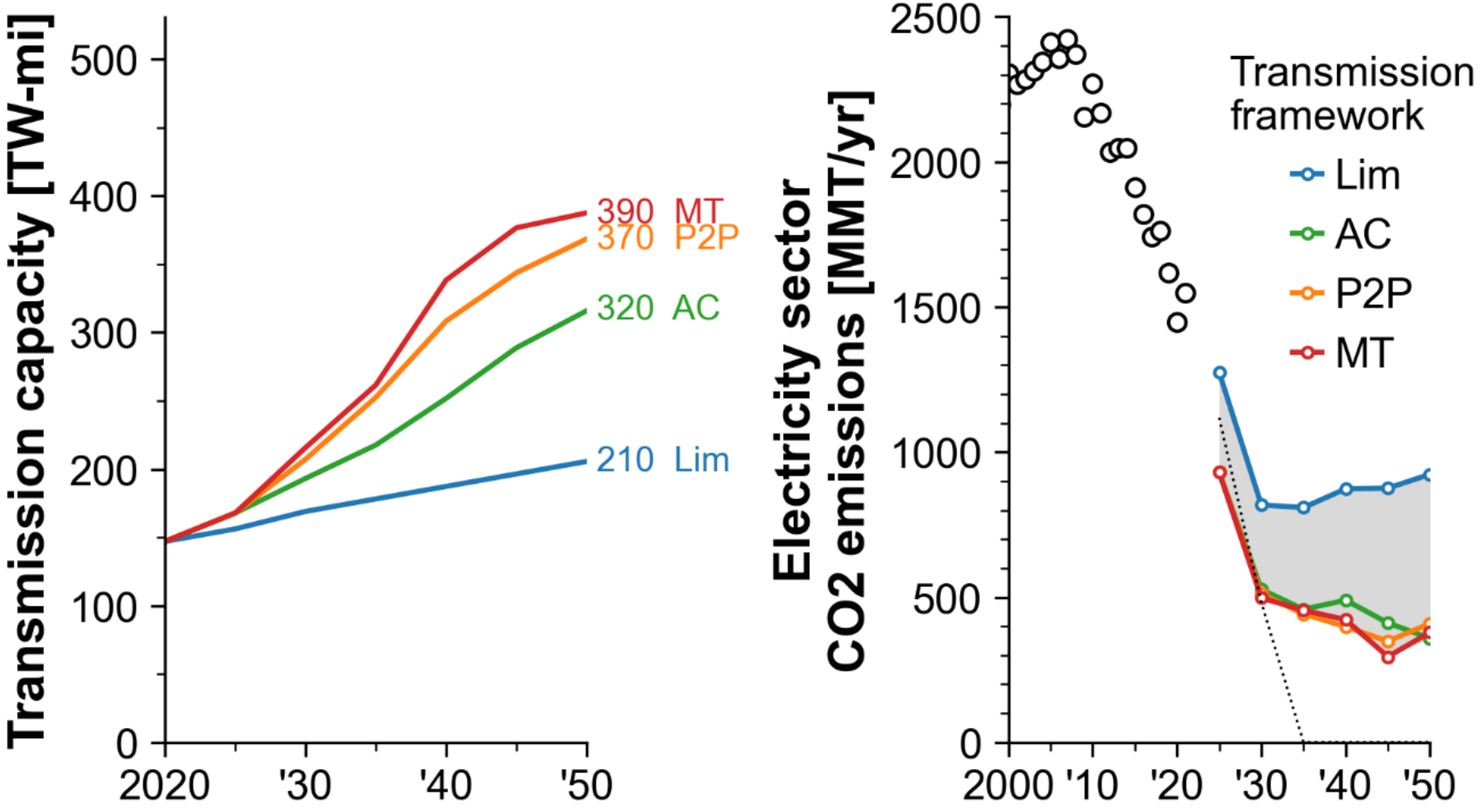
Total transmission includes local (VRE interconnection), regional, and interregional transmission



Under Current Policies

Accelerating transmission deployment beyond historical rates reduces power system CO_2 emissions by 10 to 11 billion metric tons (43% to 48%) through 2050.

Mid-demand



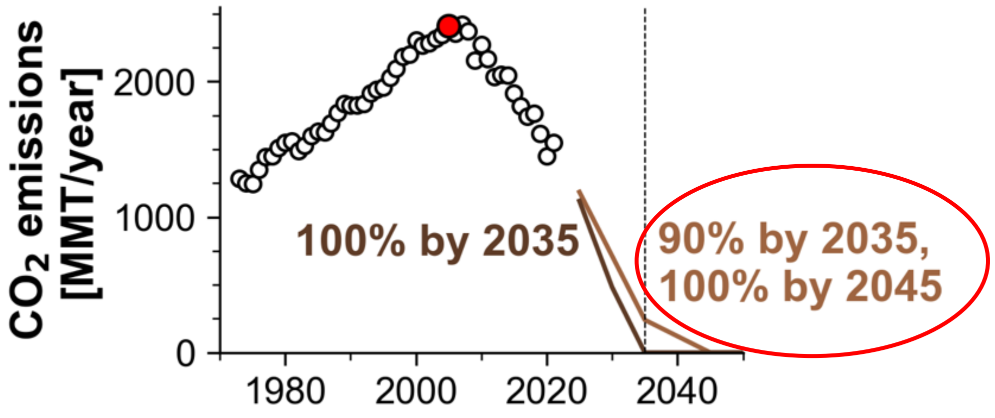
Central decarbonization scenario

- **90% emissions reductions (from 2005 levels) by 2035, 100% by 2045**
  - Implemented as a national annual limit on power sector CO_2(e)
  - Emissions can be offset by negative emissions technologies when allowed
  - Limit applies to direct CO_2 and upstream methane emissions
- Includes existing state and federal policies
- Nodal analyses focus on 2035 portfolios

← *Demand growth* →

↕ *Emissions constraint*

Low demand Current policies	Mid demand Current policies	High demand Current policies
Low demand 90 by 2035, 100 by 2045	Mid demand 90 by 2035, 100 by 2045	High demand 90 by 2035, 100 by 2045
Low demand 100 by 2035	Mid demand 100 by 2035	High demand 100 by 2035



Principal Finding

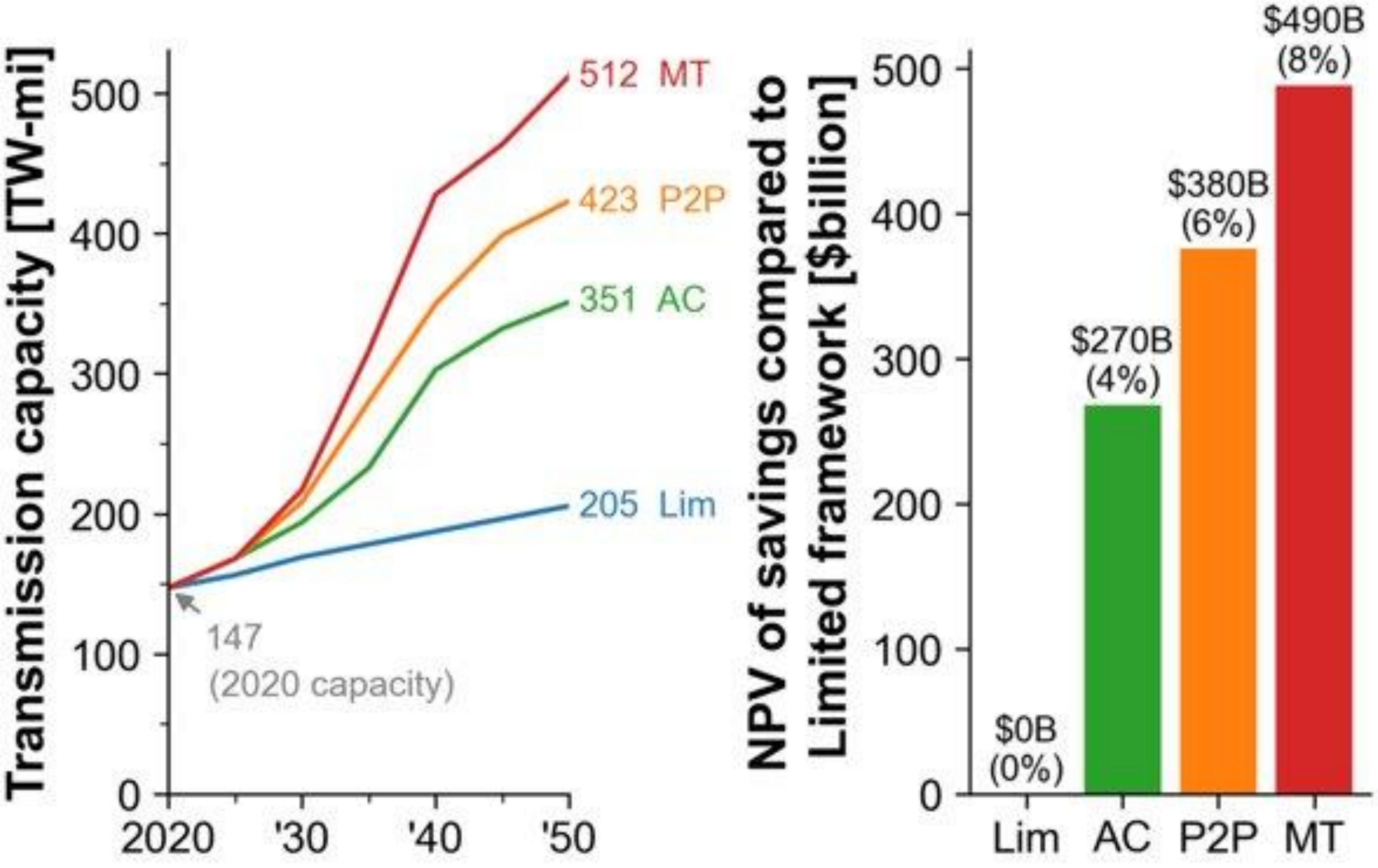
Under 90% by 2035 emissions reductions …

The study finds hundreds of billions of dollars of net benefits from large-scale transmission expansion compared to historic rates of transmission deployment.

Under 90 by 2035

Accelerated transmission expansion leads to national electric system cost savings of $270 to $490 billion through 2050.

Approximately $1.60 to $1.80 is saved for every dollar spent on transmission.



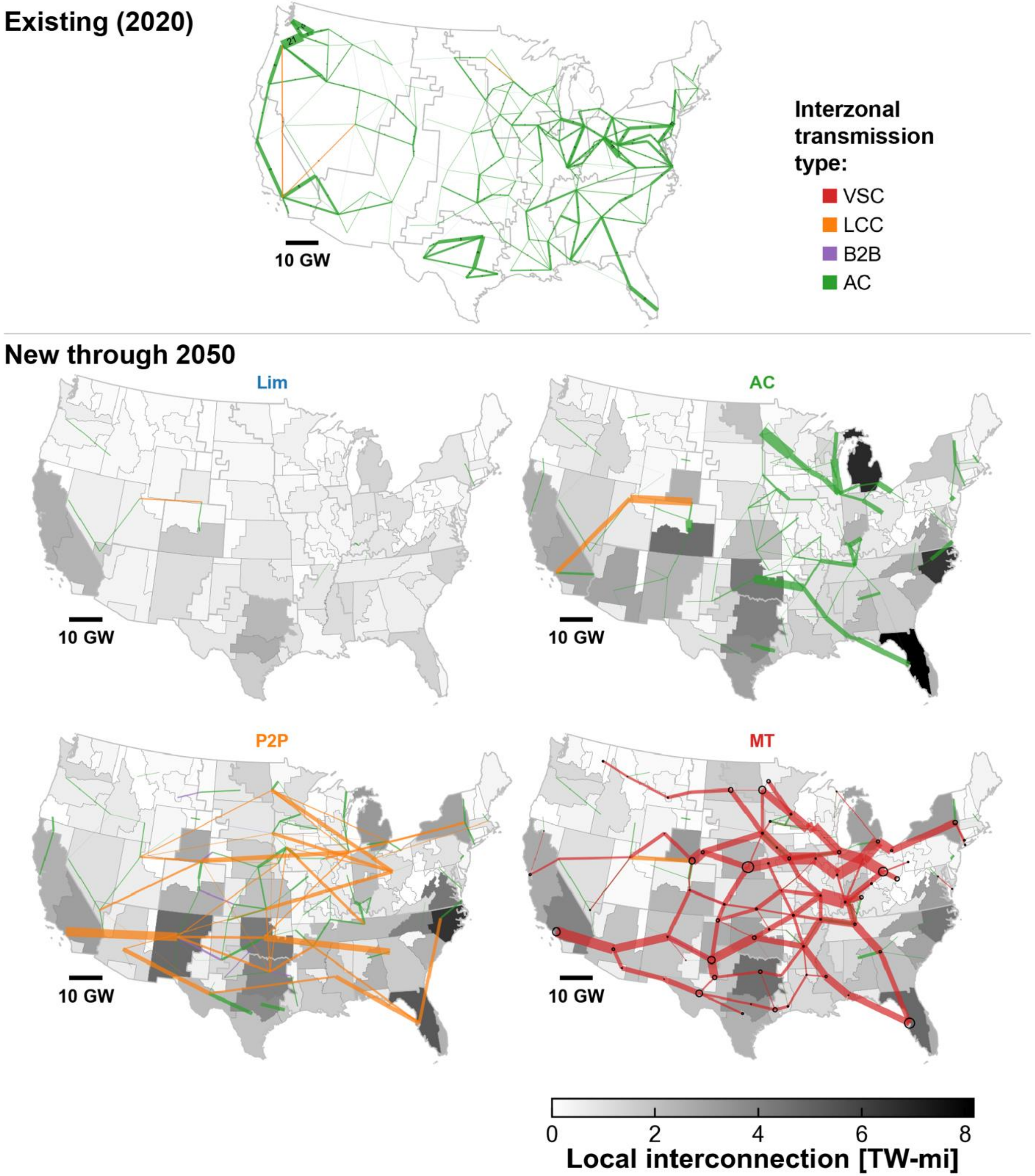
Principal Finding

Under 90% by 2035 emissions reductions …

A substantial expansion of the transmission system throughout the entire contiguous United States delivers the largest benefits across a wide variety of scenarios.

Under 90 by 2035

The U.S. transmission system expands 2.4 to 3.5 times the size of the 2020 system by 2050 in scenarios that achieve 90% emissions reductions by 2035 with lowest power sector costs.



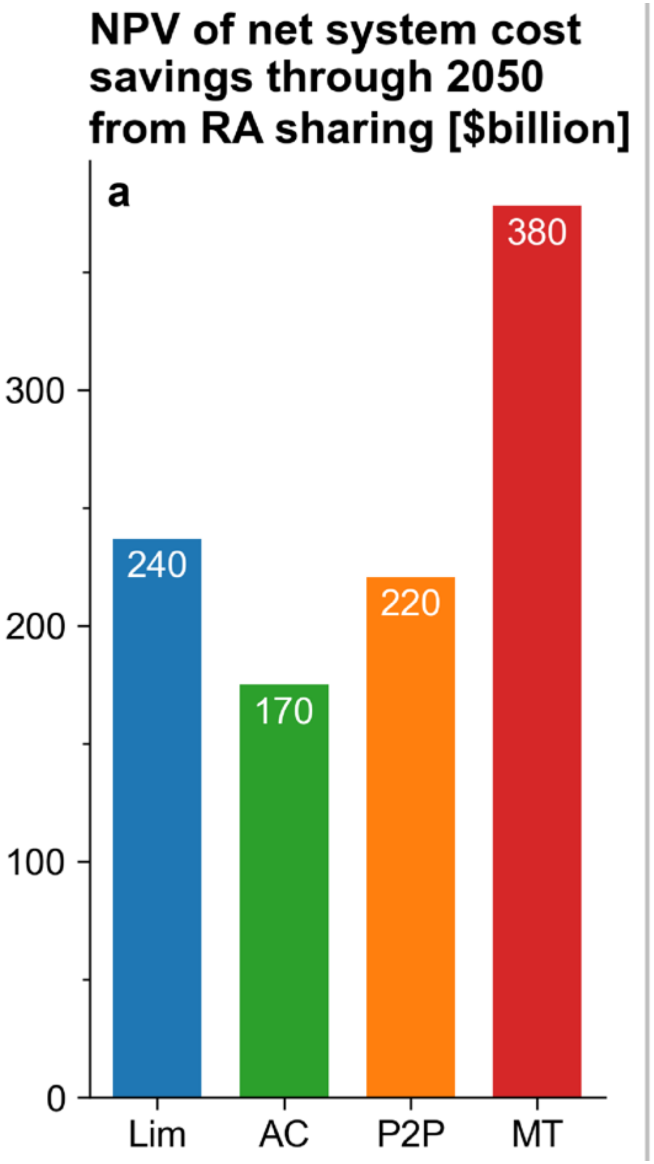
Principal Finding

Under 90% by 2035 emissions reductions …

Grid reliability can be maintained in future low-carbon grid scenarios with the lowest-cost solutions relying on coordinated transmission utilization between regions during periods of greatest stress.

Under 90 by 2035

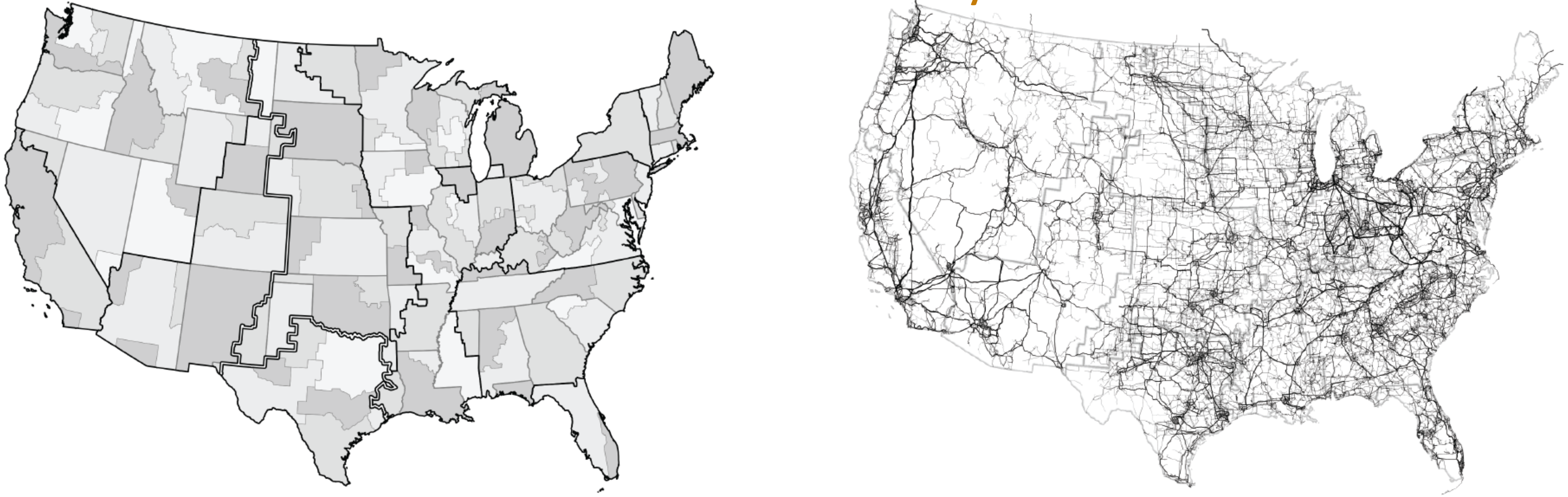
When transmission regions coordinate to achieve resource adequacy, system costs through 2050 are lowered by $170–380 billion.



When the **benefit of resource adequacy** is not considered, substantially less transmission is built

Multimodel analysis for a low-cost, reliable transmission system of the future

Additional WECC Focused PCM and Nodal Economic Analysis Based on Earlier Set of CEM



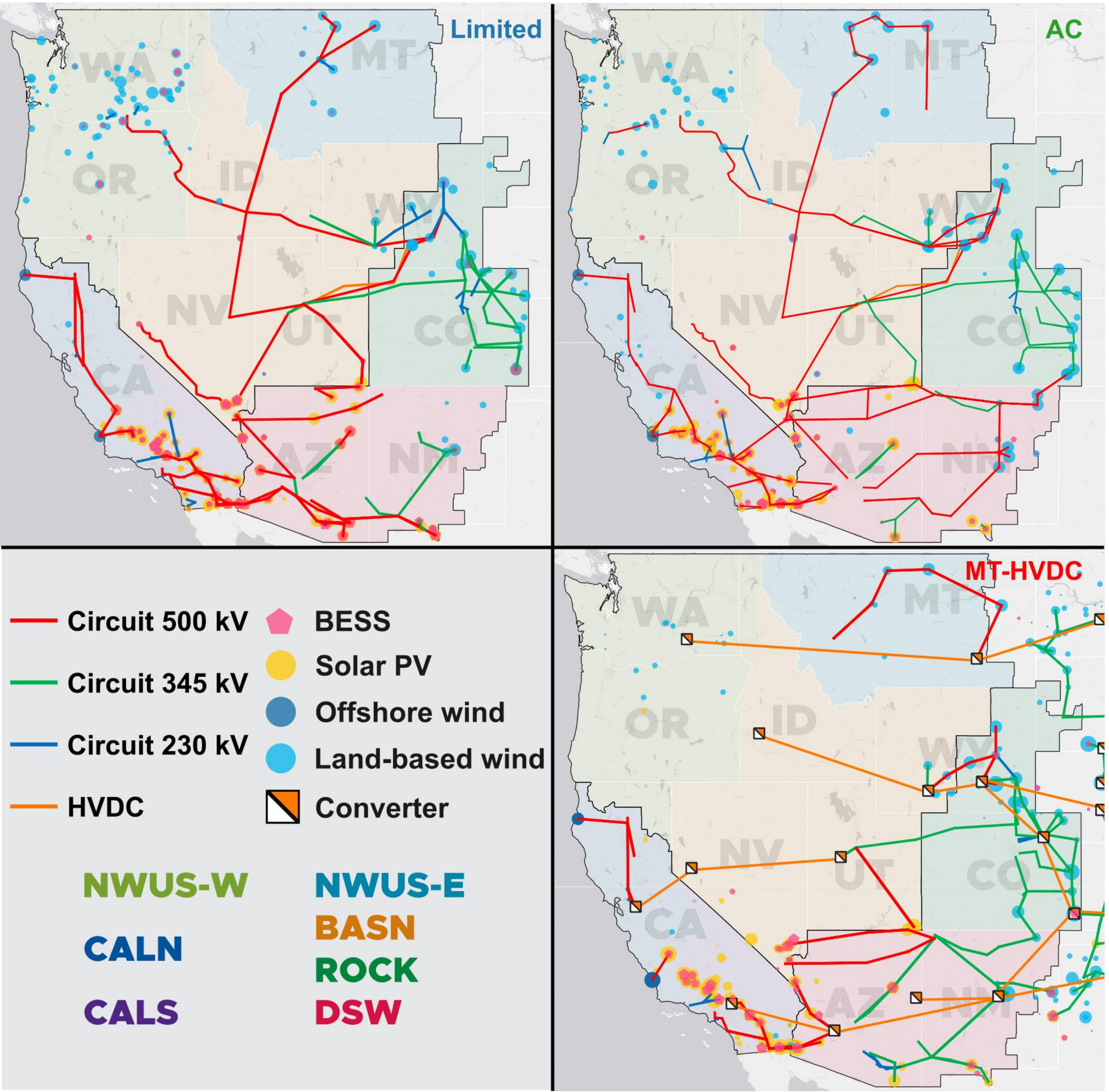
Zonal Resolution
Long-Term Scenarios through 2050

- Capacity Expansion
- Economic Analysis
- Resource Adequacy

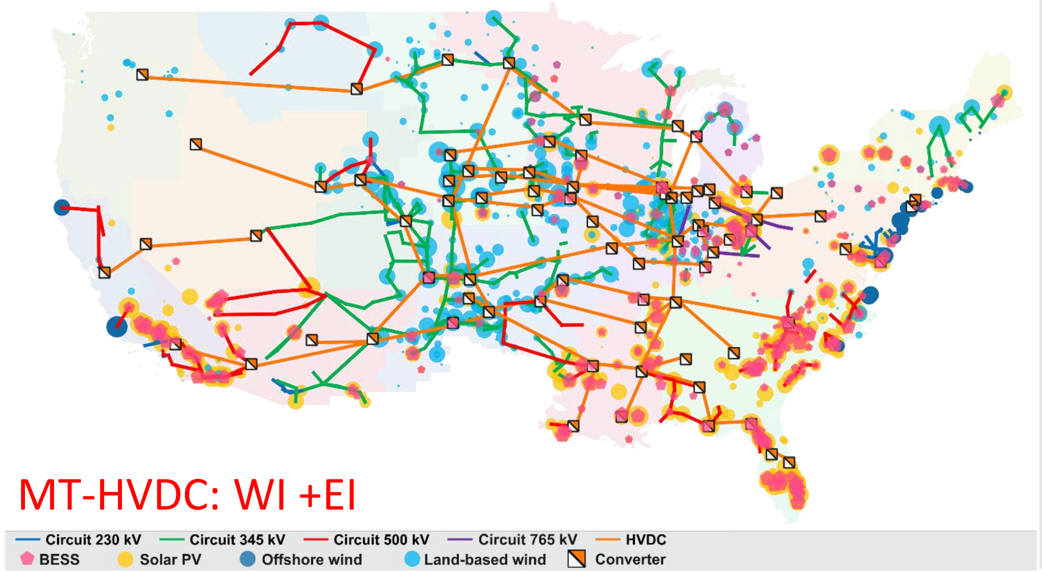
Nodal Resolution
2035 Transmission Portfolios

- Production Cost
- Power Flow
- Stress Analysis

Transmission expansion results on the Western Interconnection footprint Based on earlier CEM Results



WI only



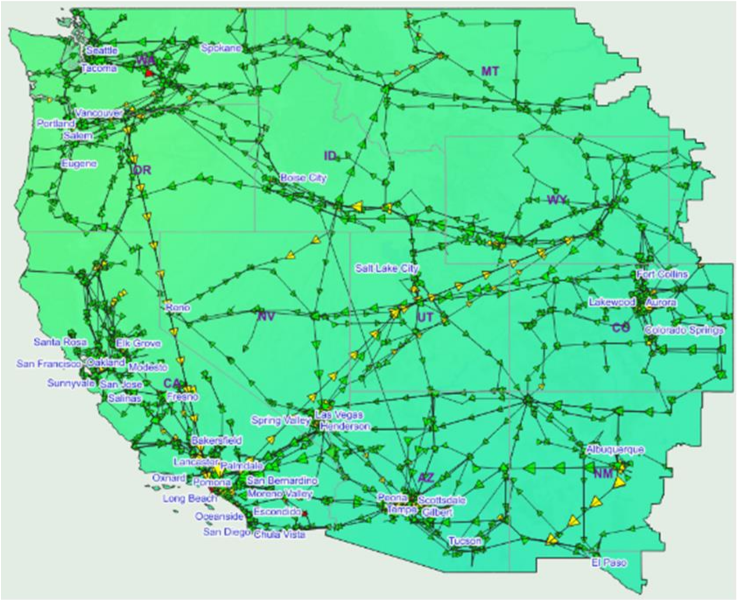
MT-HVDC: WI +EI

"Preliminary Results | Do Not Cite | Line locations are illustrative only."

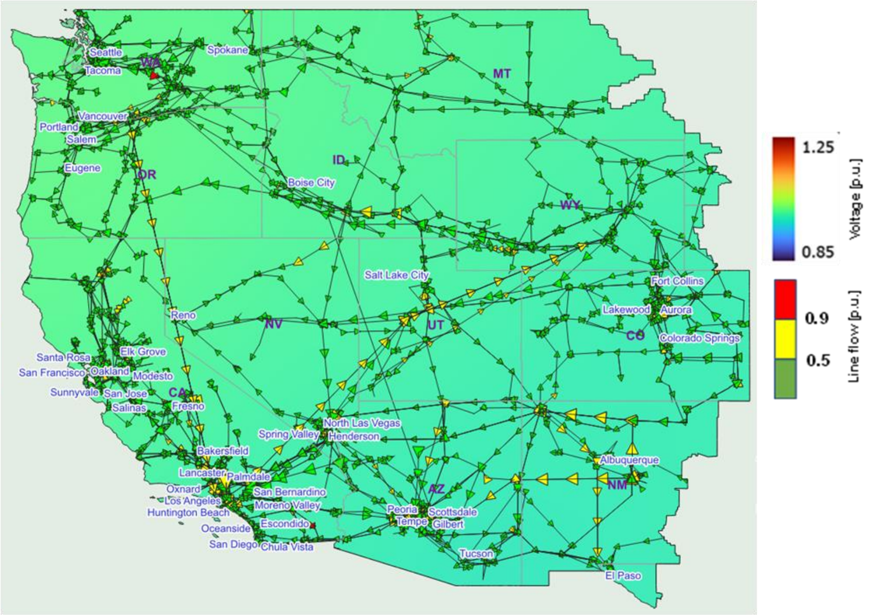
Power flow analyses specific to the Western Interconnection demonstrate highly decarbonized systems can withstand selected typical contingencies on new-build transmission lines even when lines are highly loaded.

Energy storage provides a substantial portion of the primary frequency response for the modeled large power plant contingencies.

Pre-Contingency: Inter-regional AC

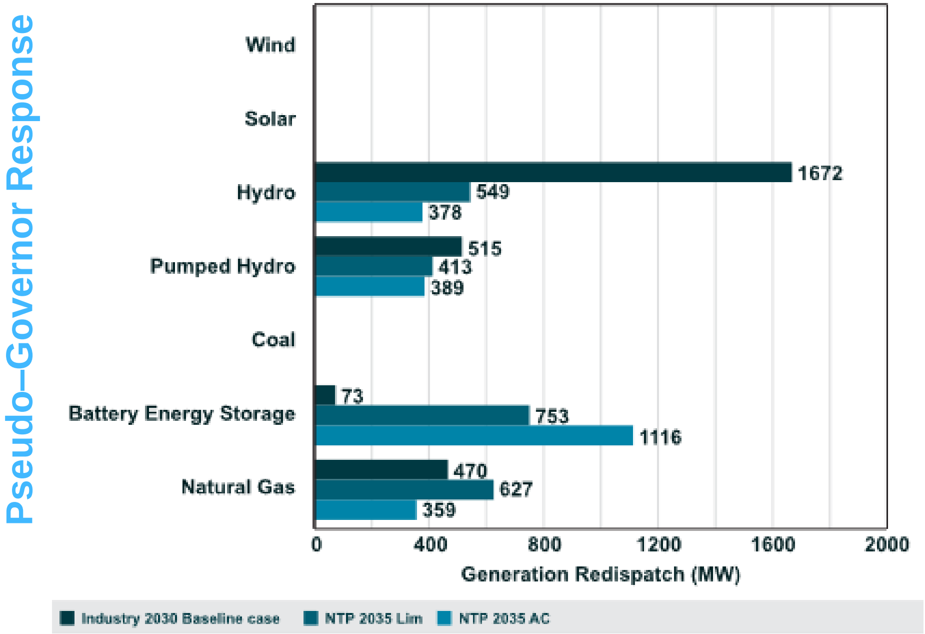


Post –Contingency: Inter-regional AC



- Good voltage profiles across WECC are obtained for different imported hours from PCM

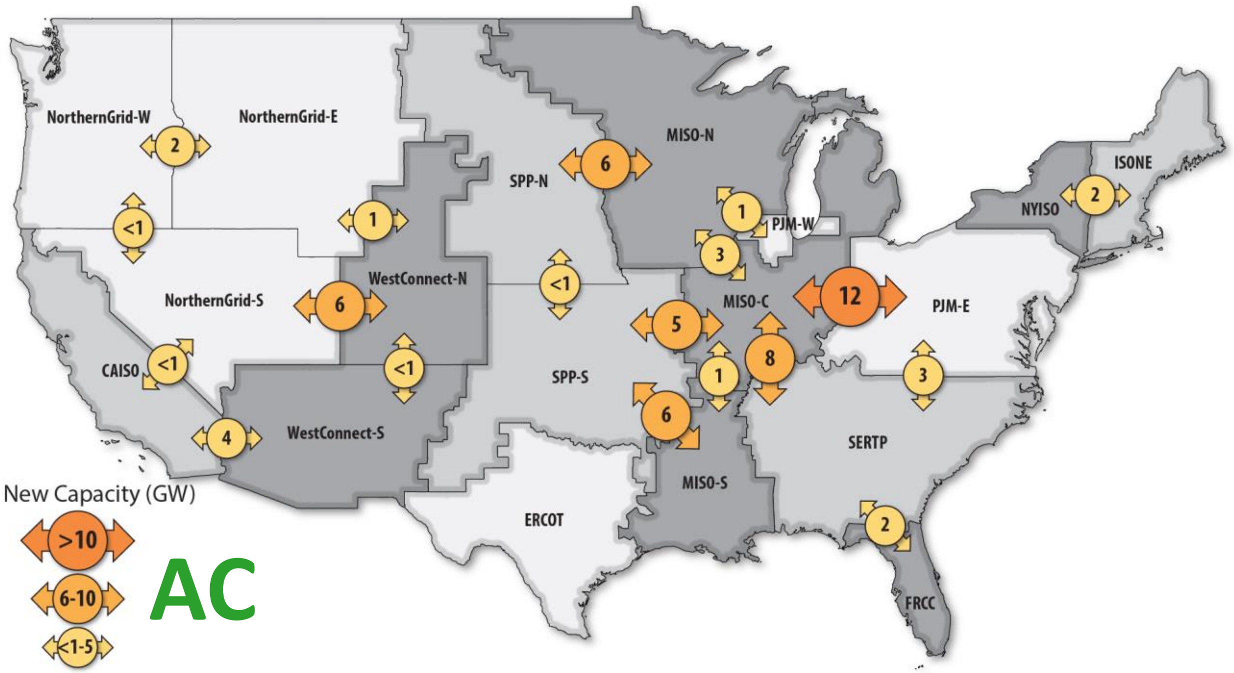
- Overall, no additional voltage violation in post contingency cases beyond what is observed in the pre-contingency cases



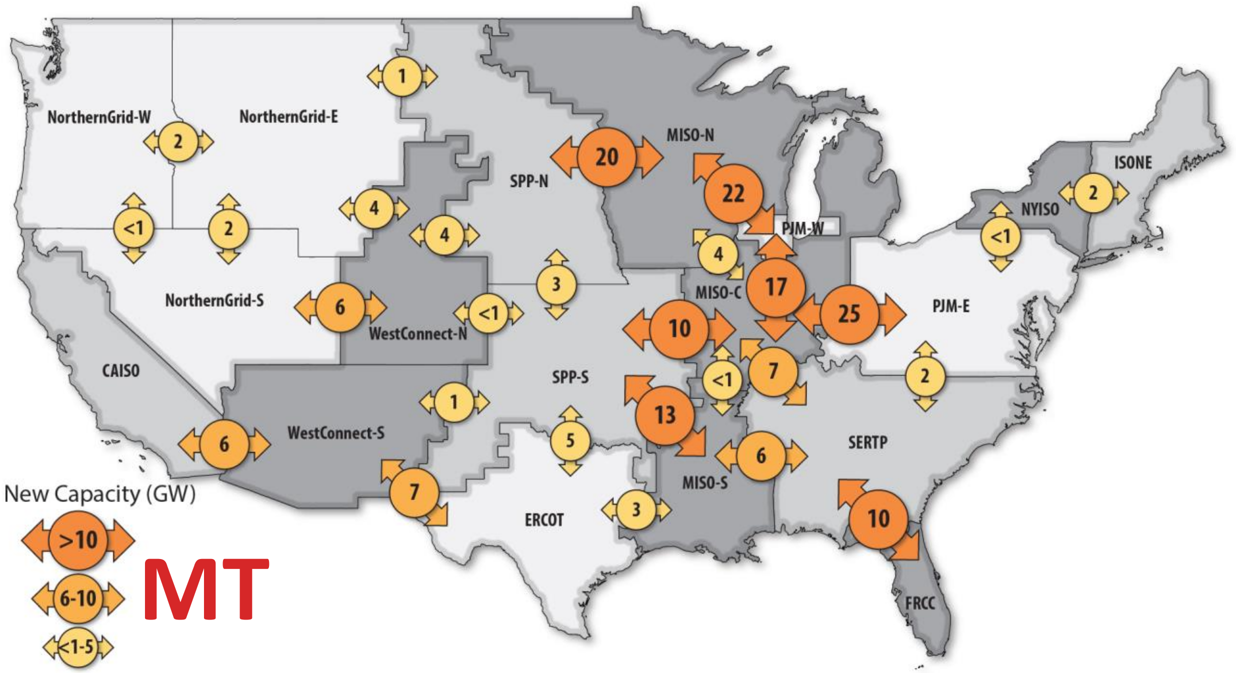
Principal Finding

Under 90% by 2035 emissions reductions …

The NTP Study identifies several examples of transmission that could be promising candidates for more in-depth consideration by planners and developers.



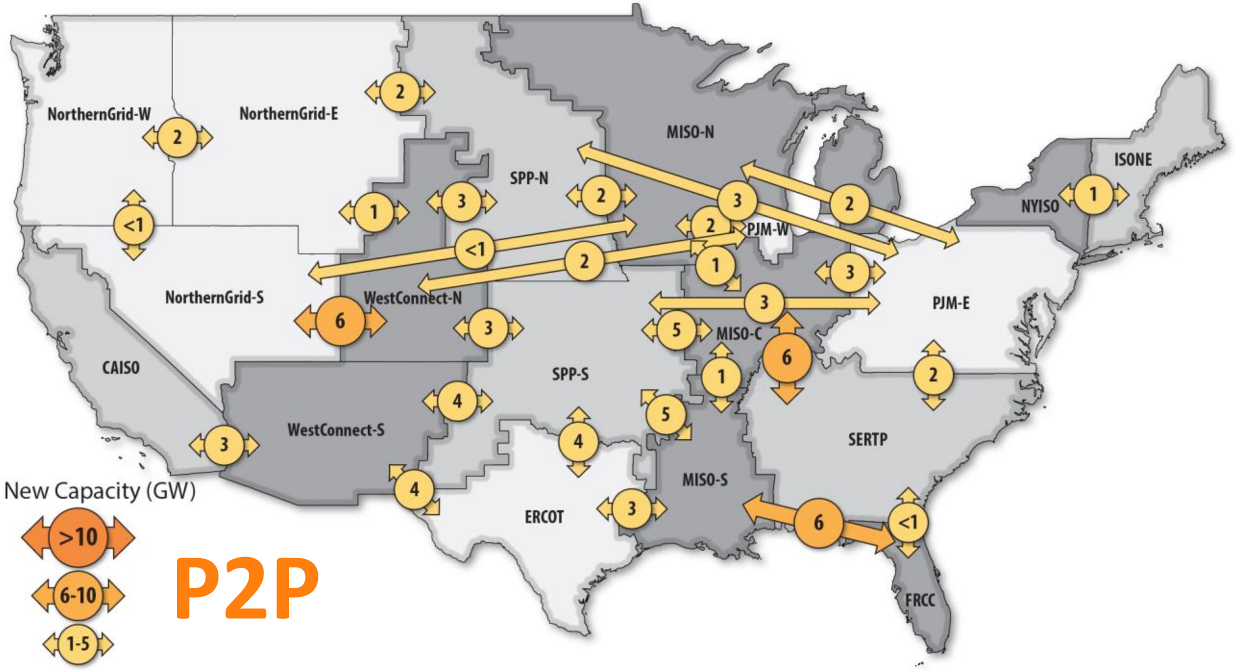
AC



MT

HOT interfaces represent transmission capacity expansion [2020-2035] results between regions across many scenarios. Transmission projects that align with these HOT interfaces could be strong candidates for further study and serve as a starting point for accelerated transmission expansion.

Under 90 by 2035

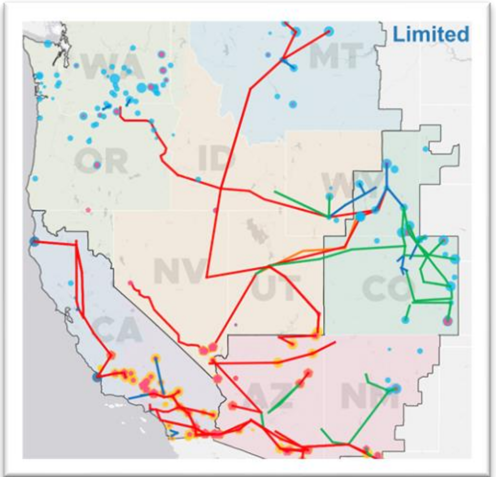


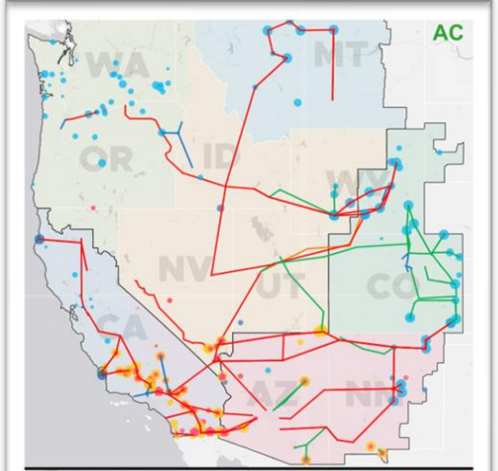
P2P

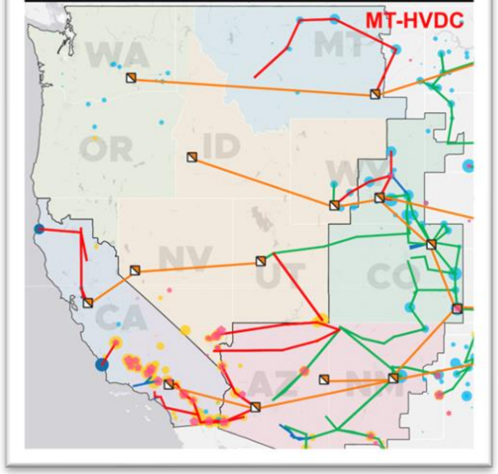
Under 90 by 2035

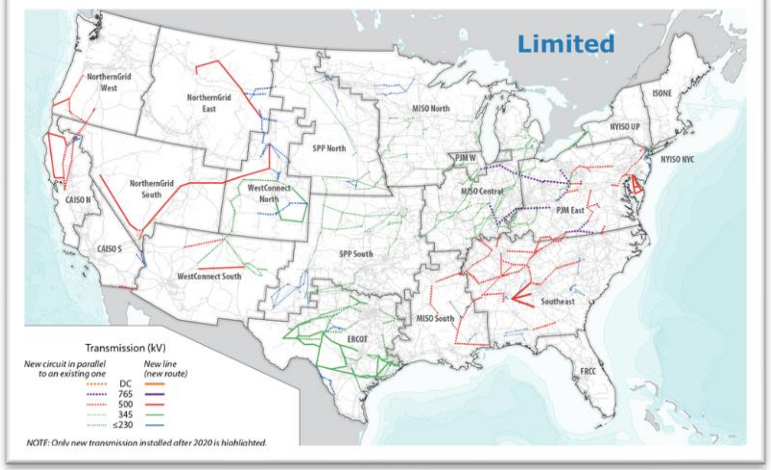
These do not represent proposed routes or detailed siting considerations

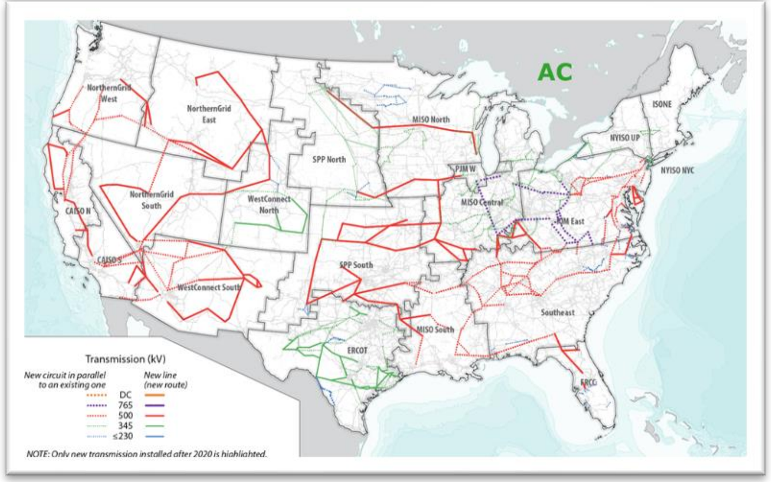
Transmission portfolios that deliver broad-scale benefits to consumers were developed using laboratory and industry tools. These transmission portfolios demonstrate new interregional transmission combined with intraregional transmission upgrades can help meet the flexibility requirements of high renewable energy power systems.

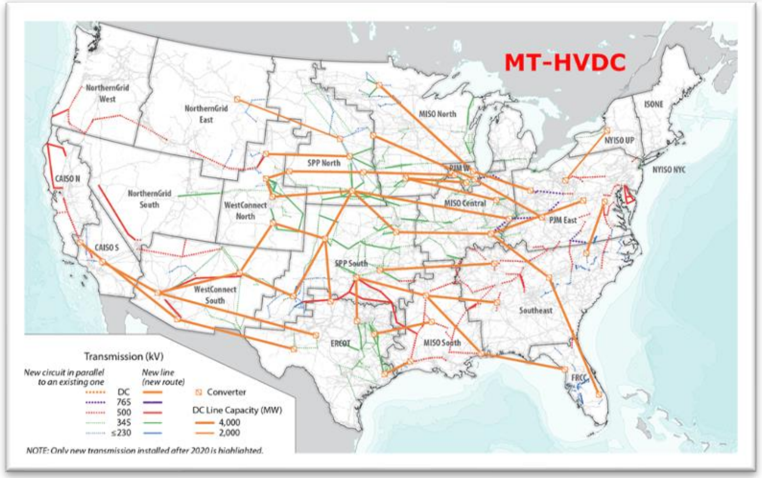












Principal Finding

Regardless of future policy, market, and technology conditions…

Grid planning at the national or multi-regional scale requires enhanced institutional coordination, accessible data, and new grid modeling approaches, which have advanced under the NTP Study in partnership with technical and planning experts.

Thank you

Pacific Northwest NATIONAL LABORATORY

NREL NATIONAL RENEWABLE ENERGY LABORATORY

U.S. DEPARTMENT OF ENERGY

Connected West

Exploring "Next Generation" Transmission Investments to Support a Clean, Electrified, and Reliable Western Grid

Briefing Presentation

September 2024

Prepared for:

GRIDWORKS

GridLAB

ENERGY STRATEGIES

Purpose of This Study

Connected West is a 20-year transmission planning study aimed at forecasting long-range transmission infrastructure needs of the Western grid required to support a highly decarbonized and electrified economy. The study focuses on identifying “next generation” transmission investments, targeting the identification of portfolios of new transmission expansion projects that represent investment above and beyond upgrades that have been previously proposed by Western utilities and developers. By providing insights and recommendations based on these portfolios and their performance, the Connected West study serves as a new data point on scenario-driven long-term transmission deployment in the West.

Disclaimer

This work product utilizes information obtained from publicly available sources and, in some cases, has relied upon subscription data and other third-party information available to Energy Strategies. While these sources are considered reliable, Energy Strategies does not recommend that the information contained herein be the sole source of information for decision-making purposes. Users of this report are encouraged to seek additional sources and professional advice before making any decisions based on the information provided in this study.

The findings and observations contained in this report are based on Energy Strategies’ independent analysis and do not represent the views of any of the Technical Review Committee organizations and cannot be attributed to any individual Technical Review Committee member.

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Special Thanks

The authors would like to thank the Technical Review Committee (TRC), Gridworks, GridLab, and other study supporters for their invaluable contributions, guidance, and insights throughout the development of the Connected West study. Their expertise and dedication were instrumental in shaping this study. Thank you for your commitment to advancing the future of the Western grid.

Report Contents

Motivation and Purpose of Connected West

Connected West Study: Motivation and Need

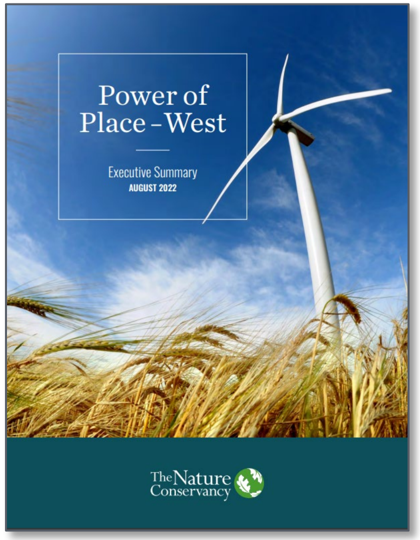
- **In response to regional transmission planning gaps, fragmented transmission expansion, a lack of interregional project proposals, as well as federal initiatives identifying new transmission corridors, the Connected West study explores “next generation” transmission investments for the West**
- **The study is an informational 20-year transmission planning outlook focused on a low-carbon & high electrification scenario that:**
  - ○ Identifies **three transmission portfolios** of expansion projects that help meet system needs by 2045
  - ○ Captures a **broad set of transmission benefits**
  - ○ Considers portfolios of both **emerging and traditional transmission expansion technologies**
  - ○ Features **robust geospatial analysis** of transmission corridors

Key Attributes of Connected West Study

- 20-year assessment (~2045 study year)
- Focused on US portion of WECC system
- Detailed representation of grid
- WECC 2032 ADS serves as “seed case”
- Nodal dispatch modeling (GridView™)
- Powerflow analysis (PowerWorld)
- Resource plan per *Power of Place: West* study
- Consideration of electrification-driven demand growth
- Assumes planned and “anticipated” transmission is built
- Geospatial routing of transmission options
- Assumes West-wide day-head nodal market
- Forecast of offshore wind in CA and OR
- Modernized transmission benefit assessment
- Portfolio-based transmission approach

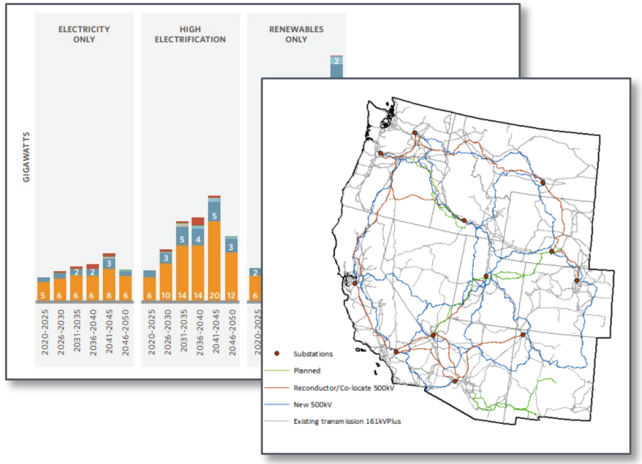
Connected West Study: Building from *Power of Place: West*

The study builds from recent planning assessments and existing models, including the Nature Conservancy's Power of Place: West study



- Study effort sponsored by Nature Conservancy featuring economy-wide energy and transmission expansion model developed by Evolved Energy Research
- Incorporated generation and transmission land use considerations to explore how the West can achieve climate *and* land conservation goals in 2050.

Load forecasts and optimized resource and transmission plans sourced from *Power of Place*



- Connected West Study builds on Power of Place.
- Specifically, the "High Electrification" scenario results relating to load forecasts, resource buildouts, and transmission expansions informed this study.
- In addition, extensive databases on land use and sensitivities informed the transmission routing analyses performed by Montara Mountain Energy.

Connected West is <u>transmission focused</u> and provide a more detailed view of system needs based on a future consistent with *Power of Place*

☑ Identification of transmission needs

☑ Portfolio-based transmission assessment exploring both benefits and costs of sets of transmission solutions

☑ Focus on quantifying broad set of benefits useful for identifying valuable long-term upgrades

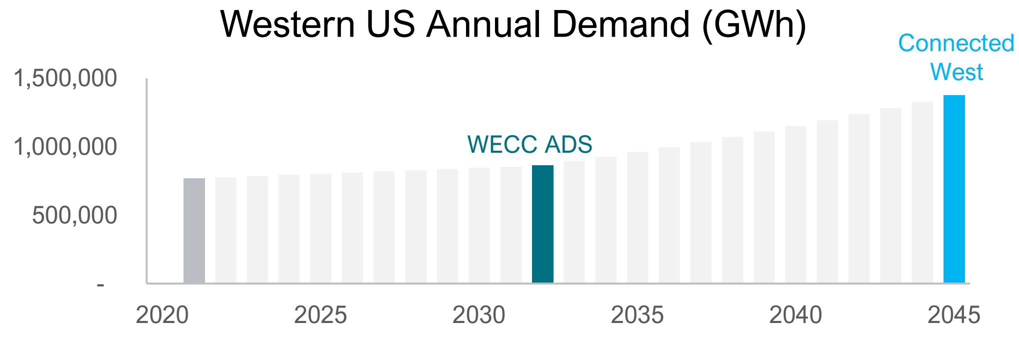
- Connected West leverages the *Power of Place's* optimized capacity expansion model results, helping to resolve the "chicken and egg" planning challenge.
- Assumes the resource portfolio is reasonable for a high-electrification future and then identifies transmission needed for it.
- Considers value proposition of transmission expansion.

Connected West Overview

- **The Connected West study explores portfolios of new transmission upgrades that help to meet the evolving needs of the Western grid under an economy-wide decarbonization and high electrification future**
  - The study is focused on exploring the "next generation" of transmission investments – those that represent grid expansion that is above and beyond known planned projects
- **The study evaluates a range of transmission solutions and configurations, focusing on technical performance, benefits, costs, land usage, and development feasibility of portfolios of upgrades**
- **The work aims to serve as a resource for Western grid planners and stakeholders, offering conceptual transmission roadmaps that support infrastructure needed to decarbonization and electrification of the Western economy**
  - In doing so, the study introduces innovative study techniques that can be leveraged in future Western planning endeavors

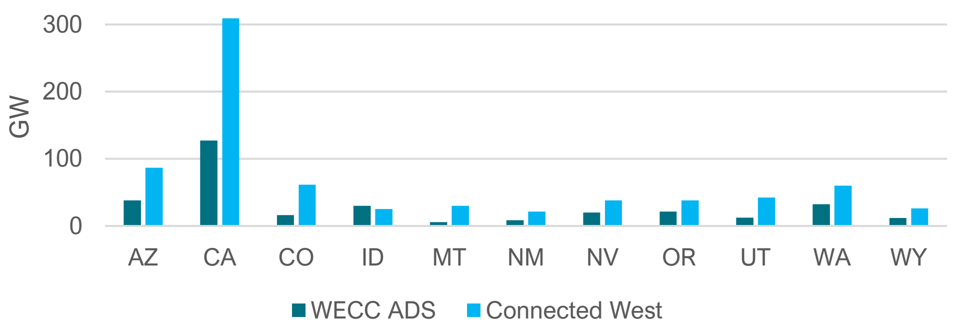
Key Forecasts for the Connected West Scenario

Western US Annual Demand (GWh)



Peak demand increases by approximately 100 GW by 2045, consistent with an electrified Western economy.

Installed Generation Capacity (GW)



Generation fleet more than doubles to nearly 750 GW primarily through the addition of clean resources and storage.

Motivation for Connected West: Questions Driving the Study

How far do planned and anticipated transmission projects get the West toward meeting 2045 transmission needs driven by the assumed future scenario?

?

Assuming such upgrades do not meet 2045 transmission needs, how large is the remaining gap in terms of investment ($) and MWs of transmission capacity?

?

What corridors should the West prioritize when considering the next tranche of transmission investment that may be needed over the approaching 20-years?

?

How do new greenfield corridors fair in this prioritization versus upgrades to existing lines?

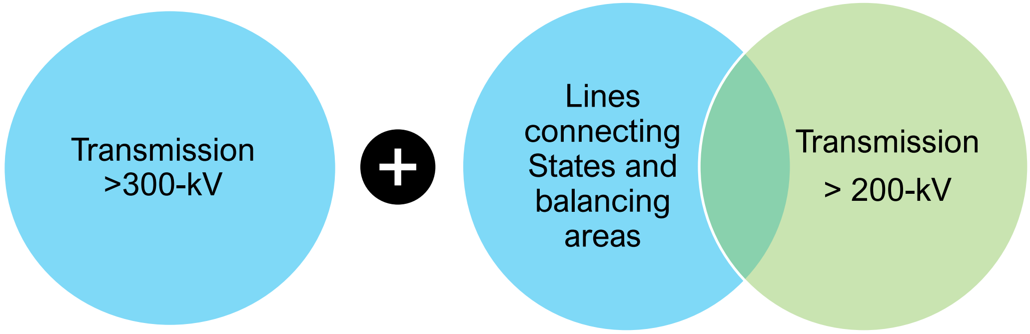
?

- **The study uses transmission planning analyses, including powerflow studies and congestion assessments, performed on a 2045 "Reference Case" to help answer these questions.**
- **Geospatial analyses and assessments of the value proposition of each transmission portfolios further support the study's efforts to answer these questions.**

Scope of Transmission Assumptions and Limitations

- **Given the ambitious scope of macro-scale, west-wide transmission planning over a 20-year horizon, the study necessarily limited its technical focus**
  - Transmission planning analyses in this study sought to address specific categories of transmission issues for certain grid conditions and as such the study inherently does not address all grid challenges
  - As Connected West will not identify all necessary transmission additions, it will understate transmission investment required to achieve low carbon & high electrification outcomes in 2045
- **Low-voltage upgrades, gen ties, and intra-area transmission upgrades are examples of transmission needs not captured in the study**
  - Branch monitoring was limited to 300-kV and higher facilities, plus any 200-kV and higher facilities that intersect state or balancing authority (BA) borders, or were otherwise determined by the study team to be regional in nature

Connected West Transmission Scope



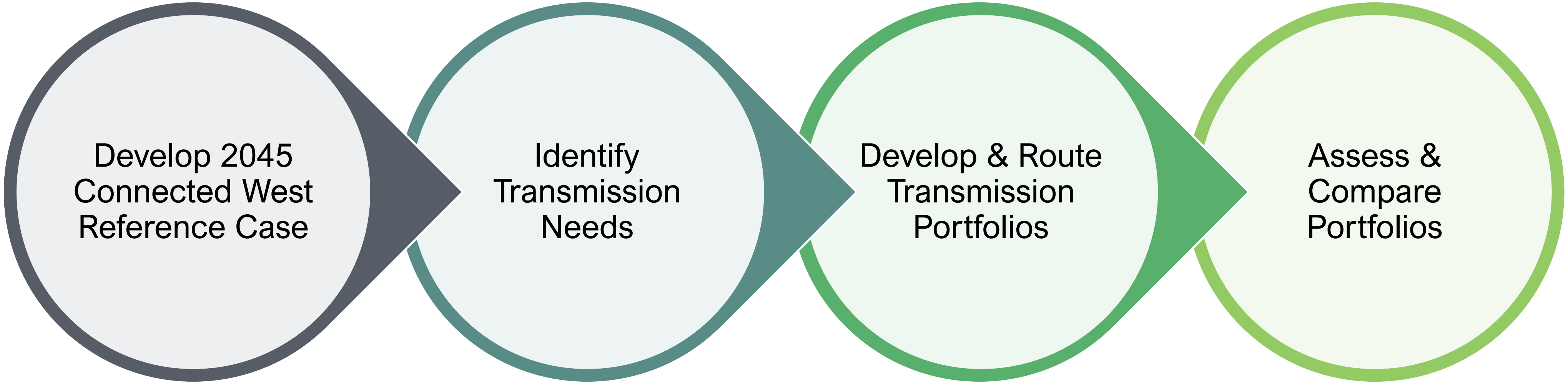
In addition to the upgrades above, some “regionally significant” lines were included in the scope

Transmission Planning Needs Not Captured

- ✗ Generation tie lines
- ✗ Metro area upgrades
- ✗ Distribution upgrades
- ✗ Local network upgrades
- ✗ Stability issues
- ✗ New Eastern Interconnection ties

Study Methods & Key Assumptions

Study Process



Develop 2045 Connected West Reference Case

Identify Transmission Needs

Develop & Route Transmission Portfolios

Assess & Compare Portfolios

The study process was designed to provide insights into the necessary investments and the potential benefits of a modernized transmission network that meets the needs of an electrified and decarbonized future.

2045 Connected West Reference Case

- **The 2045 Connected West Reference Case serves as the study's basis for identifying transmission need under this scenario-driven assessment**
- **The Reference Case features a resource mix that is both deeply decarbonized and sufficient to power a heavily electrified economy**
  - 95% of western US generation is sourced from clean energy resources, consistent with a net-zero economy-wide emission future for 2050
  - Electrification forecast accounts for building technology shifts, ZEV sales, and fuel switching among other technologies required to achieve net-zero economy wide emissions by 2050
- **2045 Reference Case assumes the construction of most major planned & proposed transmission lines in the West**
  - This future grid was evaluated via congestion and powerflow analyses to identify a "transmission gap" in the 2045 horizon
- **Three transmission upgrade portfolios addressing this "gap" were identified as part of the study process & represent the key solutions identified in the Connected West study**

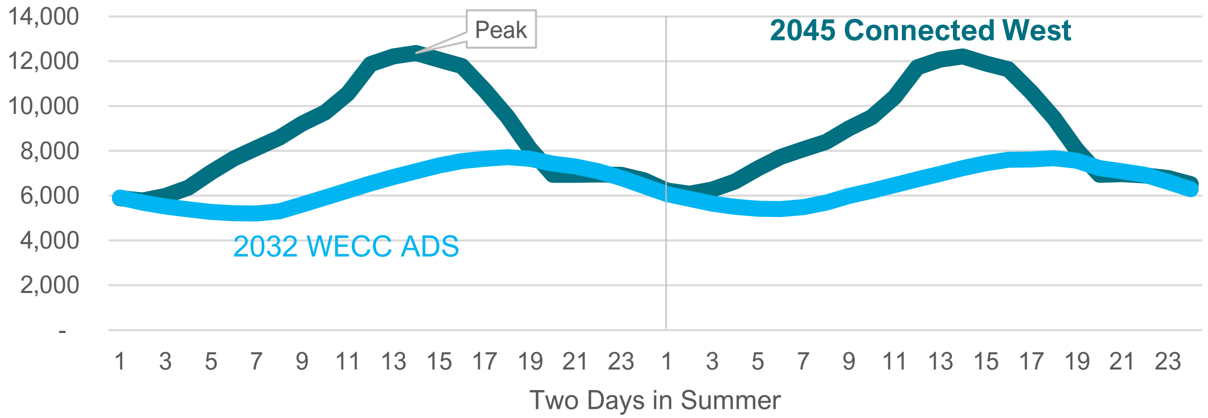
Key Assumptions in Connected West Reference Case

Assumption	WECC 2032 ADS*	Connected West 2045 Reference Case
Seed Case	N/A	WECC 2032 ADS*
Load Forecast	Peak demand: 182 GW Annual energy: 119 aGW	Peak demand: 281 GW Annual energy: 179 aGW
Generation Capacity (WECC-US)	328.1 GW *includes generation from CAISO TPP not in ADS	745.6 GW (+127%)
Transmission	All existing and planned transmission upgrades, sourced for Western local and regional transmission plans	An additional 16 major projects in development added, representing 5,900 line miles and 35 GWs of new capacity
Market Modeling	No regional energy markets assumed.	West-wide day-ahead market
Transmission Monitoring	All high-voltage transmission	All 300-kV and higher facilities, plus any 200-kV and higher facilities that intersect state borders or BA or were otherwise deemed regional in nature

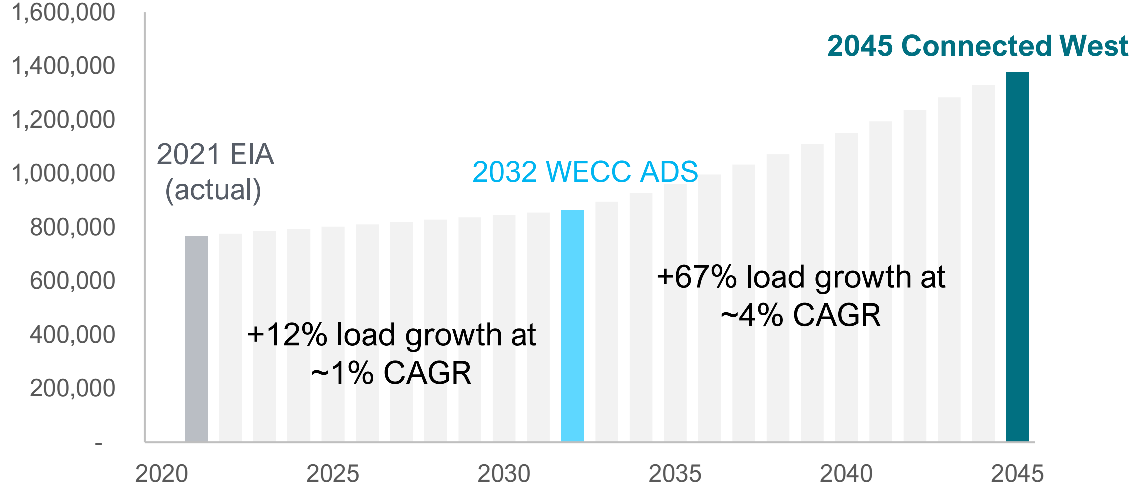
Load Forecast Captures "High Electrification"

- **Load forecasts for Connected West were sourced from the *Power of Place: West* "high electrification" scenario, which assumes 100% sales of electric building technologies by 2040, 100% ZEV sales by 2040, and some fuel switching for industrial production required to achieve net-zero economy-wide emissions by 2050**
    - Demand response sourced from PoP forecast and modeled as energy-limited dispatchable resource
    - Load shapes reflect flexible new loads modeled in PoP study
- **State-level forecasts from Power of Place: West were disaggregated to balancing areas based on historical BA-state load factors**

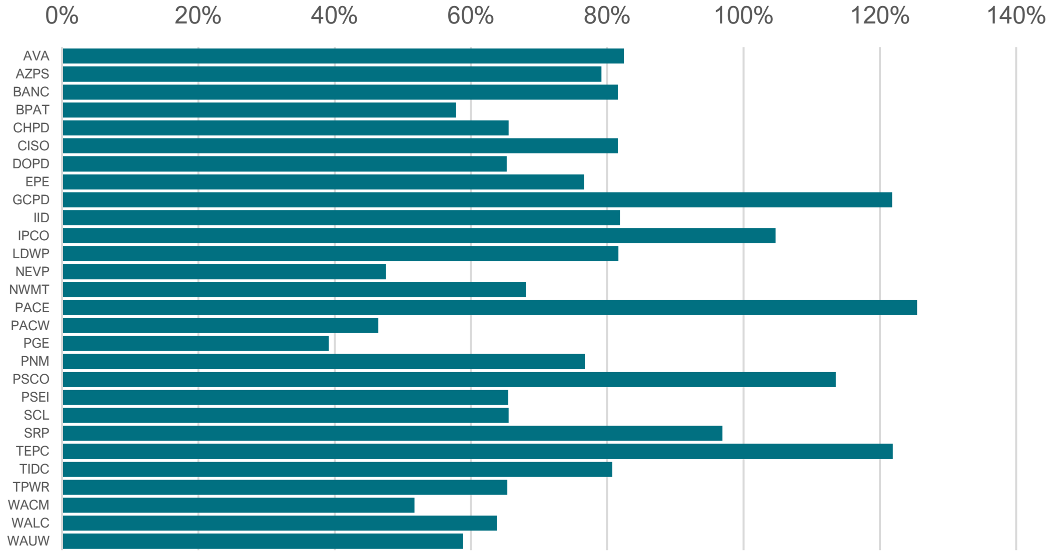
AZPS Balancing Area: August 23rd and 24th



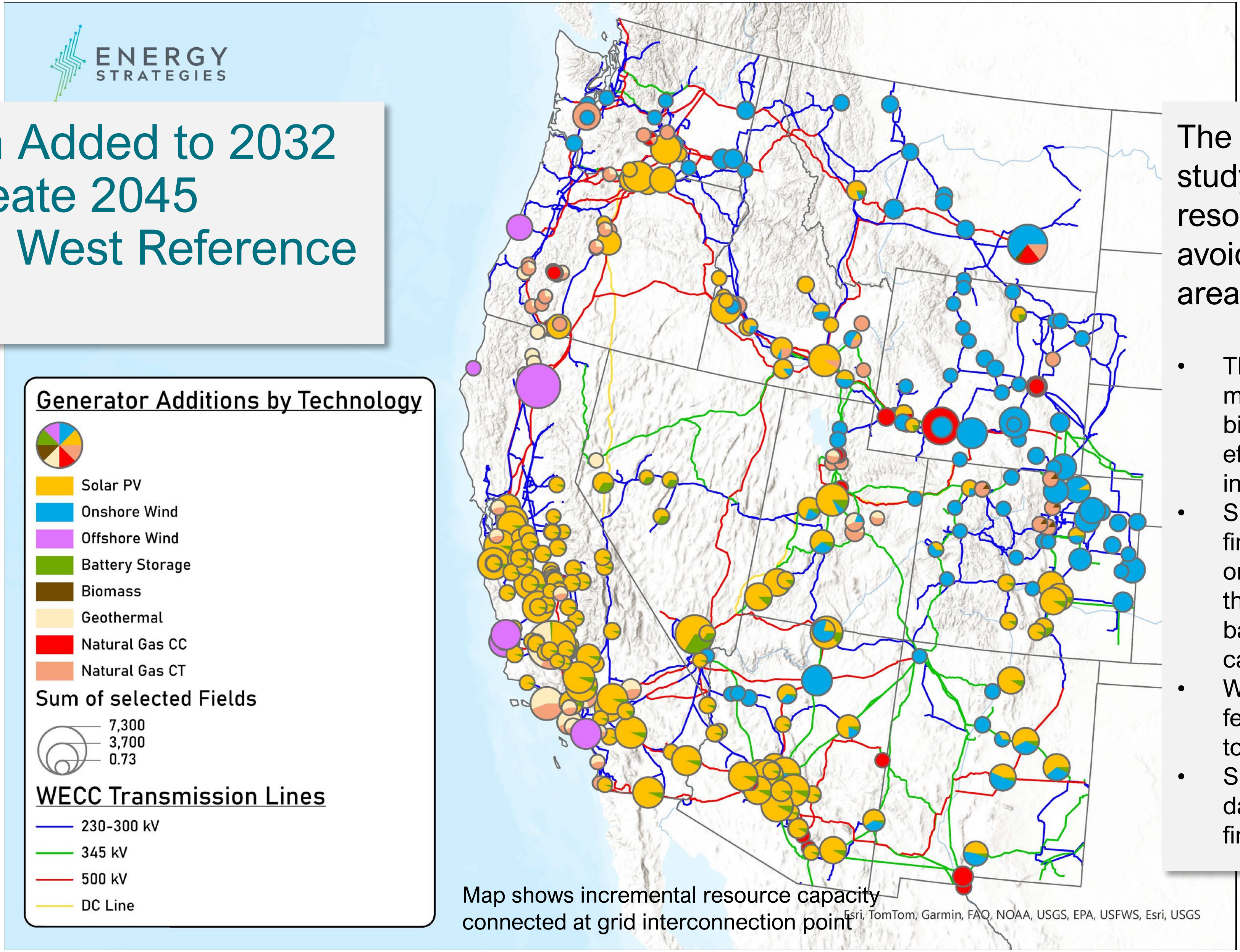
Western US Annual Retail Energy Demand (GWh)



Change in Annual Energy by Balancing Area (%): 2021 Actual (EIA) to 2045 Connected West



Generation Added to 2032 ADS to Create 2045 Connected West Reference Case



Map shows incremental resource capacity connected at grid interconnection point

Esri, TomTom, Garmin, FAO, NOAA, USGS, EPA, USFWS, Esri, USGS

The Power of Place-West study prioritizes high-quality resource locations and avoiding sensitive natural areas and working lands.

- The Power of Place-West siting methodology was augmented to bias towards transmission efficiency and commercial interest
- Siting algorithm was adopted to find reasonable injection points on the grid based on proximity to the project location and a voltage-based approximation of injection capability
- We maintain that development feasibility results from PoP apply to this study
- Siting approach and PoP-West data is a key factor in forming the findings of this study

Transmission Expansion assumed in 2045 Reference Case

5,900 line miles

$30B of investment

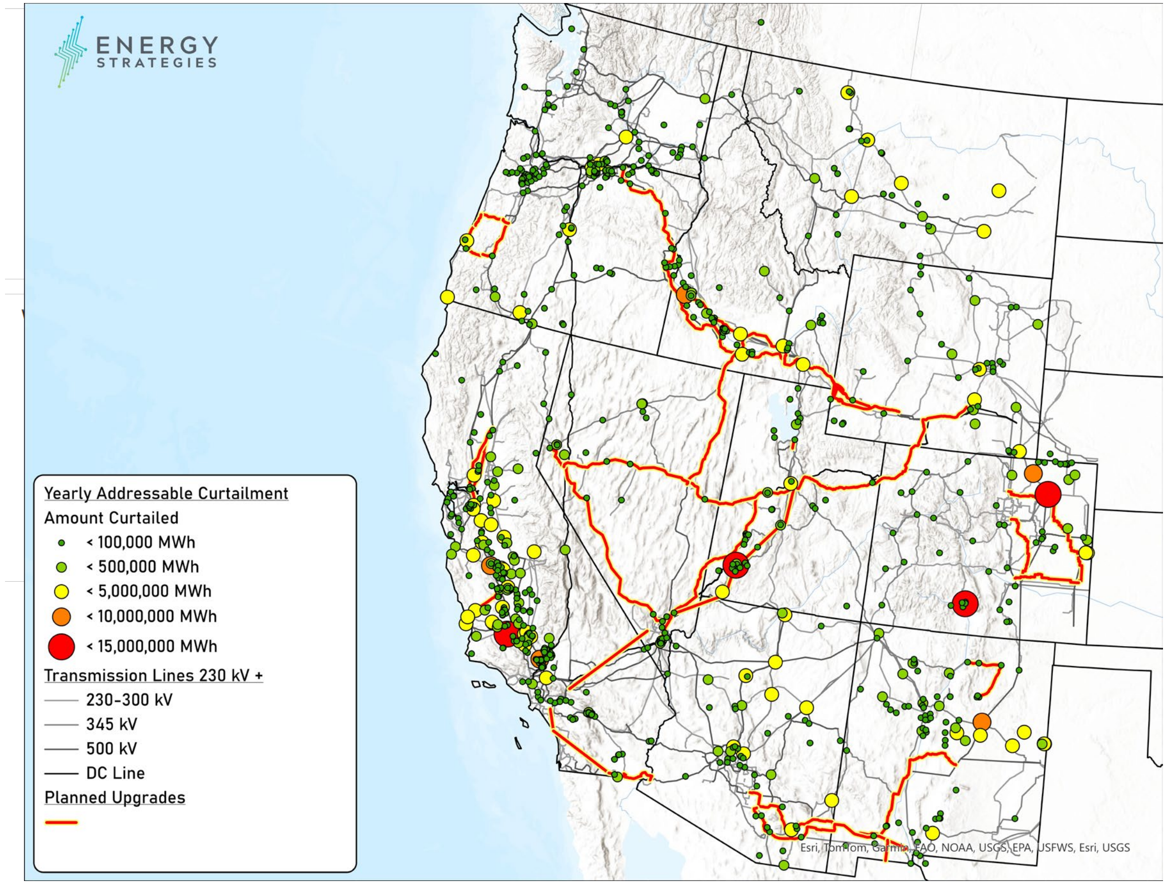
35 GW of new capacity

Project Name	Description	Length (miles)	Cost* ($M)	Capacity (MW)	Estimated Completion**
Boardman to Hemmingway (B2H)	500-kV line from Longhorn (Boardman) to Hemingway	290	$1,200	1,000	2026
CAISO 22-23 TPP	~46 transmission upgrades of varying size	460	$7,300	N/A	2034 or sooner
CAISO OSW upgrades	Conceptual upgrades from CAISO 20-Year Outlook (500 kV)	220	$2,400	5,000	2044 or sooner
Oregon OSW upgrades	Conceptual upgrades from NorthernGrid Economic Study Request for Offshore Wind in Oregon (500 kV loop and upgrades to 115 and 230 kV system)	373	$820	4,000	2032
Colorado Power Pathway	Double-circuit 345-kV transmission connecting Denver front range to NE, E, and SE Colorado (5 segments)	610	$2,000	3,500	2027
Crosstie Project	500-kV line from Clover to Robinson Summit	214	$750	1,500	2027
Gateway South	500-kV line from Aeolus to Mona/Clover	416	$2,500	2,000	2024
Gateway West (all segments)	Includes all remaining 500-kV segments west of Bridger/Anticline (D3 & E)	500	$2,880	2,000	2028
Greenlink West and North	525-kV loop from Robinson Summit to Reno area to Las Vegas	700	$2,420	2,800	2028
Lucky Corridor - Mora Line	345/115-kV line between Springer and Arriba substations	115	$83	180	2025
Lucky Corridor - Vista Trail Line	345-kV line between Springer and Taos substations	65	$800	850	2027
Southline	345-kV line between NM and AZ	280		1000	2028
SunZia (Line 1)	525 kV HVDC line from eastern NM to Pinal Central (AZ)	550	$3,000	3,000	2026
SWIP North	500-kV line between Midpoint and Robinson Summit	285	$1,090	2,070	2027
TransWest Express	HVDC line from Wyoming to Utah to Nevada with AC component terminating at Eldorado 500-kV	732	$3,000	3,000	2027
TenWest Link	500-kV line between Delaney and Colorado River substations	125	$400	3,200	2024

Identifying Transmission Needs & Solutions

- **Reference Case model results were used to identify the location and magnitude of 20-year transmission needs**
  - Initial screening exercise used to inform subsequent reliability assessments
  - Results from 2045 Reference case production cost model were compared to a copper sheet model
    - Copper sheet model retains reference case generation and network topology, but none of transmission limits (line and interface ratings) are enforced. Provides a view of operation with a "perfect" grid
    - By comparing curtailment in copper sheet with the transmission-constrained Reference Case, we calculated "addressable curtailment" for each node
    - Helps us prioritize delivery of resource that have value to system, versus those that are curtailed regardless of transmission expansion
- **Key metrics compared to identify transmission needs included:**
  - **Locational Marginal Prices (LMPs)** – locational (nodal) price changes due to transmission congestion
  - **Renewable Energy Curtailment** – renewable energy unable to be delivered to load due to transmission limitations
  - **Transmission Line & WECC Path Congestion** – specific lines & paths that become congested due to flow distribution in an AC grid network

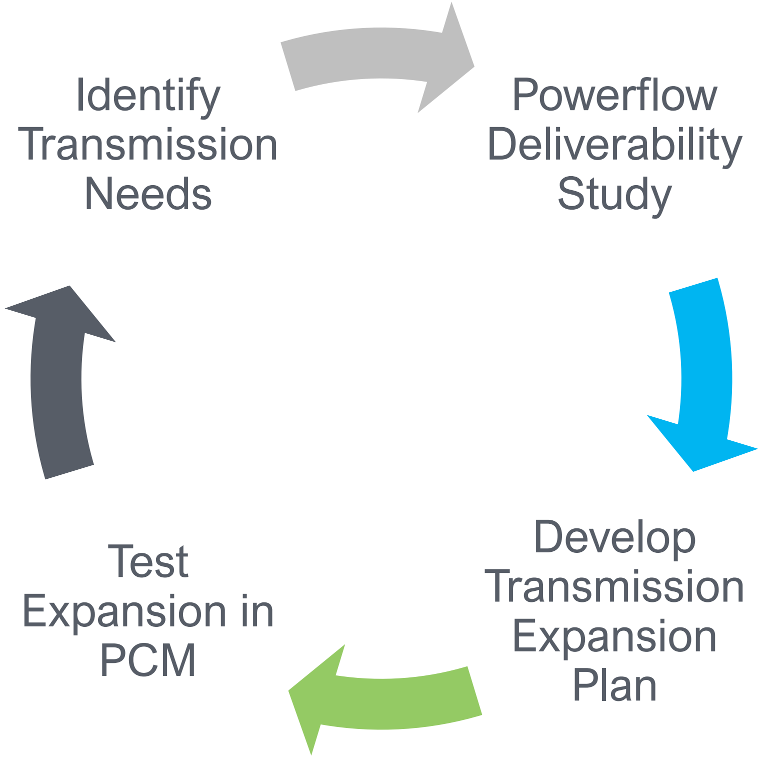
Connected West Reference Case "Addressable Curtailment"



Identifying Transmission Needs & Solutions

- **Energy Strategies identified transmission solutions using an iterative process:**
  - **Identify Transmission Needs:** Review LMPs, curtailment, and branch & path congestion to identify areas in need of transmission upgrades
  - **Power flow Deliverability Study:** Developed and studied several "zonal" power flow cases to ensure that the local system & ties are sufficient to transfer power from resource zones to load areas during stressed system conditions
  - **Develop Transmission Expansion Candidates:** Identify transmission solutions that resolve voltage issues and thermal overloads on monitored lines, WECC paths or tie lines between study zones under system intact or contingency conditions
  - **Test Expansion in PCM:** Represent network upgrades in nodal production cost model & re-run Reference Case for updated solution
- **This process was repeated as necessary until key transmission needs metrics were satisfied**

Transmission Solutioning Approach



Identify Transmission Needs

Powerflow Deliverability Study

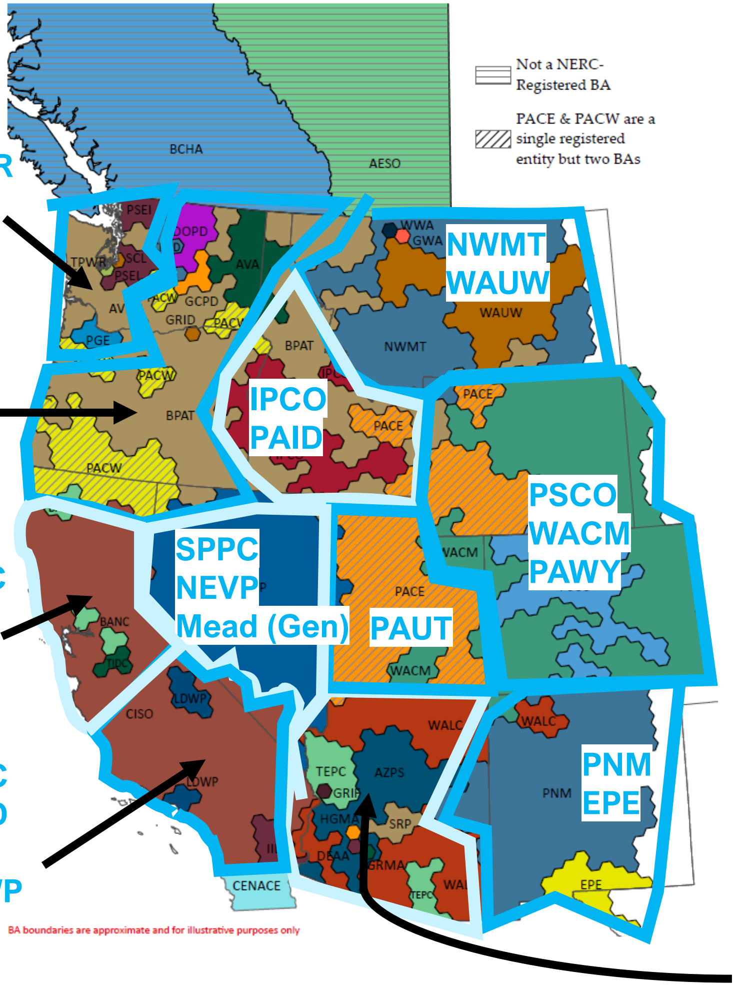
Develop Transmission Expansion Plan

Test Expansion in PCM

Power Flow Deliverability Methodology

- **The WECC system was divided into 11 sub-zones each with a deliverability case**
  - Each sub-zone evaluated under stressed off-peak conditions
  - Sub-zones with significant generation analyzed as export zones, while those with large loads studied as import zones
- **Developed solutions to resolve issues within and associated with exports/imports from study zone**
  - Upgrades mitigate issues such voltage collapse, base case divergence and thermal overloads under contingencies
- **Upgrades from each sub-zone were compiled into portfolios and tested in PCM**
  - Transmission congestion and renewable curtailment metrics used to refine previously identified network upgrades

Deliverability Analysis Sub-Zones



PSEI
TPWR
SCL
PGE

AVA
CHPD
DOPD
GCPD
PACW
BPAT

NWMT
WAUW

IPCO
PAID

PSCO
WACM
PAWY

SPPC
NEVP
Mead (Gen)

PAUT

BANC
CIPB
CIPV
TIDC

CISC
CISD
IID
LDWP
VEA

PNM
EPE

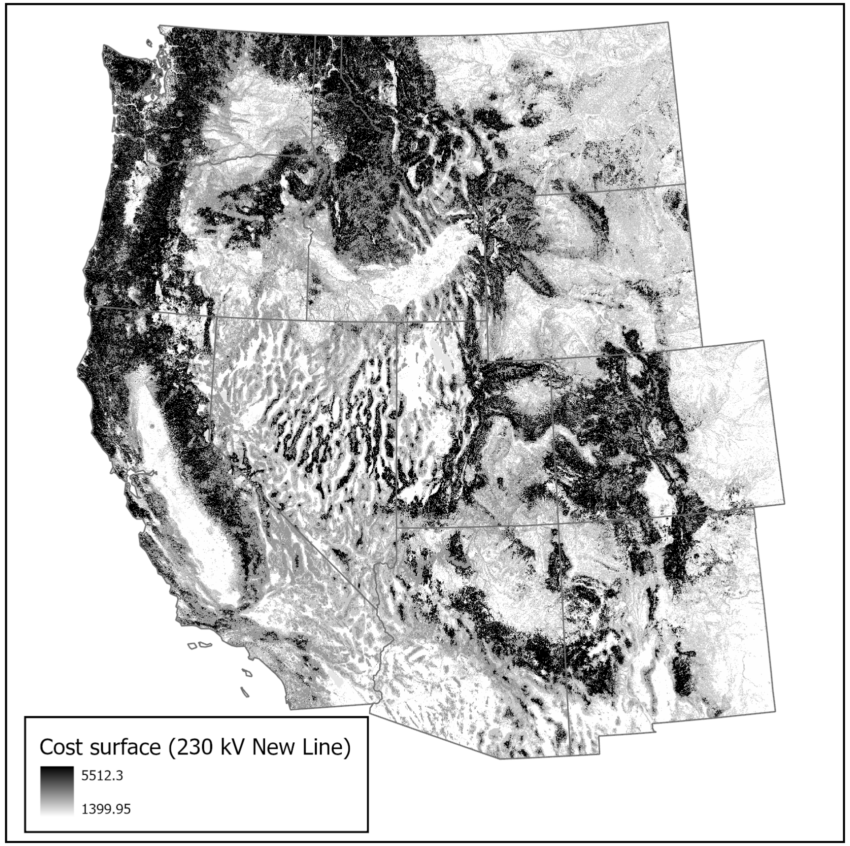
AZPS
SRP
TEPC
WALC
Palo Verde (Gen)

BA boundaries are approximate and for illustrative purposes only

Routing & Costing Transmission Solutions

- **Transmission solutions identified by iterative process provided to Montara Mountain Energy for optimal-cost-path geospatial routing**
  - Routing tool used geospatial cost surfaces to identify optimal-cost-path route between two points on the grid
  - Energy Strategies provided per-mile base transmission cost to Montara specific to line types & technologies considered in the study
  - Routing tool included adders to this base cost based on terrain, land use, and ability to use existing rights of way
- **Energy Strategies included costs from routed lines into a comprehensive transmission portfolio cost calculation that included right-of-way costs and the costs of other system upgrades (transformers, capacitors, substation upgrades, converter stations, etc.)**
  - Cost figures sourced from publicly available sources including MISO MTEP and WECC TEPPC cost calculators

Transmission Routing Cost Surface Example



Approach to Transmission Benefits

- **The study focused on evaluating the efficiency of transmission expansion within a series of corridors considered simultaneously (e.g., as a portfolio)**
  - To facilitate this evaluation the cost of the portfolio was compared to the benefits estimated for that portfolio
  - The resulting benefit-cost ratios help the study to explore tradeoffs between the transmission portfolios
- **Seven benefit categories were assessed for each transmission portfolio**
  - These benefits seek to capture the wide-ranging cost-savings resulting from building new transmission infrastructure
- **Both costs and benefits were compared on a present value basis, adopting a 3% (real) societal discount rate**
  - Benefits and costs were calculated based on a 40-year horizon

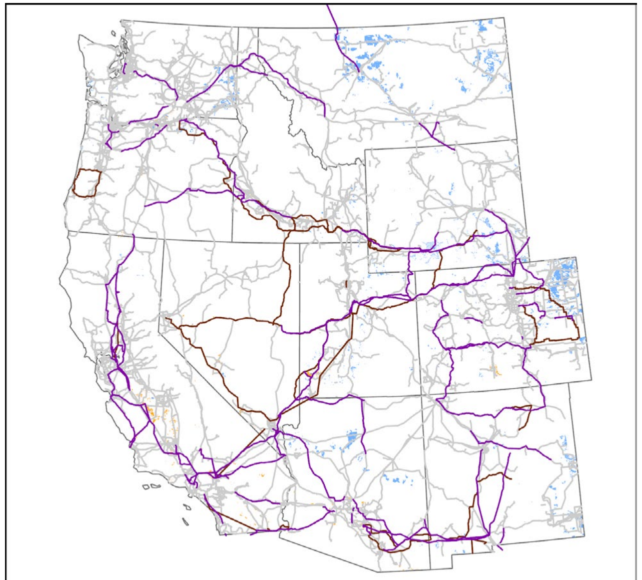
Transmission Benefits Considered

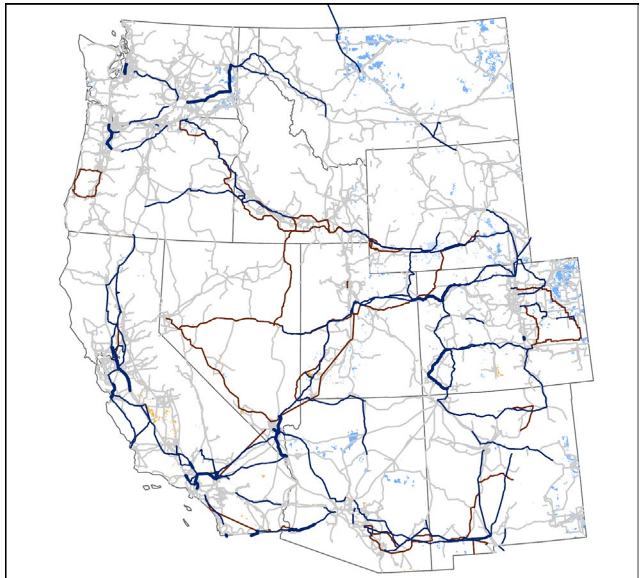
Benefit	Metric
Operational Savings	Change in WECC-wide production cost.
Avoided Emissions	Avoided emissions savings based on simulated emissions reductions and a forecasted carbon price
Avoided Loss of Load	Avoided loss of load valued at $40,000/MWh, with the benefit calculated as the product of reduced loss of load in simulation sand the loss of load price/value.
Resource Adequacy (Capacity Savings)	MWs of resource and load diversity enabled via transmission upgrade multiplied by the value of avoided capacity.
Extreme Event Mitigation	Use historical weather and grid condition data to simulate short-term operational conditions with and without project to determine change in load payments & potentially benefit of avoiding cost of unserved load (loss-of-load = $40,000/MWh).
Avoided Transmission Benefit	Cost of transmission upgrades that would be required to maintain system reliability and serve 20-year loads if the Connected West Transmission Portfolio is not built.
Reduced Transmission Losses	Generation Capacity avoided because of decrease in transmission losses as a result of the transmission upgrades.

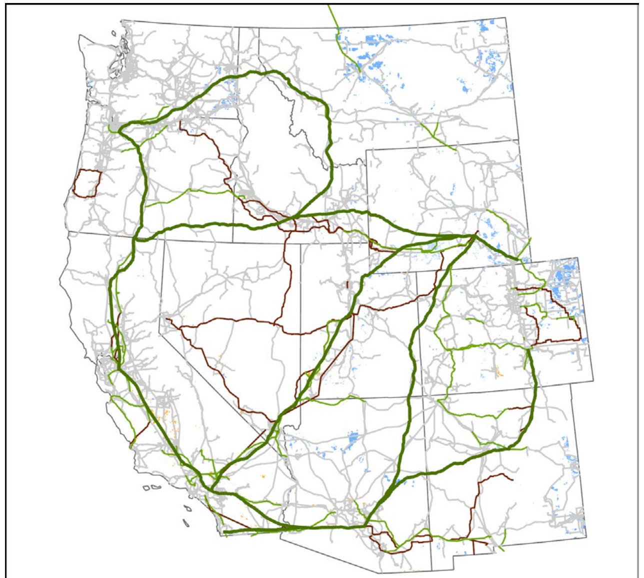
Comparing Transmission Portfolios

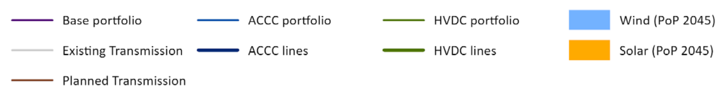
- **Net benefits ($M) are the primary metric used to compare transmission portfolios in the Connected West study**
  - Net benefits was calculated as the sum of present-value benefits minus the total present-value portfolio cost
- **Study findings also derived from qualitative and non-monetary impacts of transmission infrastructure including:**
  - Grid connectivity
  - Land impacts
  - New rights-of-way
  - Wildfire risk
  - Feasibility of nascent technologies
  - Study limitations


Existing and Planned


AC Overlay Portfolio


Advanced Conductor Portfolio


HVDC Overlay Portfolio



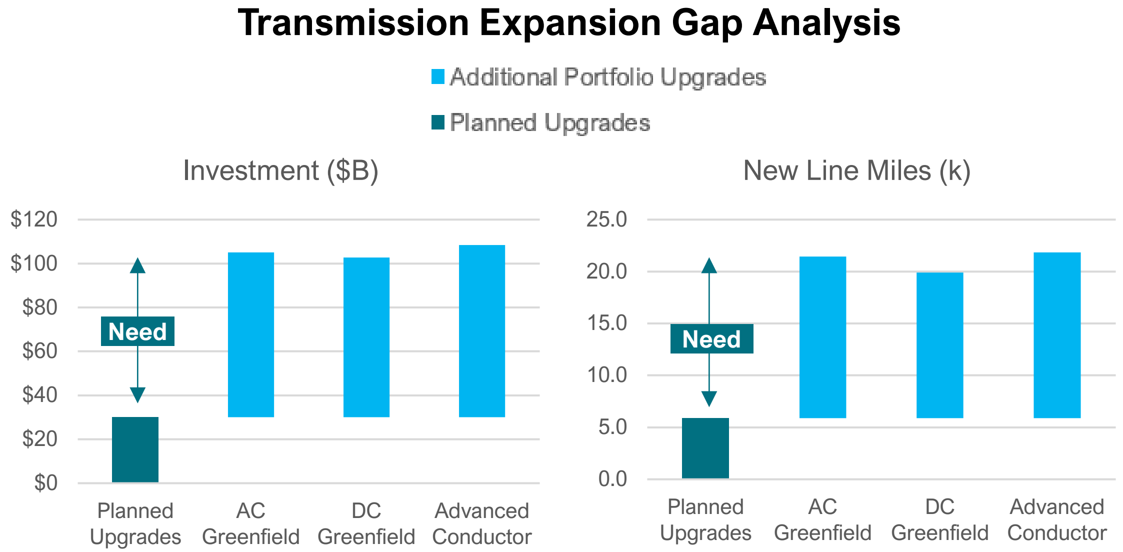
Key Findings

Key Findings #1: Continued Grid Expansion is Required

- **To support an electrified and highly decarbonized Western grid in 2045, additional transmission expansion beyond what is currently planned is required**
  - Total new transmission identified in this study exceeds 20k line miles, which is ~20% of existing high-voltage transmission >200kV
  - Roughly 25% of these line miles are available from planned upgrades assumed in the study

Planned transmission upgrades assumed in the study are insufficient

- **This transmission investment "gap" that needs to be filled to support reliability and grid efficiency – representing the "next generation" of regional-scale transmission investments – represents approximately $75 billion of further capital investment bringing total regional transmission investment to ~$100 billion over the approaching 20-years**
  - This gap should be considered a "floor" not a "ceiling" for incremental transmission investment needed for this future



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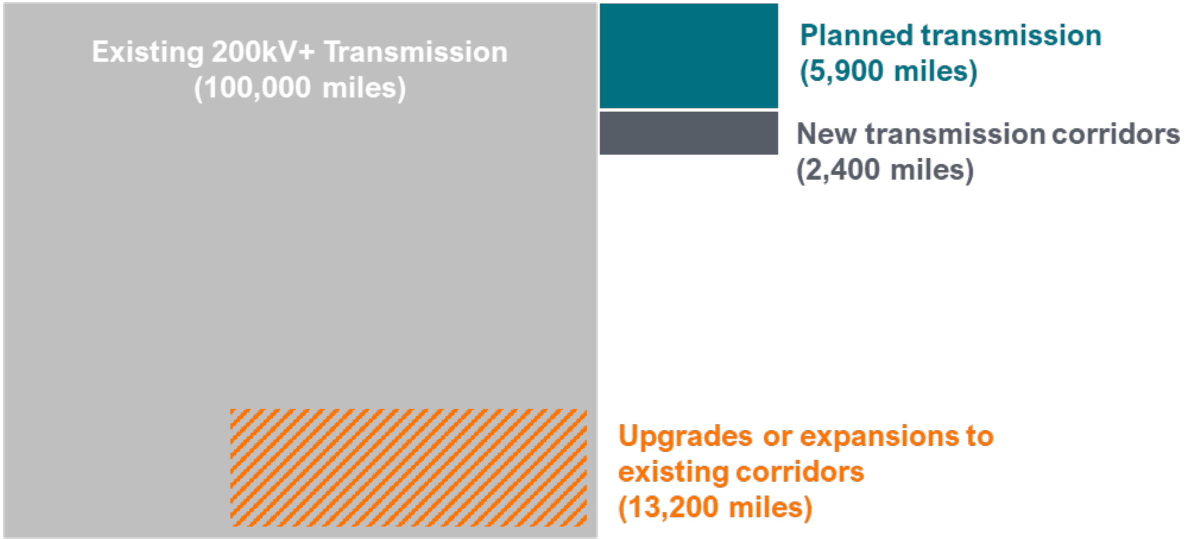
Connected West Transmission Additions: Perspective from the Existing System



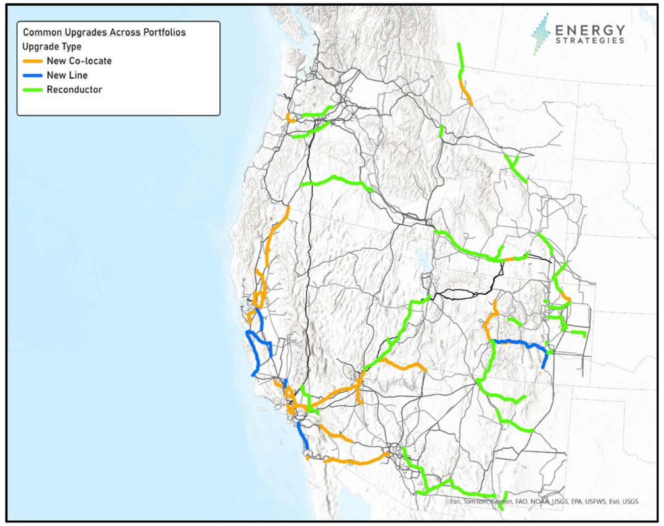
Note: Transmission solutions identified in Connected West portfolios focus on high-voltage and inter-regional transmission needs. Line-mile estimates do not capture all transmission necessary to facilitate the future envisioned in this study.

Key Findings #2: Reconductoring and Co-locating Transmission Lines is a Core Strategy for All Portfolios

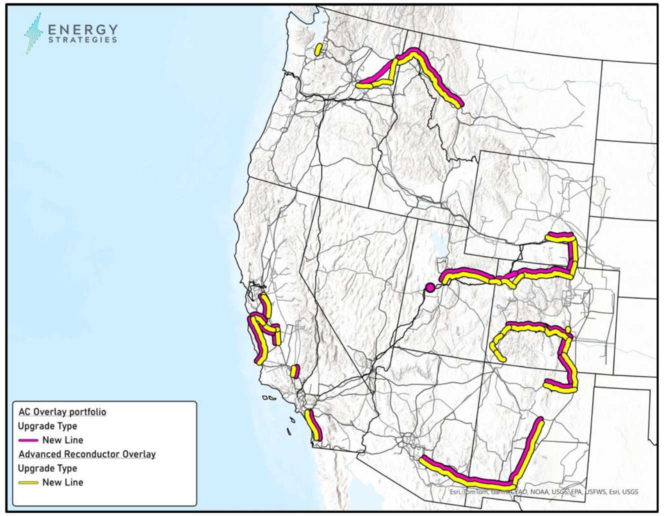
- **Results indicate that a significant portion of new transmission capacity across the West can be met with reconductoring upgrades, co-locating new lines, and advanced grid technologies such as high-capacity conductors**
    - In some portfolios, reconductoring projects and co-locating new lines accounted for ~85% of the required line miles, minimizing the need for new greenfield transmission corridors

- **However, greenfield transmission development cannot be avoided in certain cases, based on needs of the system**
    - After making best use of the existing system and rights-of-way, greenfield transmission expansion is more manageable, with a need of ~2,400 miles of new transmission right-of-way
    - Critical areas for new greenfield development include corridors between Colorado and Wyoming/Utah/New Mexico, Arizona and New Mexico, Montana and the Pacific Northwest/Mid-Columbia area, and in-state California paths

Many Common Reconductoring Upgrades Across Portfolios



Priority Greenfield Corridors Identified

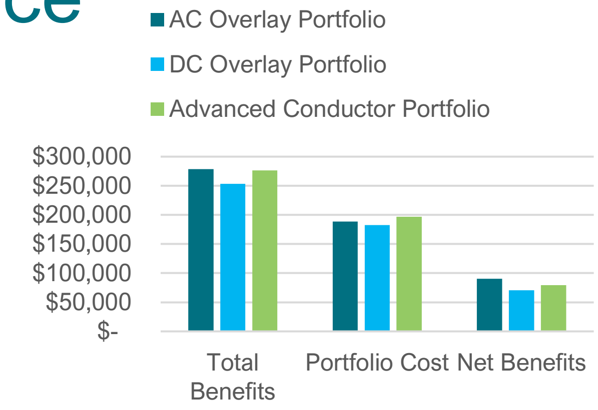


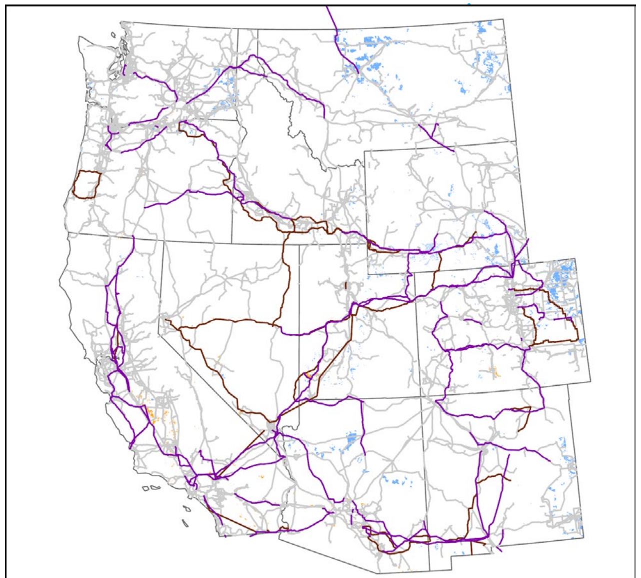
Key Findings #3: Portfolios Offer Comparable Benefits & Performance

- **The portfolios developed in the study have comparable costs and benefits, with all portfolios offering a favorable benefit-cost ratio of approximately ~1.4**
  - Net benefits are heavily driven by increased connectivity between regions, resulting in load diversity savings (avoided capacity investments), fuel/operational efficiencies, and the value associated with avoiding economic harm caused by extreme events
- **All transmission portfolios are common in offering increasing connectivity between balancing areas and planning regions**
  - Across the 3 portfolios, 33-42% of area-to-area connections needed upgrades, and all three portfolios required at least one new area-to-area connection (the HVDC portfolio required 7 new area-to-area connections)
  - Supports the need for robust planning coordination among utilities and regions – piecemeal grid expansion could leave these issues unaddressed

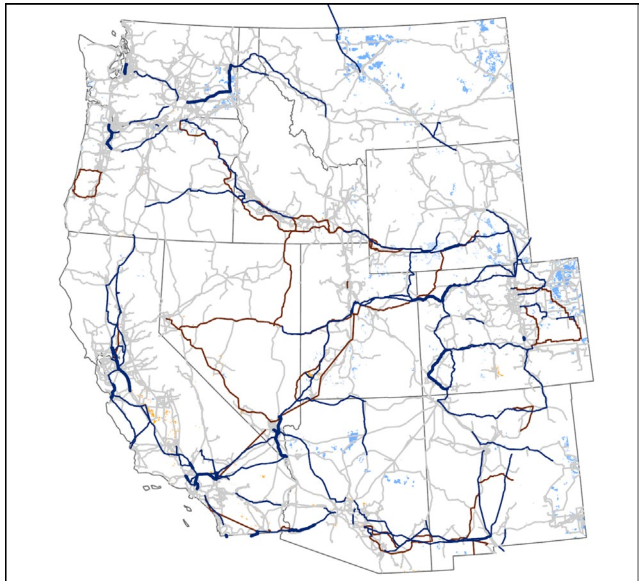
Portfolio Economic Performance

40-year Present Values (2023$, millions)

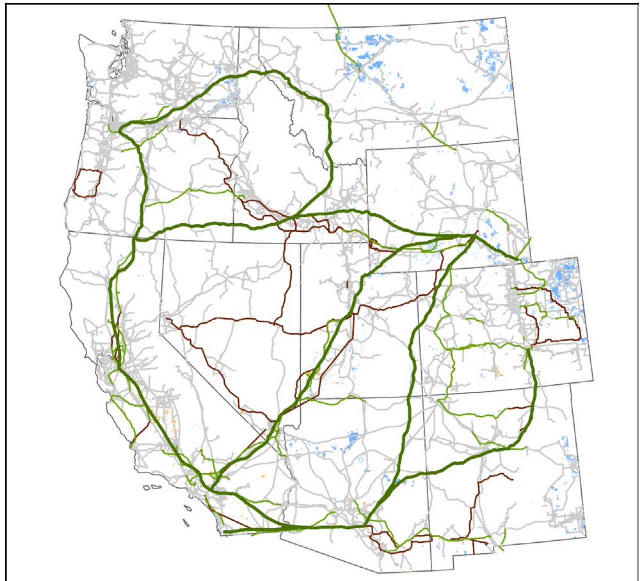




AC Portfolio



Advanced Conductor Portfolio



HVDC Portfolio

Additional Takeaways

- **The results of this study assume seamless planning coordination at the transmission provider area and planning region footprint**
  - The degree of planning coordination and joint project execution that occurs will impact the scope and amount of transmission needed
  - It is likely that less coordination will cause more transmission to be built to achieve the same outcomes
- **Advanced high-capacity conductors were an effective Grid Enhancing Technology (GET), making up roughly 1/3 of the line miles in the relevant portfolio**
  - Other GETs like dynamic line ratings and power flow controllers were evaluated and ultimately not well suited for needs in this study as they did not offer sufficient incremental and firm capacity to serve as a viable solution given the severity of reliability and capacity needs in the 20-year timeframe
  - Such technologies are often better suited for incremental or developing issues on the system, likely to be identified in nearer-term studies focused on a subset of issues
- **Areas ripe for resource development do not have sufficient transmission capacity to accommodate levels of new generation**
  - Many required substantial transmission backbone reinforcements, in many cases on local 115-kV and 230-kV systems in places like rural Montana, Wyoming and Colorado – Suggests a need for significant rural transmission deployment and robust collector systems to achieve decarbonization and electrification targets envisioned in this study
- **Incremental transmission needs are sensitive to magnitude & location of planned transmission expansion**
  - Areas where the study assumed substantial planned transmission investments required fewer portfolio upgrades (e.g., Nevada and its Greenlink project complex)
  - However, in some states planned transmission did not keep up with forecasts of load and generation growth (e.g., Wyoming, California)
- **While transmission lines in this future have a significant cost, they would be funded by, in part, by new customers and demand that doesn't exist today**
  - Energy demand (GWh) is expected to almost double on the WECC system by 2045 from the proliferation of electrified appliances & vehicles, and a system that uses renewables to supply energy-intensive alternative fuel production processes

Findings & Results

Findings and Results

Part I: Reference Case Results & Observations

Part II: Transmission Expansion Portfolios

Part III: Answers to Key Questions

Part IV: Additional Findings

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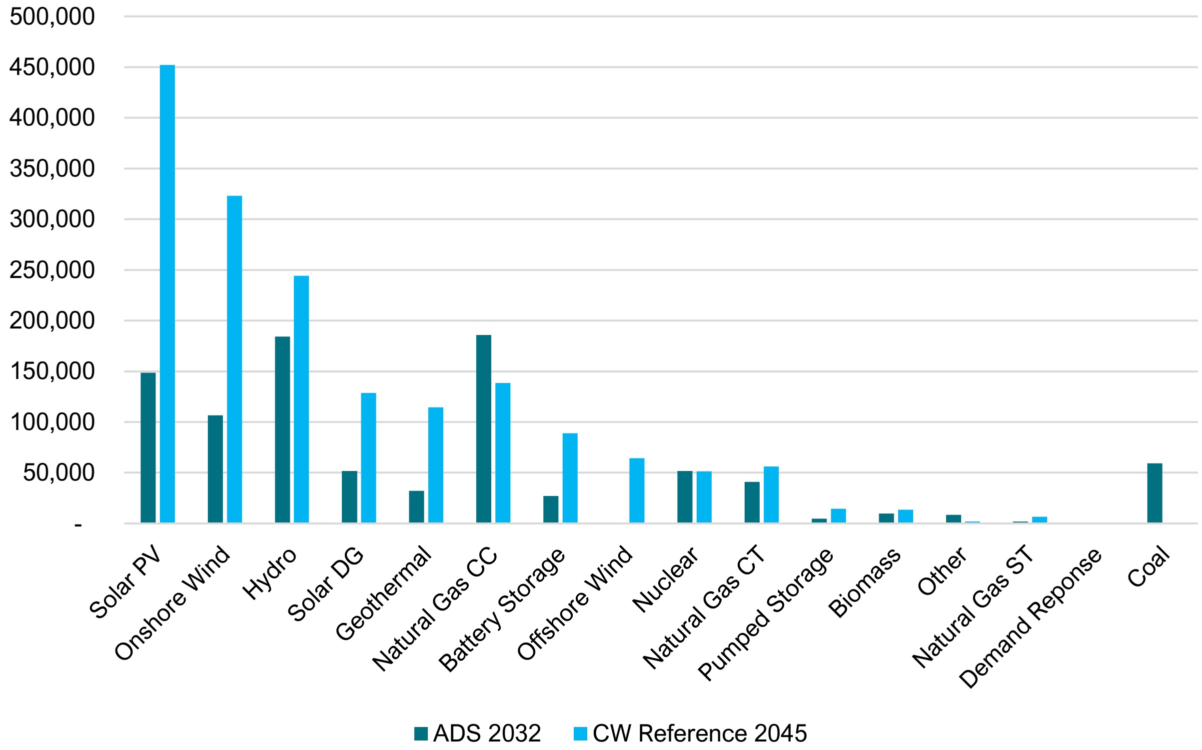
Generation by Type in Connected West Reference Case

- **Generation increases across nearly all resource types to meet load increases and decarbonization objectives in 2045**
- **The 2045 Reference Case contains:**
  - Significant increases in solar (+373 TWh), wind (+217 TWh), geothermal (+82 TWh), battery storage (57 TWh), and pumped storage (10 TWh)
  - Comparable amounts of hydro and nuclear
  - Less gas generation
  - No coal generation

Total Annual Generation by Resource Category



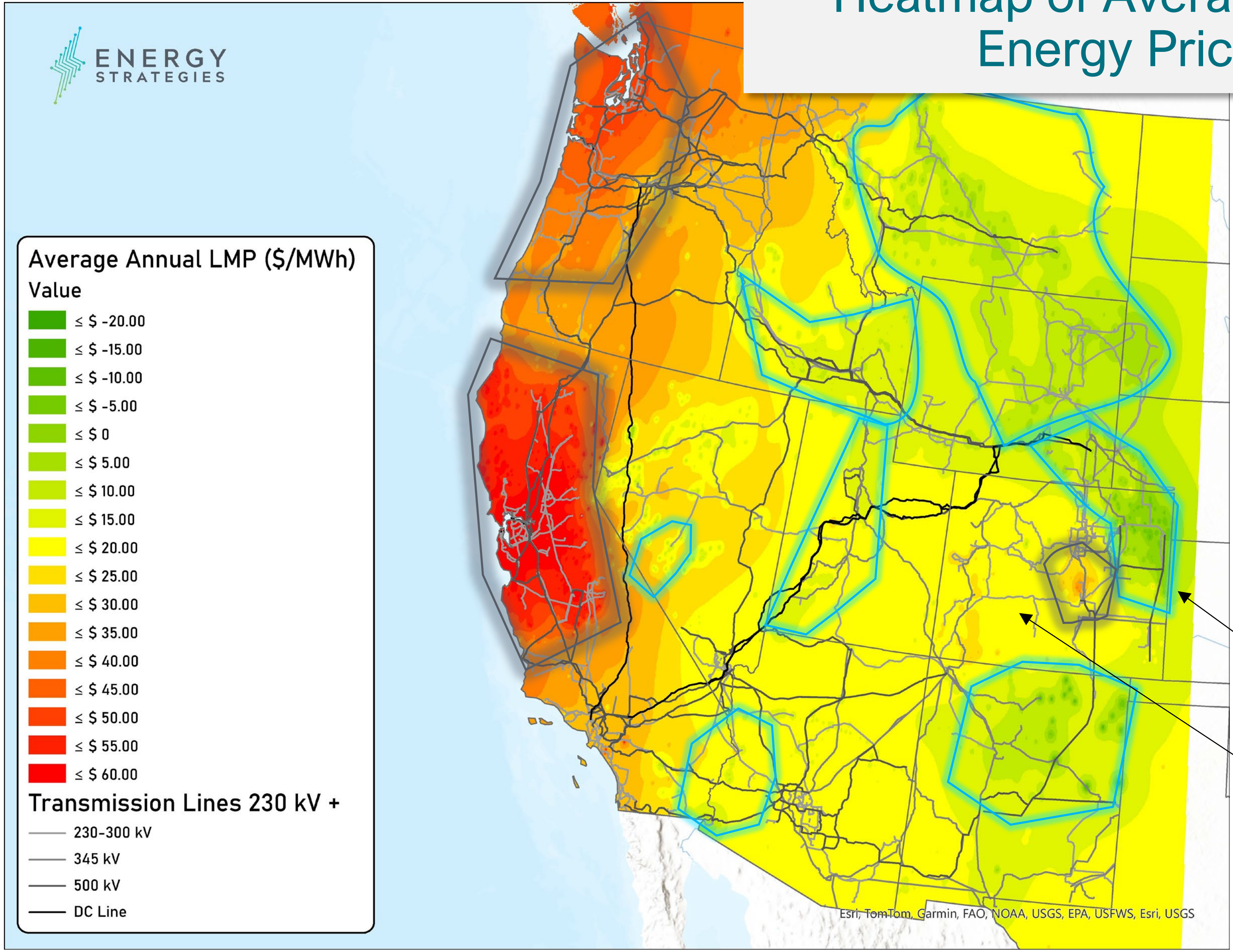
Clean Energy Penetration (%)

2032 ADS:
67%

2045 Connected West:
92%

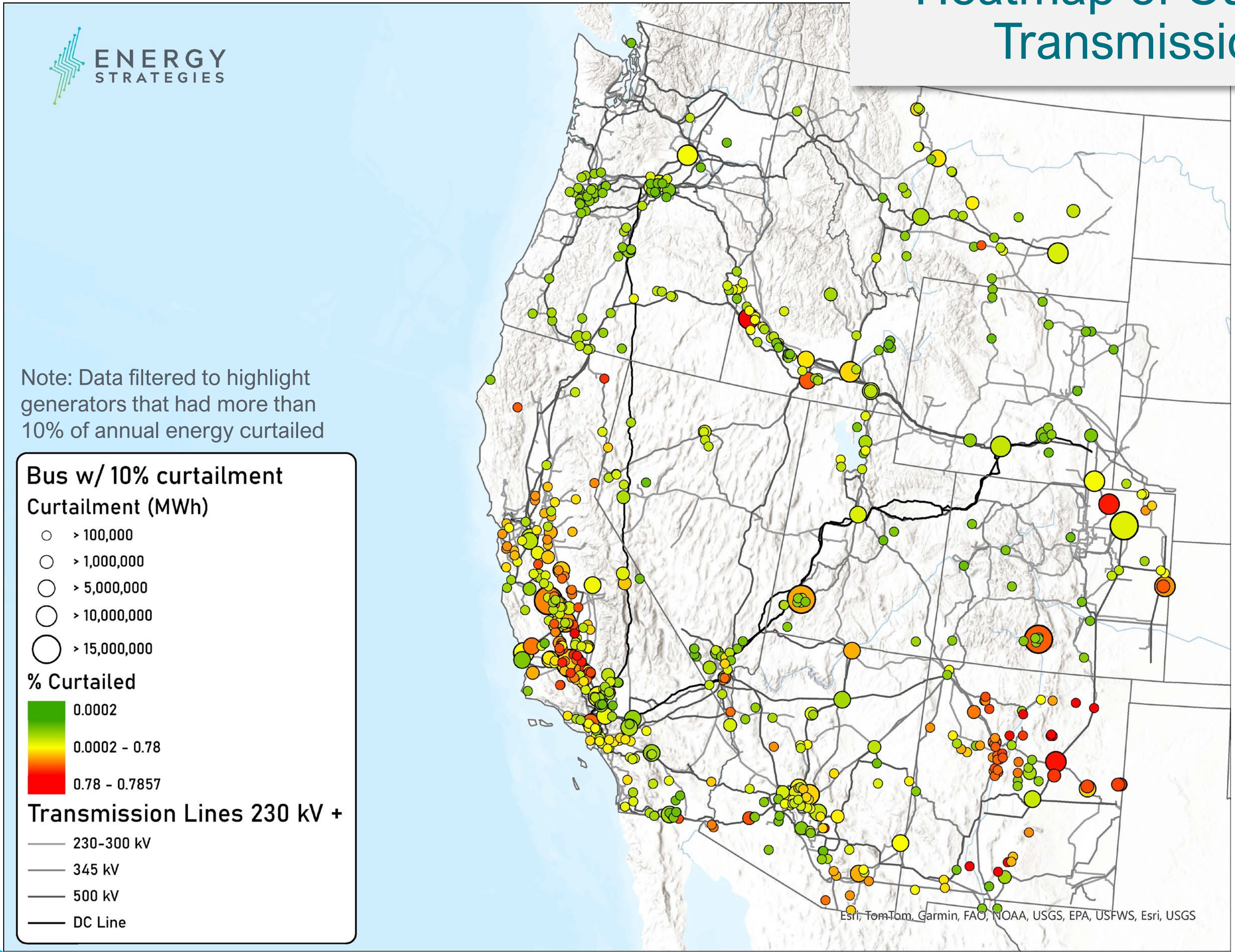
Connected West achieved a **95% clean energy mix** once transmission limitations were addressed. This is on track with Power of Place which targeted a net-zero emission 2050 future.

Heatmap of Average Annual Nodal Energy Prices (LMPs)



- **LMP is the price of electricity at a specific location, reflecting supply and demand balance, losses, transmission constraints, and generation costs**
  - Prices vary by location, providing key information about grid constraints
- **Price differences between areas indicates transmission congestion**
  - Identifying congestion helps prioritize areas to evaluate for transmission upgrades
- **The 2045 Connected West Reference Case has two dominant types of congestion, based on annual average LMP data:**
  - **Export limited:** Areas in Montana, SE Wyoming, NE Colorado, Eastern New Mexico, and certain locations in Idaho, Utah, Nevada, and S. California
  - **Import limited:** Central California, PNW Coastal Loads, Denver Metro

Heatmap of Curtailments Due to Transmission Congestion



Note: Data filtered to highlight generators that had more than 10% of annual energy curtailed

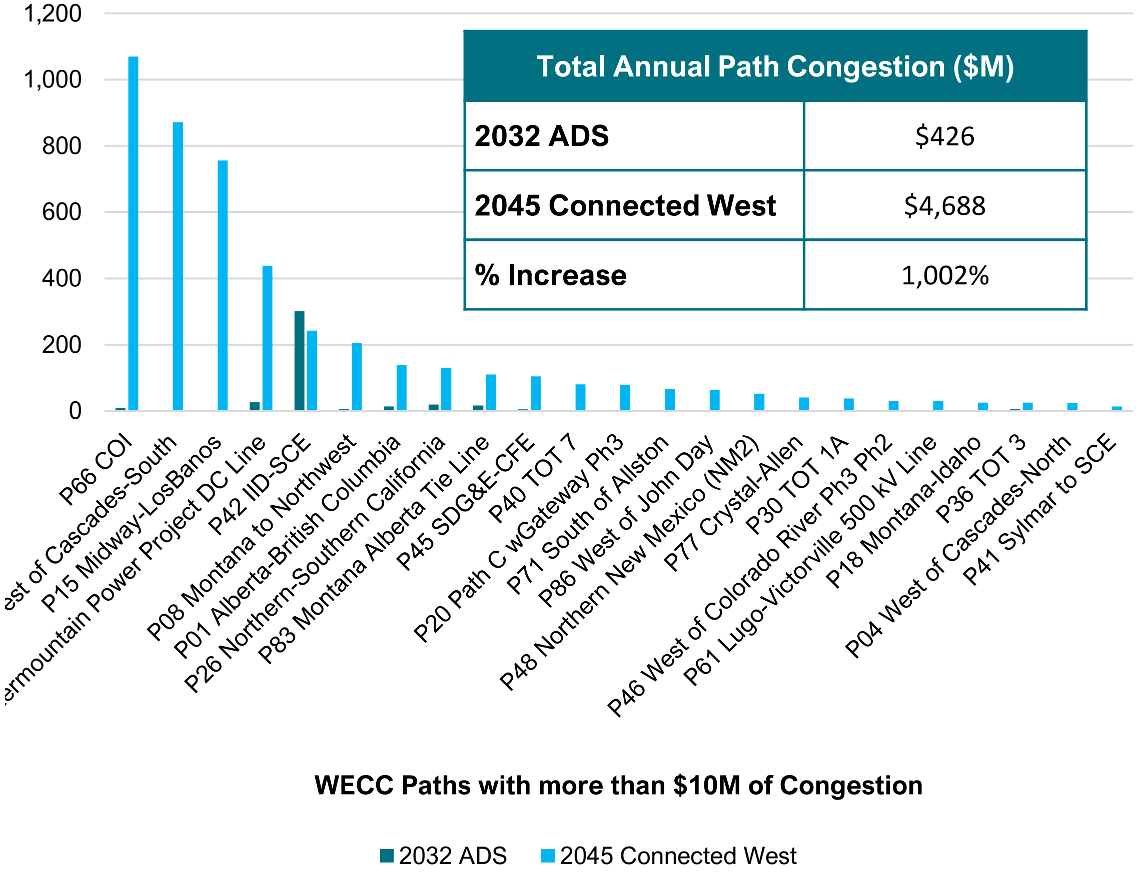
Esri, TomTom, Garmin, FAO, NOAA, USGS, EPA, USFWS, Esri, USGS

- **Curtailment data can provide insights into where and when the grid is unable to handle the full available generation**
  - While the 2045 grid is likely to experience some curtailment due to “system level” overgeneration events or inflexibility, locational transmission-driven curtailments are frequent and cause “outlier” curtailment in targeted areas
- **Curtailment can help us find potential transmission bottlenecks**
  - Addressing transmission constraints that cause curtailment will increase the amount of energy delivered to the system
- **The 2045 Connected West Reference Case has renewable curtailments prevalent in:**
  - Montana, Colorado, Wyoming and New Mexico have the most severe curtailments
  - Arizona and California both have frequent curtailments
    - Some may be driven by low energy prices vs. transmission
  - Utah and Idaho also have material curtailments, along with some areas of Nevada
- **Areas without circles on the chart indicate zones that likely have sufficient transmission capacity for purposes of this study**

Transmission Congestion on WECC Paths is Severe

- **WECC paths are typically groupings of parallel lines that have a path rating that defines the maximum transfer capability of the "interface"**
- **The 2032 WECC ADS had relatively low amount of congestion observed on WECC Paths**
- **Congestion increased significantly in the 2045 ADS (10x) as measured by annual congestion cost**
    - The top 10 congested paths were congested for an average of nearly 41% of the year
    - In the ADS, these same paths were congested 11% of the year
- **While individual branch congestion suggests a need for targeted upgrades to mitigate congestion (see next slide), this significant congestion on WECC paths suggests major inter-area transmission upgrades will be needed for the system to operate efficiently under the Connected West 2045 scenario. Target areas include:**
    - Cross-Cascade paths in PNW
    - California-Oregon intertie and internal California upgrades
    - Montana and Idaho export

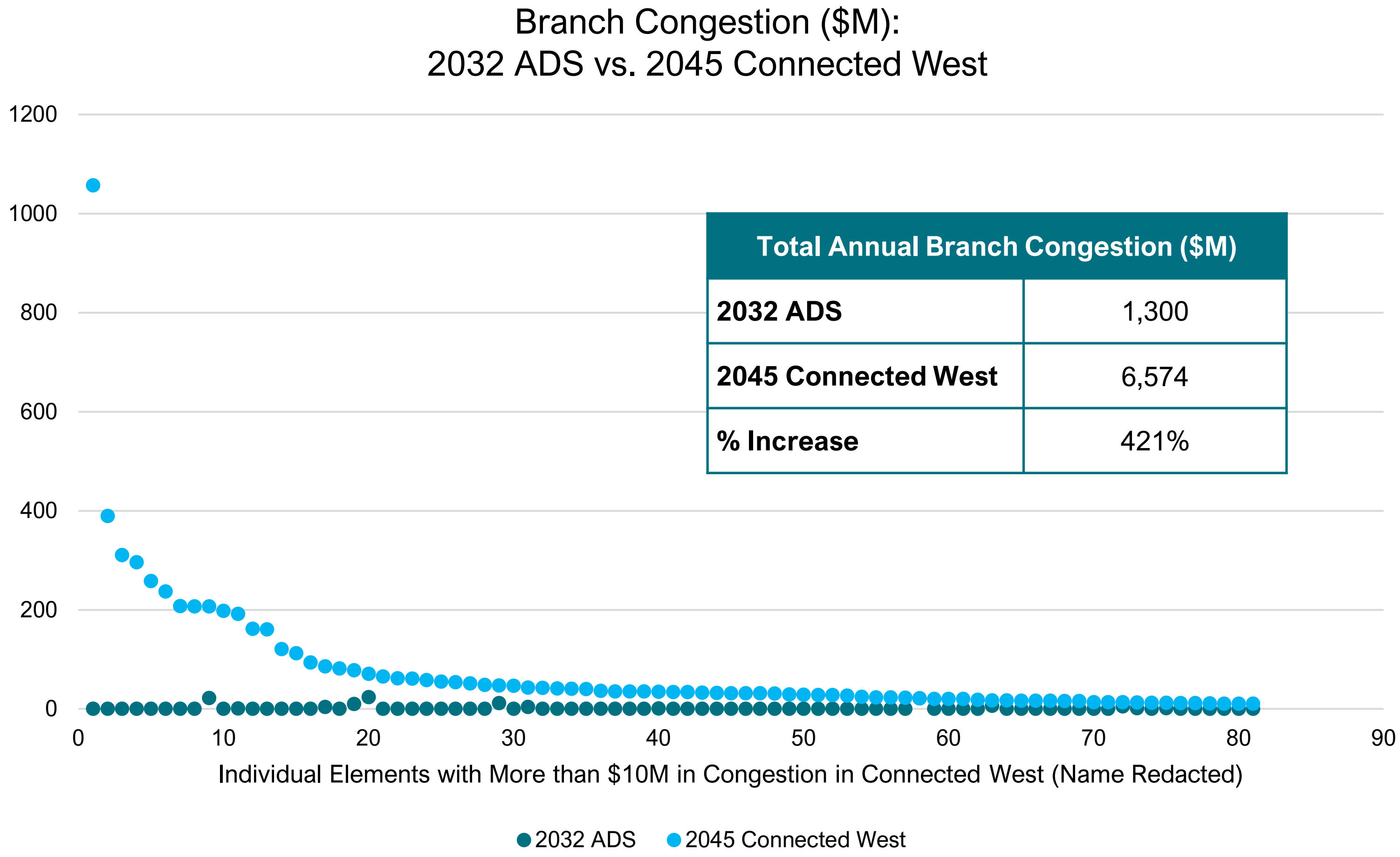
WECC Path Congestion ($M): 2032 ADS vs. 2045 Connected West



Total Annual Path Congestion ($M)	
2032 ADS	$426
2045 Connected West	$4,688
% Increase	1,002%

Transmission Congestion on High-voltage Branches is Severe

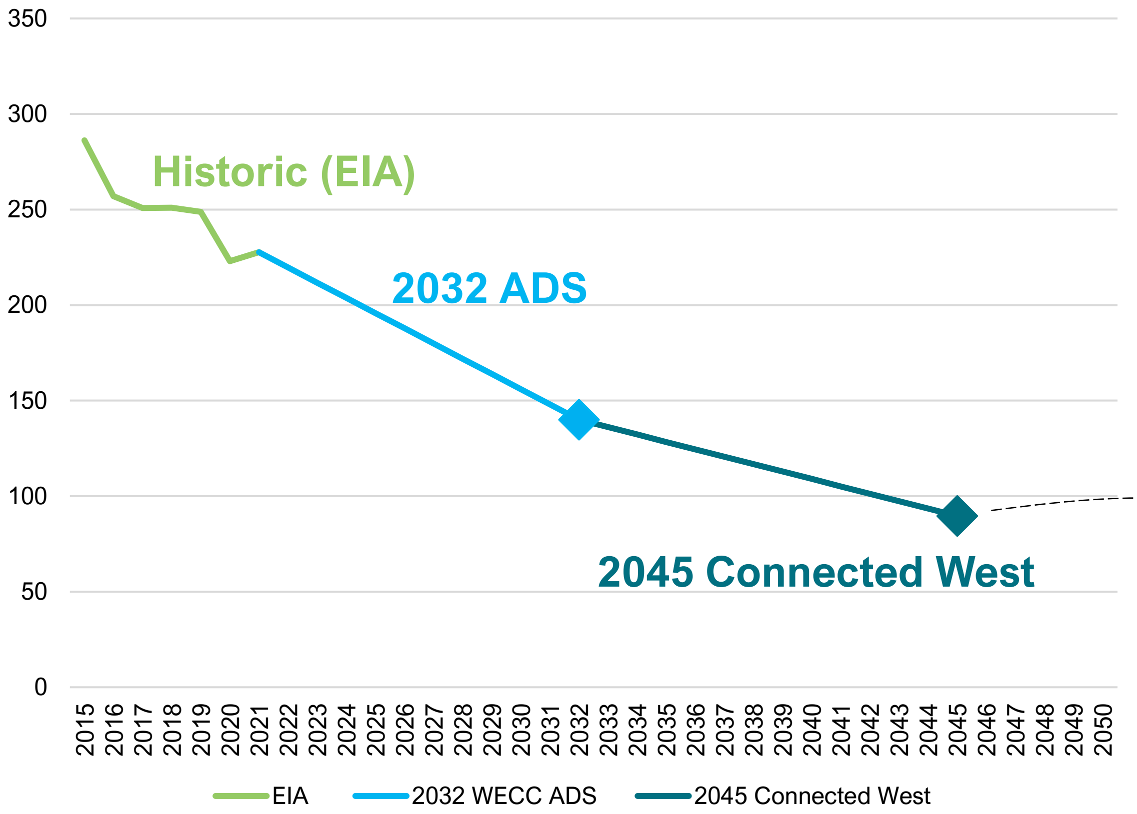
- **Transmission congestion on high-voltage elements, which includes lines and transformers, increased by 406% in the 2045 Connected West Reference Case relative to the 2032 ADS**
  - Note this does not capture ALL transmission congestion as the study limited transmission monitoring to high-voltage lines and inter-area lines only
- **Relatively low levels of congestion in ADS are severely exacerbated in 2045 Connected West**
  - 81 branches in Connected West have congestion >$10M per year
  - 15 have congestion greater than $100M per year
- **Results indicate a need for additional transmission capacity for system to operate efficiently under the Connected West future**



Total Annual Branch Congestion ($M)	
2032 ADS	1,300
2045 Connected West	6,574
% Increase	421%

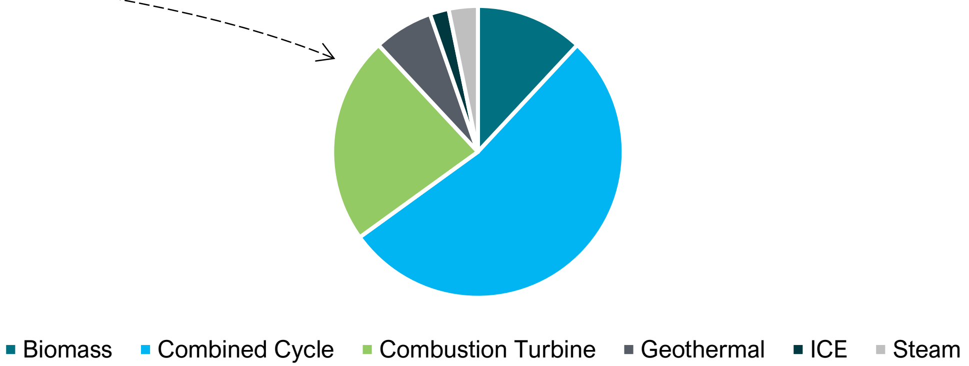
Relative to 2032 ADS, 2045 Connected West reduces annual CO_2 emissions by 64 million metric tons

Western US States Annual CO2 Emissions (million metric tons, electric sector):



- **The 2045 Connected West Reference Case, even without needed transmission upgrades, achieves <u>36%</u> reduction in CO_2 emissions from WECC 2032 ADS, and <u>72% reduction</u> from 2005 levels**
  - Electric sector emissions only!
- **Emissions in 2045 are mainly driven by combined cycle units located in DSW market (Arizona, California)**
  - This study assumes fuel carbon contents consistent with WECC ADS. This may understate the usage of clean fuels or other carbon reduction methods represented in the PoP study.

Source of 2045 Connected West CO2 Emissions



Takeaways from Reference Case Modeling

Load

WECC system will experience load growth under high-electrification future

- Some areas have loads twice what they are today
- The system had a peak that is 100 GW greater, and annual energy needs up ~75%
- Flexible loads and demand response are imbedded in this work and do not address all transmission challenges
- Likely does not account fully for data center growth, so load could be higher.

Generation

WECC fleet more than doubles (by capacity) from 2032 to 2045 to keep up with demand

- To maintain a low-carbon grid, most additions are renewable resources and storage (4x in renewables)
- Use of thermal fleet declines by 2045, but apparent roll for certain units to provide peaking.
- 87% clean energy penetration by 2045 (even with significant transmission constraints)
- PoP-West suggests this buildout is feasible from land perspective.

Transmission Forecast

The study assumes a significant level of transmission investment between now and 2045, building all major projects

- This represents 5,900 miles and $27 billion of investment
- This forecast of transmission expansion included in the study is in additional to BAU upgrades not specified, like generator interconnections, smaller system upgrades, and distribution-transmission interface investment

Curtailment & Prices

Curtailment is observed frequently and at massive scale relative to what is encountered today and forecasted for the 2030's

- Curtailment occurs both near load centers and remote resource zones.
- Power prices are frequently negative in resource areas.
- Transmission congestion is primary driver for many curtailment and pricing issues.
- 27% of renewable energy is curtailed.

Transmission Constraints

Even with investment in transmission between now and 2045, transmission constraints hamper efficient operation of grid. Many regions will require upgrades to unlock generation and help reduce power prices near load centers

- Study is likely to underestimate total transmission need as other drivers of transmission exist and modeling is not comprehensive.

Findings and Results

Part I: Reference Case Results & Observations

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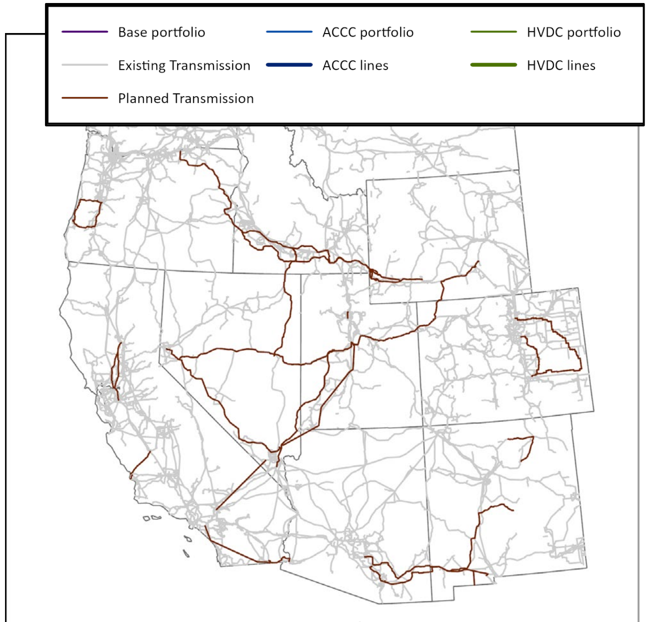
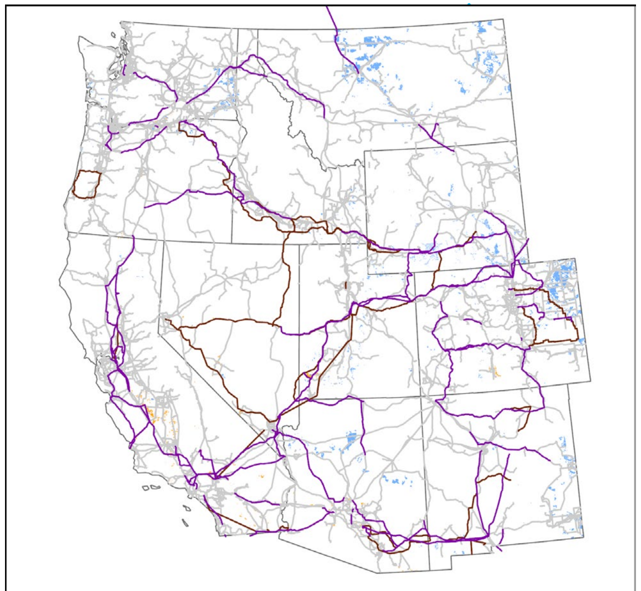
Connected West Transmission Portfolios

- **Three thematic portfolios developed to address transmission constraints**
    - **AC Greenfield Portfolio** consists of reconductoring existing lines, expansion of existing rights of way and new project in new corridors using traditional conductor technology (ACSR or ACSS conductors)
    - **DC Greenfield Portfolio** consists of a network of HVDC lines across the WECC system with some AC upgrades required to allow transfer power to and from the DC network
    - **Advanced Conductor Portfolio** consists of new high-capacity transmission conductors located within existing transmission corridors, along with traditional ACSR or ACSS conductors were used when advanced conductors are not feasible due to length of network upgrade required exceeded approximately 65 miles*
- **All portfolios required certain AC system upgrades, primarily in the form of reconductoring projects**
- **Portfolios had capital costs in the range of $73-78B, which are incremental to the costs of planned projects assumed in the study**

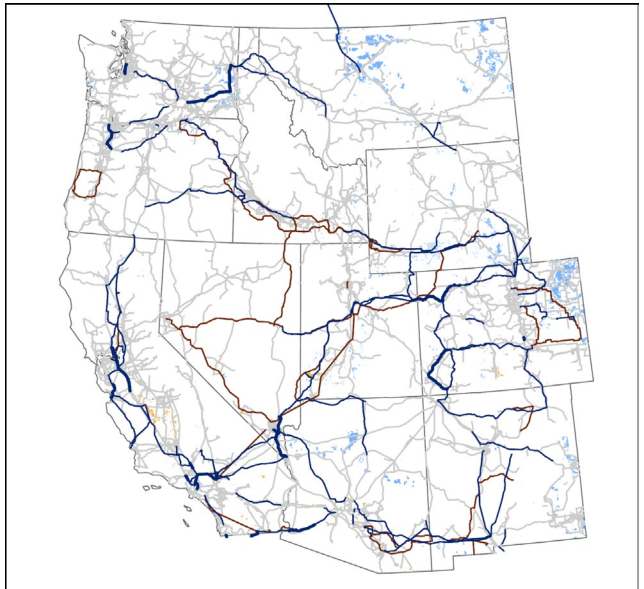
*Further optimization of the use of Advanced Conductors could be studied for longer lines requiring compensation or for new corridors, but those were considered emerging techniques which were beyond the scope of this study.



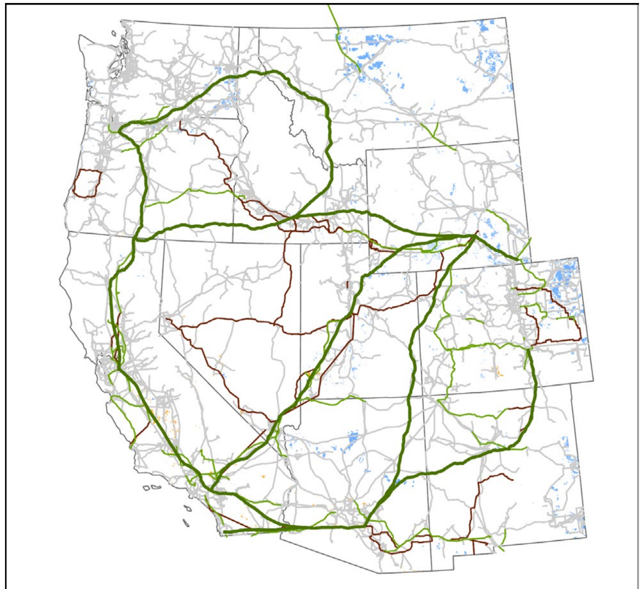
Existing and Planned: $30B capex



AC Portfolio: $75B capex



Advanced Conductor Portfolio: $78B capex



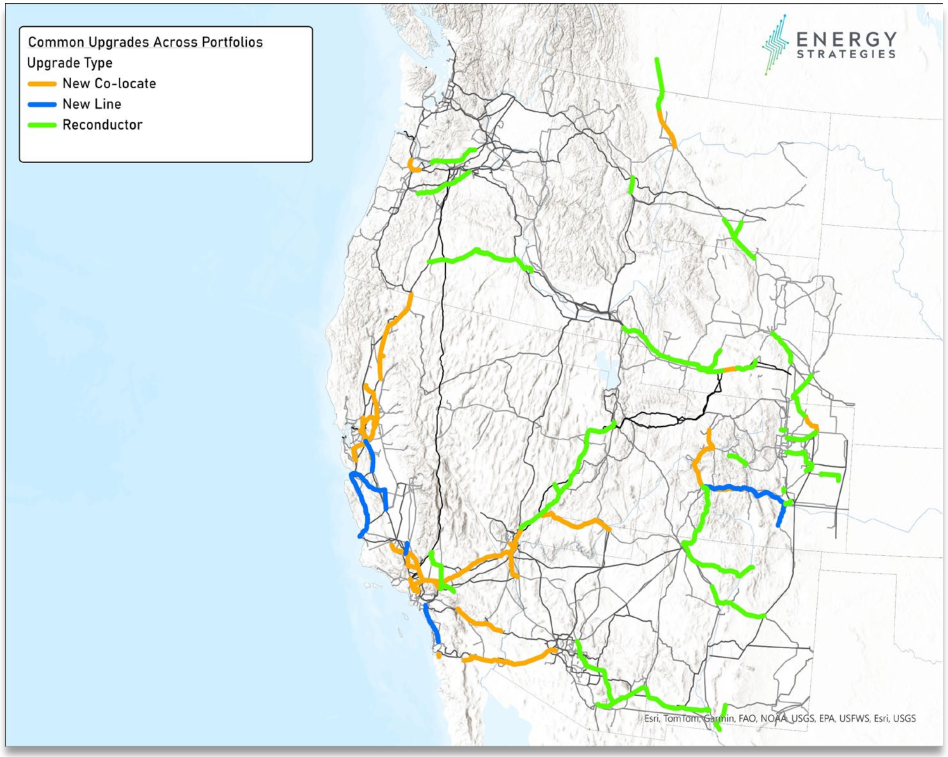
HVDC Portfolio: $73B capex

Transmission Portfolio Summary: Comparison of Buildouts

- **All three portfolios share ~60% of the same underlying AC upgrades, which were primarily reconductoring projects, with some common new and co-located AC lines**
    - Significant portion of the common upgrades were in Colorado, Wyoming, Arizona and California
- **While the AC Greenfield and Advanced conductor portfolios have more miles of upgrades, the DC Greenfield portfolio requires three times more greenfield line miles than the other portfolios because DC lines cannot generally share ROWs with existing AC lines**
    - Advanced Conductor portfolio largely consists of the same lines as the AC portfolio, except reconductoring existing lines with ACCC conductors instead building new line with ACSR/ACSS conductors.
    - Advanced conductor portfolio is the most expensive portfolio due to higher cost of ACCC (Aluminum Conductor Composite Core) conductors vs ACSR (Aluminum Conductor Steel Reinforced) (but it results in the most new capacity)

	AC Overlay	Advanced Conductor Portfolio	HVDC Overlay Portfolio
Reconductor Cost ($M)	$13,744	$19,530	$7,284
Cost of New Line Co-Located in Existing Corridors ($M)	$45,381	$46,103	$13,800
Cost of New Greenfield AC Lines ($M)	$14,873	$11,729	$3,831
Cost of New Greenfield DC Lines ($M)	$0	$0	$18,159
Converter Station Costs ($M)	$0	$0	$28,663
Other Equipment Costs ($M)	$1,064	$1,124	$996
Total Portfolio Cost ($M)	**$75,062**	**$78,486**	**$72,733**

Common Upgrades Across Portfolios



Esri, TomTom, Garmin, FAO, NOAA, USGS, EPA, USFWS, Esri, USGS

Transmission Portfolio Summary: AC Greenfield

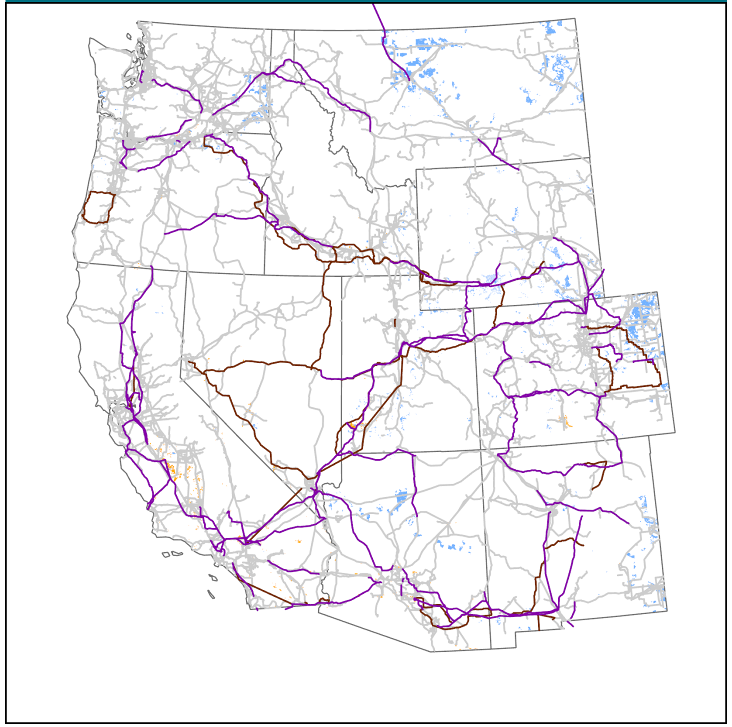
- The thematic **AC Greenfield** portfolio ($75B capex) relied primarily on traditional reconductoring upgrades, new transmission projects requiring expansions or repurposing of existing corridors, or new transmission projects requiring the development of entirely new corridors

Operational Performance in 2045	
Annual curtailment (%)	22%
Average energy price (LMP)	$23
US Clean energy penetration (%)	94.4%
US CO_2 reduction from Ref Case (%)	23%
Transmission congestion cost ($M)	$2,277
Branches with > $50M of Congestion	11

Technical Details	
Total Length (mi.)	15,749
Reconductoring miles	5,779
Co-located miles	7,444
New build miles	2,385
HVDC miles	140
Advanced conductor miles	0
New corridors land use (acres)	73,246
230-kV miles	2,447
345-kV miles	3,302
500-kV miles	9,998

Portfolio Costs & Benefits (present value)	
Total Cost ($M)	$188,366
Total Benefit ($M)	$278,851
Net Benefit ($M)	$90,486
Benefit-Cost Ratio	1.48

AC Greenfield Portfolio



Transmission Portfolio Summary: DC Greenfield

- The **HVDC Greenfield** portfolio ($73B Capex) relied primarily on a new network of AC-DC converter stations connected by 3,000 MW rated DC lines. Some for the underlying AC upgrades from the AC Greenfield portfolio were maintained or adjusted to facilitate transfer of power to and from this new HVDC network.

Operational Performance in 2045	
Annual curtailment (%)	21.5%
Average energy price (LMP)	$25.6
US Clean energy penetration (%)	94.2%
US CO_2 reduction from Ref Case (%)	21%
Transmission congestion cost ($M)	$3,081
Branches with > $50M of Congestion	17

Technical Details	
Total Length (mi.)	14,008
Reconductoring miles	3,531
Co-located miles	3,805
New build miles	890
HVDC miles	5,783
Advanced conductor miles	0
New corridors land use (acres)	198,370
230-kV miles	2,137
345-kV miles	2,106
500-kV miles	9,765

Portfolio Costs & Benefits (present value)	
Total Cost ($M)	$182,522
Total Benefit ($M)	$253,365
Net Benefit ($M)	$70,843
Benefit-Cost Ratio	1.39

DC Greenfield Portfolio

Transmission Portfolio Summary: Advanced Conductor

- The **Advanced Conductor** portfolio ($78B capex) relied primarily on the deployment of new high-capacity transmission conductors located within existing transmission corridors. In many cases use of advanced conductors was not technically feasible due to distance or reliability issues, so many AC Greenfield upgrades were incorporated into the portfolio as well.

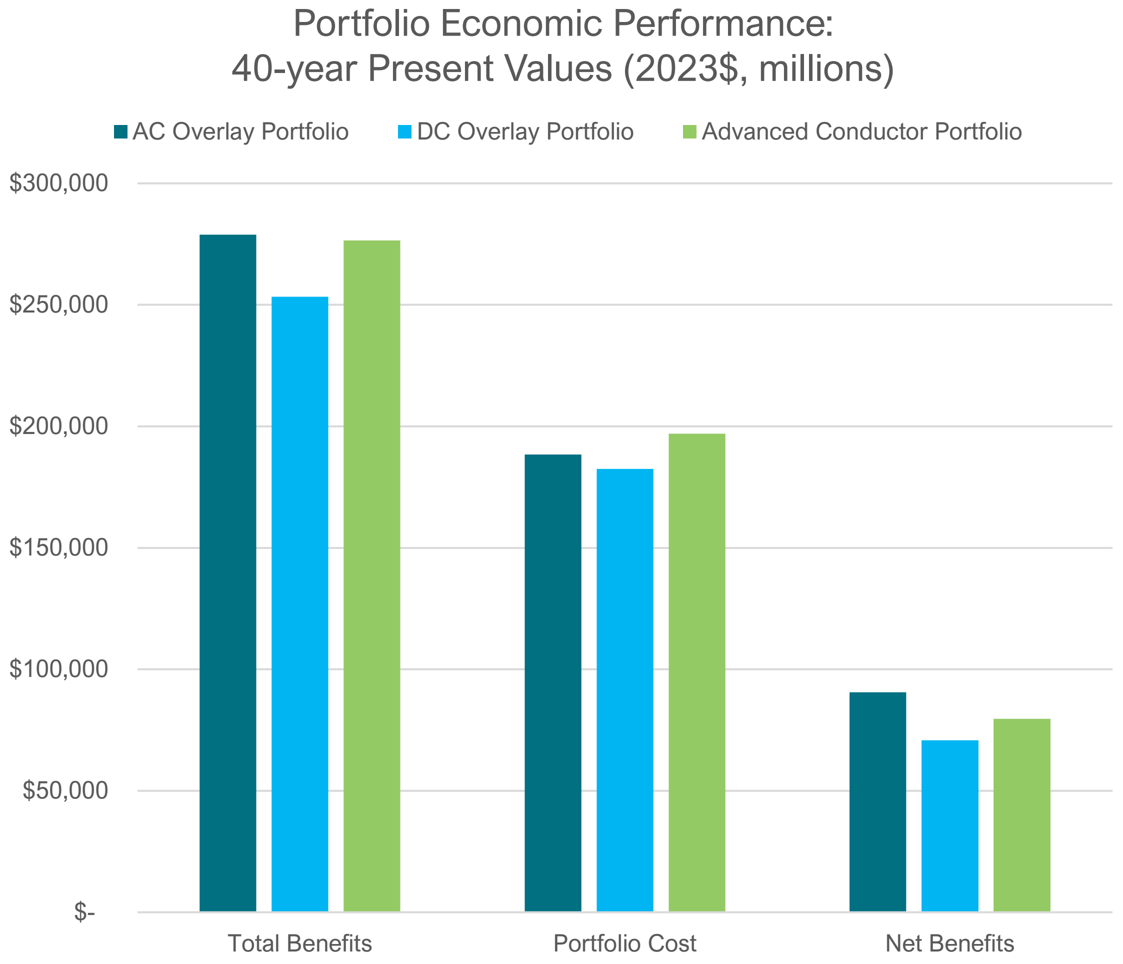
Operational Performance in 2045	
Annual curtailment (%)	22%
Average energy price (LMP)	$21.6
US Clean energy penetration (%)	94.4%
US CO_2 reduction from Ref Case (%)	23%
Transmission congestion cost ($M)	$2,094
Branches with > $50M of Congestion	7

Technical Details	
Total Length (mi.)	16,313
Reconductoring miles	6,397
Co-located miles	7,554
New build miles	2,222
HVDC miles	140
Advanced conductor miles	4,681
New corridors land use (acres)	68,362
230-kV miles	2,419
345-kV miles	3,198
500-kV miles	10,696

Portfolio Costs & Benefits (present value)	
Total Cost ($M)	$196,958
Total Benefit ($M)	$276,527
Net Benefit ($M)	$79,569
Benefit-Cost Ratio	1.40

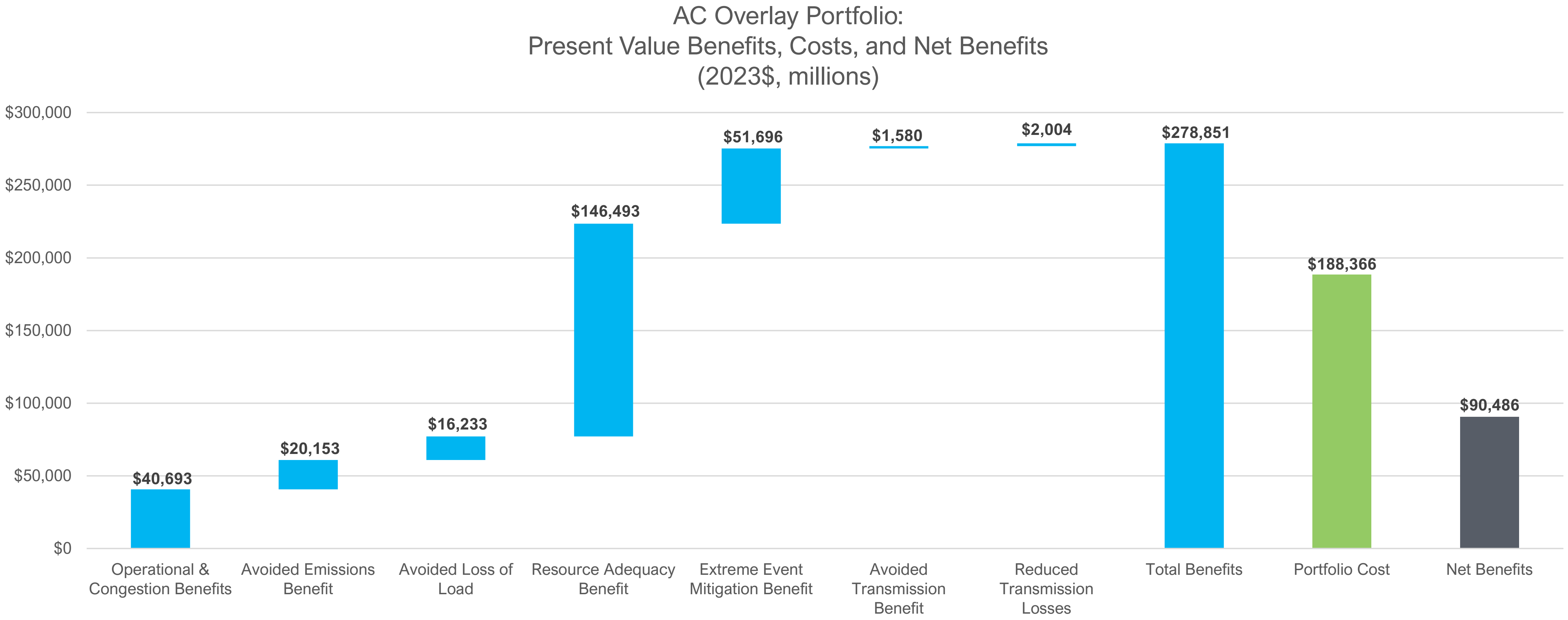
Advanced Conductor Portfolio

Transmission Portfolio Summary: Benefit Analysis Comparison

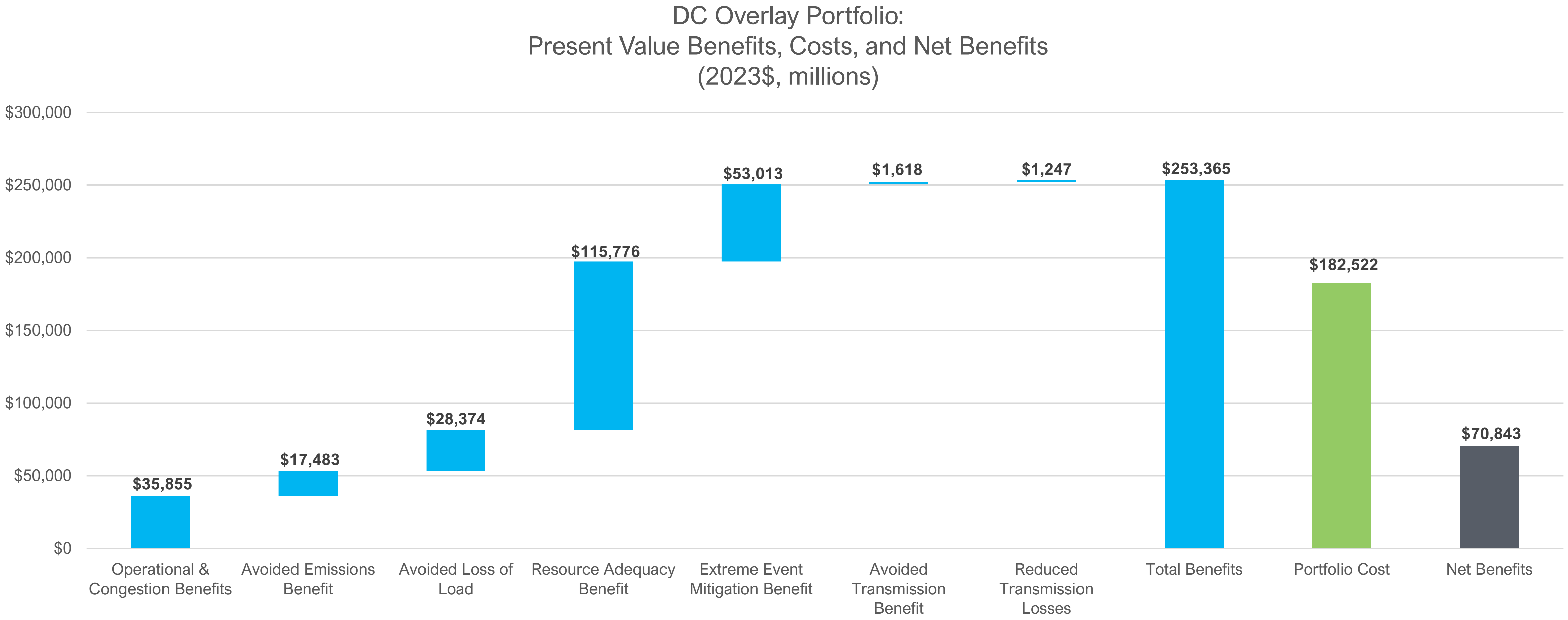


- **All transmission portfolios have comparable economic performance – there are no outliers in terms of net benefits to the system of benefit-cost ratios**
    - ○ B/C ratio of the AC portfolio is 1.48, while the B/C ratio of the two alternatives are ~1.4
- **The two AC portfolios (AC Greenfield and Advanced Conductor) cost more than the DC portfolio but have slightly higher benefits (~10% greater)**
- **Results are the value proposition are sensitive to the many inputs required, including financial assumptions, per-unit cost assumptions of transmission, benefit quantification factors, among others**
- **Since no technology dominates in terms of economic efficiency, results suggest that a blend of transmission technologies could be the most efficient transmission expansions strategy**

Transmission Benefits Summary: AC Greenfield

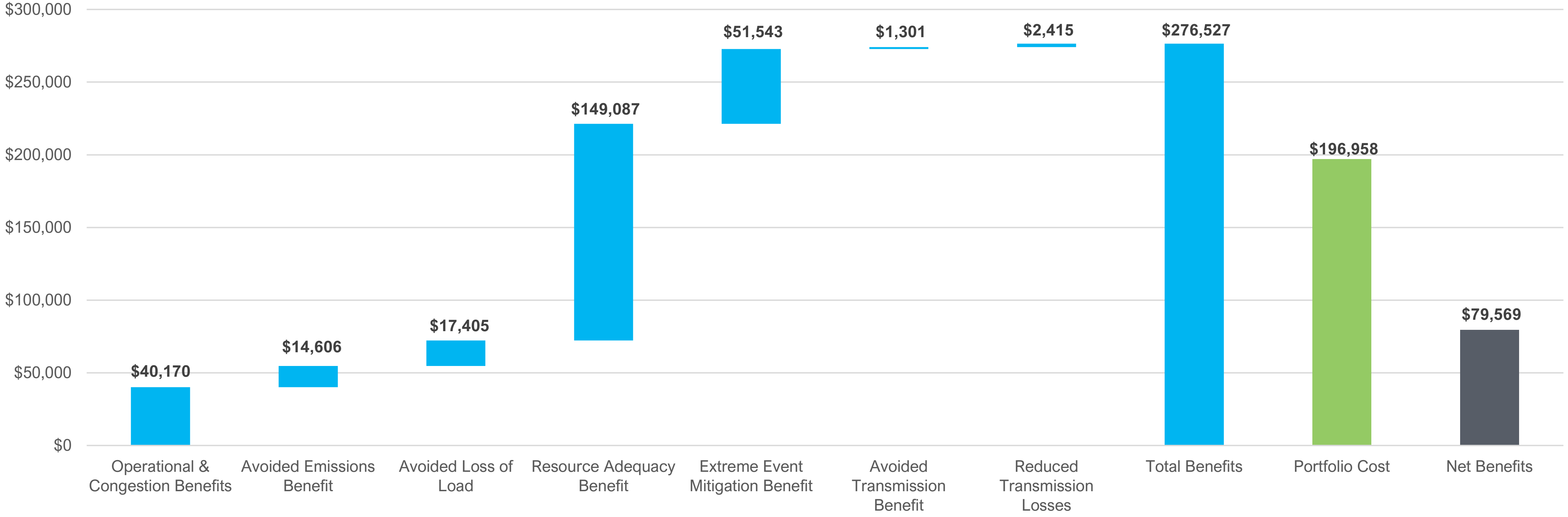


Transmission Benefits Summary: DC Greenfield



Transmission Benefits Summary: Advanced Conductor

Advanced Conductor Portfolio:
Present Value Benefits, Costs, and Net Benefits
(2023$, millions)



Key Metrics Across Transmission Portfolios

Metric	2032 WECC ADS	2045 Connected West Reference	2045 AC Greenfield Portfolio	2045 DC Greenfield Portfolio	2045 Advanced Conductor Portfolio
Meets Reliability Goals of Study	Not Assessed	No	Yes	Yes	Yes
US Wind and Solar Annual Curtailment (%)	3%	26.4%	22%	21.5%	22%
Average Energy Price, LMP ($/MWh)	$29.7	$27	$23	$25.6	$21.6
US Clean Energy (%)	67.6%	92%	94.4%	94.2%	94.4%
Transmission Congestion Cost ($M)	$1,299	$6,574	$2,277	$3,081	$2,094
US CO_2 Reduction (From Reference)	N/A	N/A	23%	21%	23%
Total Portfolio Costs ($M, present value)	N/A	N/A	$188,366	$182,522	$198,958
Total Portfolio Benefits ($M, present value)	N/A	N/A	$278,851	$253,365	$276,527
Net Benefit ($M, present value)	N/A	N/A	$90,486	$70,843	$79,569
Benefit-Cost Ratio	N/A	N/A	1.48	1.39	1.40

- **The Connected West Reference Case does not include sufficient transmission expansion for it to be considered a viable future, although it is useful for benchmarking purposes**
- **In all transmission portfolios, reduced transmission curtailment allowed for greater access to clean energy providing greater than 2% more clean energy to be delivered**
    - This equated to reduced wind and solar curtailment, and a decrease in CO_2
- **The greatest benefit resulted from AC Greenfield portfolio but each portfolio had a positive benefit**

Findings and Results

Part I: Reference Case Results & Observations

Part II: Transmission Expansion Portfolios

Part III: Answers to Key Questions

Part IV: Additional Findings

Capabilities of Projected Transmission: How far do planned and anticipated transmission projects take the Western grid towards meeting 2045 transmission needs under a high electrification and decarbonization future?

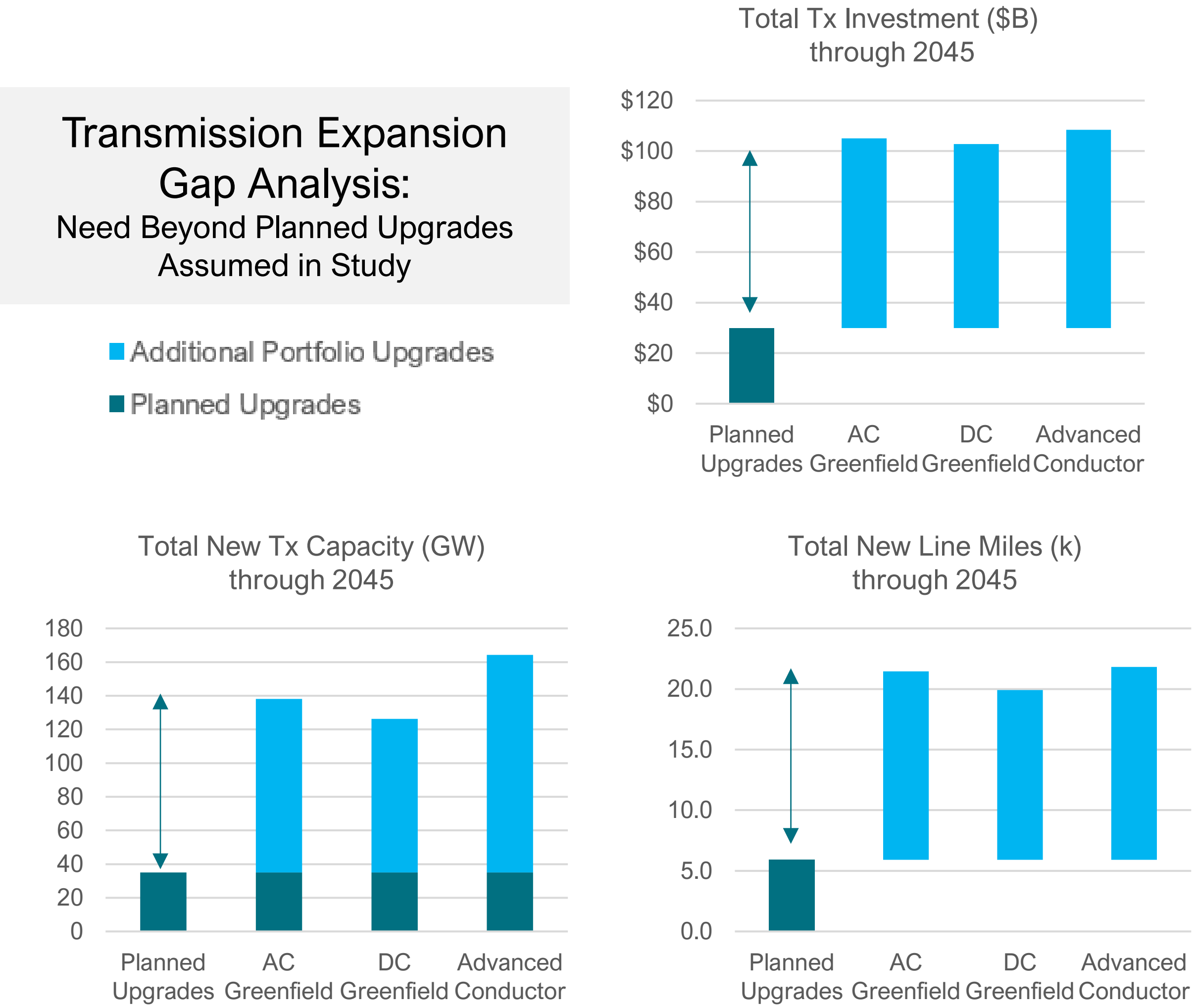
- **The planned/anticipated projects included in the 2045 Reference Case represent 5,900-line miles of new transmission, with total capital costs of ~$30 billion**
- **Even with this investment in high-voltage transmission across the West, transmission constraints hamper efficient & reliable operation of grid <u>with existing and planned upgrades alone</u>:**
  - Nearly the entire Western system experiences **severe economic congestion totaling more than $6 billion annually**, a figure that is ~4x greater than what is forecasted for the 10-year horizon
  - A lack of transmission enabling the delivery of resources to loads causes **~50 GWh of unserved load, representing nearly $2B of economic damage (annually)**, suggesting the grid cannot support the electrification of the Western economy envisioned in the study
  - Transmission systems in rural areas of Montana, Colorado and New Mexico are unable to support the export of power from generation rich areas, with significant **voltage collapse and reliability-driven outages** observed across these areas
  - Net-zero emissions by 2050 is **not achievable** due to significant renewable curtailments totaling ~27% of annual renewable generation, a figure that is 36x greater than what is planned for in the 10-year horizon
- **The high-voltage transmission upgrades assumed in the Connected West Reference Case are not sufficient for an electrified and highly decarbonized 20-year future – more transmission investment is required to reliably and efficiently operate the system**

Planned Upgrades are Insufficient for Connected West Future

Existing and **Planned**

Transmission Gaps: If the planned projects do not fully meet the 2045 needs, what is the remaining transmission gap in terms of investment ($) and additional transmission capacity (MW)?

- **Approximately $75 billion of additional high-voltage transmission investment is needed, representing investment above and beyond the $30B of planned upgrades assumed in this study**
  - This figure understates total transmission investment required based on the scope of the transmission analysis
- **The transmission gap to achieve the Connected West future can also be represented as an incremental need – above and beyond planned upgrades assumed in the study – for:**
  - At least **15,000** miles of new high-voltage transmission upgrades
  - At least **110 GW** of additional transmission capacity
- **There is approximately 100,000 miles of existing 200-kV and higher transmission in the West today, which means the Connected West AC Portfolio would rebuild 13 percent of these lines, and add an additional 2,400 miles (2-3%)**



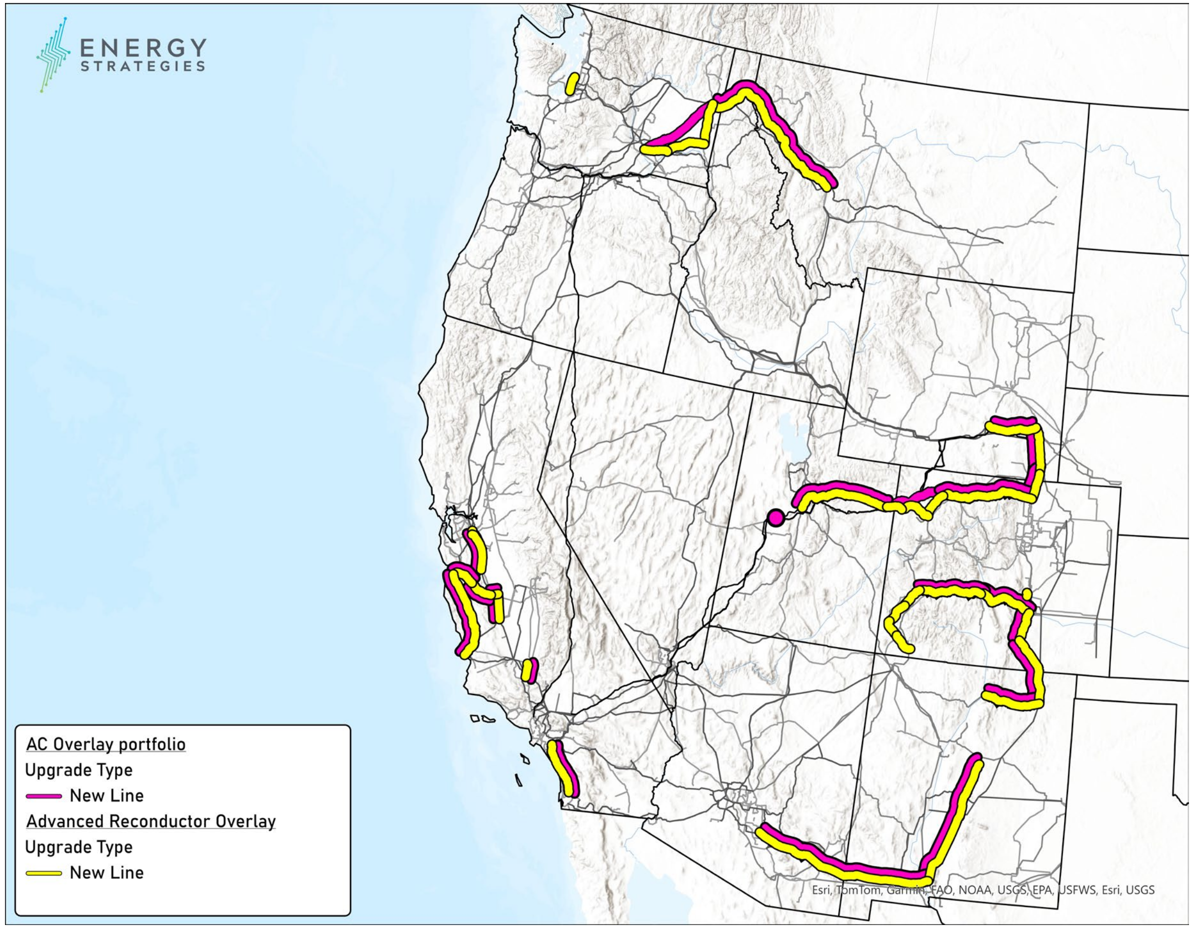
Transmission Expansion Gap Analysis:

Need Beyond Planned Upgrades Assumed in Study

Geographic Corridor Prioritization: Based on the transmission portfolios identified for the Connect West future, what geographic corridors should be prioritized for the next tranche of transmission investments over the coming 20 years?

- **Given the scope of the transmission portfolios identified in the study, <u>ranking</u> greenfield development corridors in terms of priority is difficult**
    - Due to the **network effects and scale of transmission** in each portfolio, many new physical corridors are required, with all being important
    - When combined with reconductoring/co-located lines, the **new corridors all host transmission capacity** that provides the needed technical outcomes and benefits to the grid
- **However, while each portfolio's scope of upgrades are large, there are relatively few areas where new greenfield development is required:**
    - Colorado/Wyoming/New Mexico/Utah paths
    - Arizona-New Mexico
    - Montana-PNW/Mid-C
    - California 500 kV upgrades
- **The exception is the HVDC Portfolio, which requires 3x the greenfield transmission development mileage**
- **<u>Further diligence on the feasibility of reconductoring projects included in the portfolios will impact this conclusion</u>**

Priority Greenfield Development Corridors



Portfolio Comparisons: How do new greenfield corridors compare with upgrades to existing lines? What portfolios of transmission technologies appear to make the most sense to achieve the West's long-term goals?

- **Based on the performance, net benefits, and technical makeup of each Connected West transmission portfolio, the optimal 20-year transmission expansion strategy for the West (under *this* Connected West future) is likely one that leverages *many* transmission expansion strategies, selecting the approach "best suited" for each individual need**
  - **Reconductoring upgrades** are the most common strategy making up **37%** of the upgrades in the Portfolios. Reconductoring should be relied on heavily by planners as a first option for addressing reliability and grid inefficiencies – this approach was adopted in this study
  - **Co-locating upgrades** used existing or expanded right-of-way make up **nearly 50% of the line miles** in the AC Portfolio and Advanced Conductor portfolio. Rebuilding lines in existing corridors (to double circuit) or expanding corridors to accommodate new parallel lines represent an impact-minimizing strategy leaned on heavily in this study.
  - **Greenfield AC upgrades** require *new* right-of-way, making up **~16% of line miles** in the AC Portfolio and Advanced Conductor portfolio. While critical to reliability in some areas, these upgrades were largely able to be avoided due to the reliance on co-location and reconductoring.
  - **Advanced conductors** resulted in the greatest incremental system capacity, with the benefit of fewer miles of new greenfield development compared to the AC Portfolio. Use of advanced conductoring was limited to short lines due to significant decrease in their MW capability over long distances.
  - **HVDC solutions** represent an efficient way of transferring power great distances, resulting in efficiencies that led to lower costs. However, they require new right of way because of limited existing HVDC infrastructure.
- **The study's results support an all-of-the-above approach to transmission development is required to meet the needs of an aggressive future, such as Connected West:**
  - Reconductoring & co-locating of upgrades are a core part of all three scenarios
  - Advanced conductoring & other grid-enhancing technologies should be adopted on a case-by-case basis
  - A select set of HVDC corridors may represent the most efficient means of further connecting load and generation across the system

Findings and Results

Part I: Reference Case Results & Observations

Part II: Transmission Expansion Portfolios

Part III: Answers to Key Questions

Part IV: Additional Considerations

Study Caveats and Considerations for Readers

- **The study does not identify all necessary transmission additions for the future considered and will therefore understate transmission investment required to achieve a low carbon & high electrification outcomes in 2045.**
  - For example, we don't forecast lines needed to address local load growth, connection of generators to the grid (tie lines or substation upgrades), or lower voltage upgrades
- **Connected West focuses on a single future scenario and the results are a product of the assumptions made and methods adopted.**
  - Similarly, since transmission needs are sensitive to resources siting assumptions, we expect the results of the study will change materially if a new resource mix is considered or if resources are sited in new locations
- **Additional transmission not included in the 2045 Reference Case may be constructed, which would cause this study to *overstate* the need for transmission. It is also true that certain assumed projects may not be constructed, in which case the need for transmission would be greater than forecasted.**
- **Industry views of acceptable levels of curtailment, LMPs, and congestion may change between now and 2045, so determining what is "needed" 20-years in advance is a nuanced planning issue.**
  - Data in this study points toward a paradigm shift in how we operate and plan the system if highly electrified low carbon grids come to pass.
- **The study assumes a highly integrated market that is optimally dispatch, which may cause the study to understate transmission need if such a market does not come to pass.**
- **While the results of this study are based on sophisticated grid analyses and forecasts, there are unique local operational and planning considerations not accounted for that could impact conclusions regarding the feasibility or appropriateness of transmission solutions identified herein**
  - For example, the study relies heavily on reconductoring of transmission lines. The authors did not have local insight into any challenges associated with reconductoring a particular line or repurposing a particularly right of way and assumed that in a 20-year horizon such issues could be overcome

Transmission Routing Environmental Impact Sensitivities

- **Montara Mountain Energy performed sensitivities exploring how increased consideration of environmental and conservational factors in line routing impacts Reference Case transmission portfolios**
  - This analysis was performed on **greenfield lines only**, which represent only part of the transmission solutions identified in the study's portfolios
  - Sensitivities were performed to compare impacts to the **AC Overlay and HVDC Overlay** portfolios
  - These sensitivities reflect increasing consideration and avoidance of **protected areas, environmentally sensitive areas, tribal lands, or land with high conservation value**

- **The sensitivity results demonstrate that, in some cases, avoiding environmentally or culturally sensitive areas does not materially impact portfolio transmission line miles or costs**
  - The **AC portfolio** exhibited a limited impact when impact avoidance was a priority – total portfolio costs and line miles were calculated to increase by 1-2%
  - Avoiding environmental or cultural impacts had a larger impact on the **HVDC portfolio** – total portfolio costs were calculated to increase by 4-13% and total portfolio line miles were calculated to increase by 18-22%

Thank You

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Appendices

Value of Lost Load and Net CONE

- **A weighted average value of lost (VOLL) of $40,000/MWh is assumed in the Avoided Loss of Load and Extreme Event Mitigation benefit calculations**
  - This value is supported by analysis performed by ESIG (Energy Systems Integration Group, Interregional Transmission for Resilience, 2023) which cites VOLL of $20,000-40,000/MWh today.
  - We adopt the higher end of this range based on independent research of similar studies and consideration of the importance of electric supply in the future being modeled.
- **The avoided capacity cost is based on an average Net CONE (Cost of New Entry) values from major U.S. ISOs/RTOs, including PJM, NYISO, ISO-NE, MISO, and CAISO.**
  - The average Net CONE value is calculated to be approximately $230 per kW-year, based on the most recent estimates provided by the entities listed.

Transmission Benefits Considered

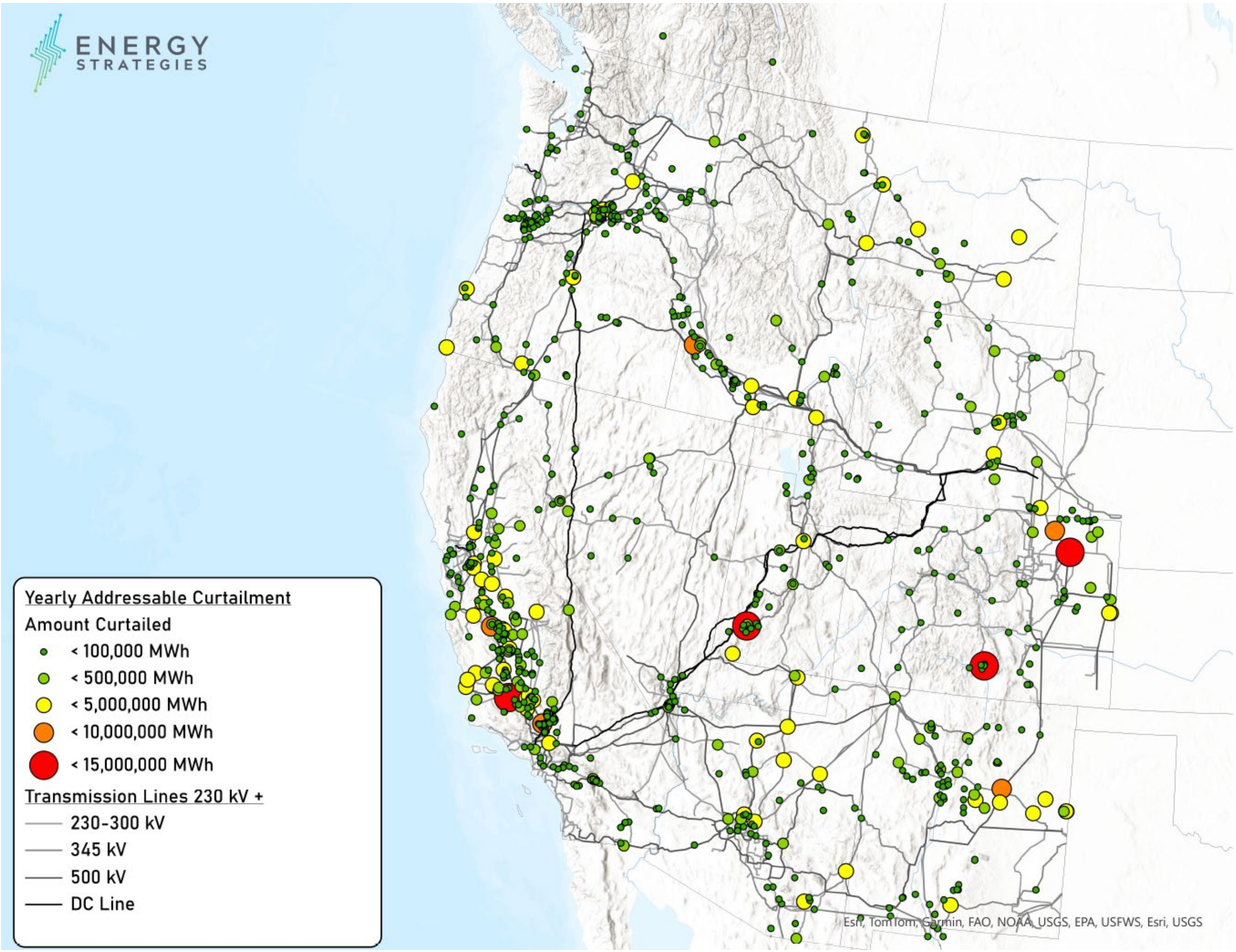
Benefit	Metric
Operational Savings	Change in WECC-wide production cost.
Avoided Emissions	Avoided emissions savings based on simulated emissions reductions and a forecasted carbon price
Avoided Loss of Load	Avoided loss of load valued at $40,000/MWh, with the benefit calculated as the product of reduced loss of load in simulation sand the loss of load price/value.
Resource Adequacy (Capacity Savings)	MWs of resource and load diversity enabled via transmission upgrade multiplied by the value of avoided capacity.
Extreme Event Mitigation	Use historical weather and grid condition data to simulate short-term operational conditions with and without project to determine change in load payments & potentially benefit of avoiding cost of unserved load (loss-of-load = $40,000/MWh).
Avoided Transmission Benefit	Cost of transmission upgrades that would be required to maintain system reliability and serve 20-year loads if the Connected West Transmission Portfolio is not built.
Reduced Transmission Losses	Generation Capacity avoided because of decrease in transmission losses as a result of the transmission upgrades.

Appendix – Deliverability Analysis Methodology

Identifying Transmission Needs

- **Reference Case model results were used to identify the location and magnitude of 20-year transmission needs**
  - Initial screening exercise used to inform subsequent reliability assessments
- **Key metrics compared to identify transmission needs included:**
  - Locational **Marginal Prices (LMPs)** – locational (nodal) price changes due to transmission congestion
  - Renewable **Energy Curtailment** – renewable energy unable to be delivered to load due to transmission limitations
  - Transmission **Line & WECC Path Congestion** – specific lines & paths that become congested due to flow distribution in an AC grid network
- **Results from 2045 Reference case production cost model compared to a copper sheet model**
  - Copper sheet model retains reference case generation and network topology, but none of transmission limits (line and interface ratings) are enforced. This provides a view of operation with a “perfect” grid
  - By comparing curtailment in copper sheet with the transmission-constrained Reference Case, we calculated “addressable curtailment” for each node
  - Helps us prioritize delivery of resource that have value to system, versus those that are curtailed regardless of transmission expansion

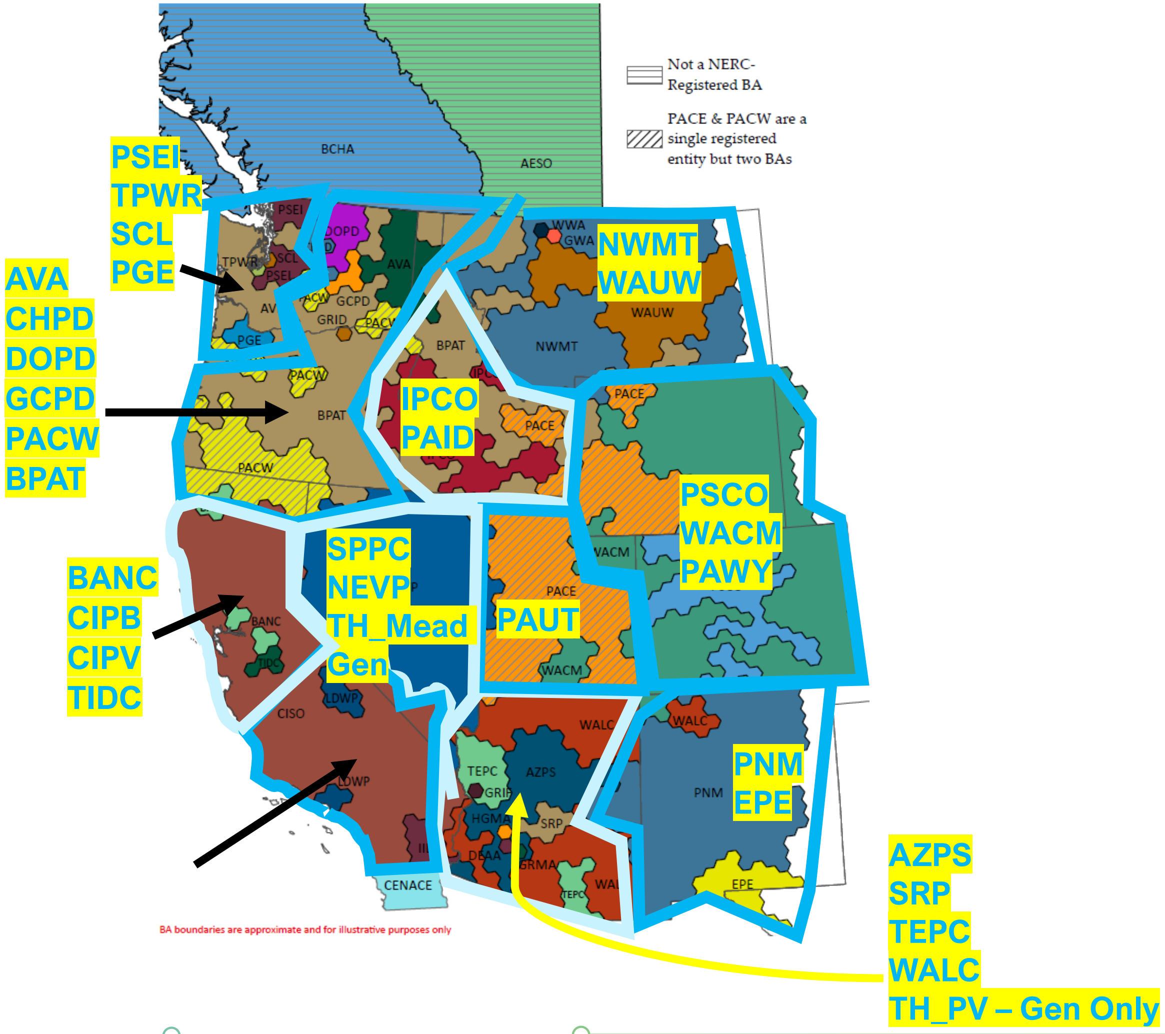
Connected West Reference Case “Addressable Curtailment”



Power Flow Deliverability Methodology

- **Power flow deliverability analysis is used to identify reliability impacts Power of Place assumptions and develop network upgrades to mitigate them**
  - 20-year power flow model developed based on 2045 Connected West Reference Case
- **Given inter-regional focus of Connected West, WECC system is divided into 11 sub-zones based on how key metrics from PCM reference case vary across the interconnection**
  - Individual deliverability case developed for each sub-zone
  - Certain zones, like Wyoming, were export-centric regions and we understood this would likely be the largest driver of transmission for this sub-zone
  - Other zones, like the Pacific NW Coastal Loads, were import sub-zones
  - Sub-zones such as Idaho have significant exports as well as imports at different times of the year. These pass-through sub-zones were analyzed individually and grouped with nearby export or import-centric zones.
- **Each of these pockets was studied individually to ensure the local system and ties are sufficient to transfer power from resource zones to load areas during stressed system conditions**
  - Dispatch mirrors off peak conditions
  - Performed N-0 and N-1 DC Contingency analysis to identify inter-zone and major intra-zone transmission limitations

Deliverability Analysis Sub-Zones

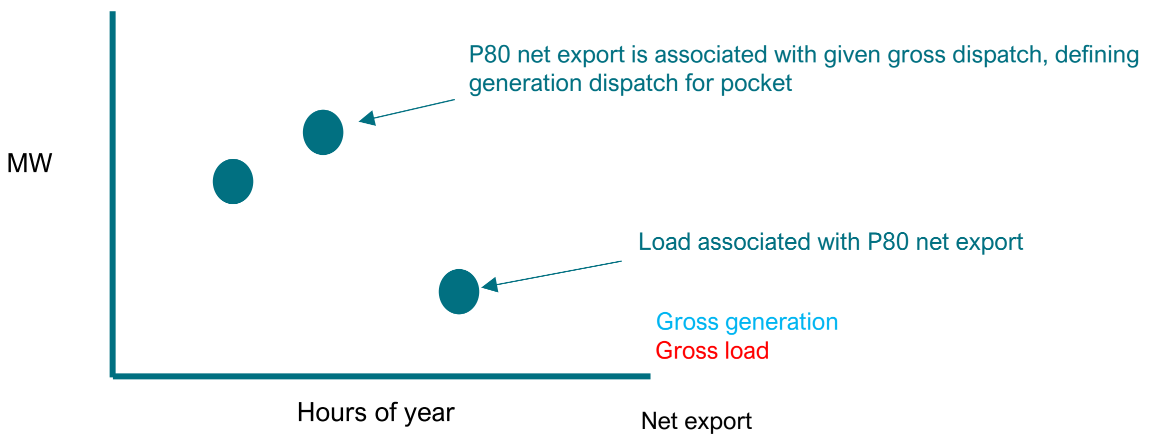


BA boundaries are approximate and for illustrative purposes only

Detailed Deliverability Study Assumptions

- **Dispatch conditions were informed by a review of hourly data from the 2045 Connected West Copper Sheet Case.**
- **Identified average dispatch conditions that represented a P80 exceedance net export (or import) condition for the given study sub-zone.**
- **P80 was selected because addressing 100% of the deliverability challenges would not be economic and remaining congestion would be identified in the PCM.**
- **Determination of dispatch values is critical study assumption subject to debate and variance at RTOs/ISOs.**

Zone #1: Hourly Data from PCM (Sorted)



Develop Transmission Expansion Plan

- **Developed solutions to resolve issues within and associated with exports/imports of the zone under study**
  - Voltage collapse and base case divergence when significant generation is added in certain pockets of a study zone.
  - Thermal overloads on monitored lines, WECC paths or tie lines between study zones under system intact or contingency conditions.
- **Transmission solutions selected based on following criteria:**
  - A new line, either co-located on existing ROW or a greenfield project, is considered from high generation pockets to prevent base case divergence.
  - New lines are also considered when overloads on a line exceed a threshold of 2400 amps for 345 kV and 500 kV lines or 1600 amps for 230 kV lines.
  - Lines are assumed to be reconductored with a higher capacity conductor if thermal overloads are less than the new line threshold.
  - Overloads on series capacitors are assumed to be mitigated by replacing existing with higher capacity ones.
  - Transformer overloads are mitigated by adding an additional one at the same location.

Test Expansion in PCM

- **Network Upgrades implemented in the 2045 Connected West Reference Case PCM**
  - Unmonitor WECC Paths since the transmission expansion recommended makes path limitations redundant
  - Phase shifter are also disabled for the same reason
- **Results of PCM is used to refine transmission network upgrades as follows:**
  - Review transmission congestion and curtailment of renewable generation to refine ratings of previously identified network upgrades.
    - This is particularly important for pass through zones, such as Idaho, when there is high generation in two or more neighboring export zones.

Portfolio	Copper Sheet	Reference	AC Greenfield	DC Greenfield	Advanced Conductor
US Clean Energy Penetration	96.24%	92.00%	94.40%	94.16%	94.40%

WestTEC
POWERED BY WPP

Western Transmission Expansion Coalition "WestTEC“

Jennifer Galaway, Senior Manager, Transmission Strategy & Regulation – Portland General Electric

NWPPC Annual Meeting, November 14, 2024

Agenda Overview

- Purpose of WestTEC
- WestTEC Structure
- Transmission Study Goals & Framework
- WestTEC Timeline

What is the Western Transmission Expansion Coalition?

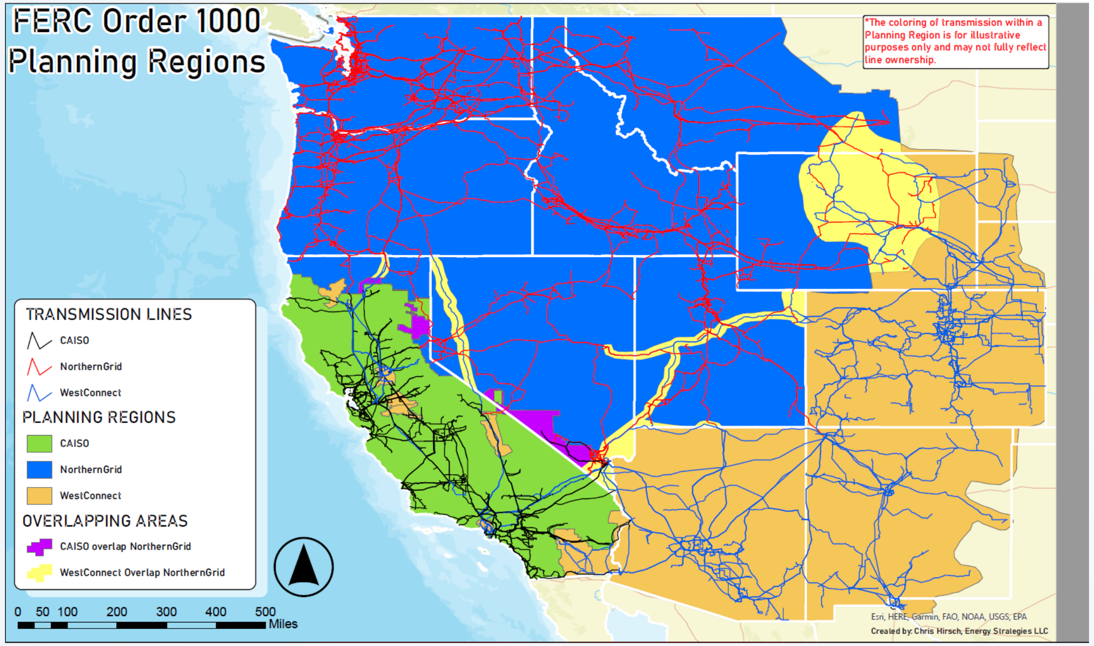
- ***“WestTEC”***
- ***Not a FERC process***
- ***West-wide 20-year transmission study (10-year look)***
- ***Industry-led with unprecedented stakeholder inclusion***
- ***Goal is to produce an actionable transmission study***

Schematics are approximate & used for illustrative purposes only.

WestTEC
POWERED BY WPP

Regional Transmission Planning in the West

Growing Recognition more Transmission is Needed



*The coloring of transmission within a Planning Region is for illustrative purposes only and may not fully reflect line ownership.

Esri, HERE, Garmin, FAO, NOAA, USGS, EPA

Created by: Chris Hirsch, Energy Strategies LLC

Current Approach to Planning *Insufficient*

- No Regional Transmission Projects have been built
- Forward looking planning limited
- Interregional Planning has been virtually nonexistent

WestTEC is a Response

WestTEC Themes

Different

Inclusive

Expedient

Transparent

WestTEC Committees

Steering Committee

Main Responsibilities:

1. Resolving and making major decisions to structure the transmission study
2. Actively collaborating with and seeking feedback from WATT, REC and public participants

WestTEC Assessment Technical Team (WATT)

- Technical committee charged with development of the Study Plan and transmission study
- Connection between Independent Consultant and all WestTEC groups

Regional Engagement Committee (REC)

- Primary regional partner committee, comprised of a broad cross section of sectors
- Provide substantive feedback on study plan and transmission study throughout the project

Additional Subcommittees

Communication and Regional Partner Engagement

- Partner with REC on public engagement communication to ensure consistent collaboration and joint ownership of managing public webinars and feedback.

Data Strike Team

- Representatives from all WestTEC committees to produce a data source and data management plan for the WestTEC Project

Scenarios Sub-team

- Identify process and develop drivers and future conditions to create alternative scenarios for transmission study plan

What are the study’s goals?

» The primary goal is to produce an **actionable transmission study** that is useful to planners, developers, regulators and the study’s regional partners

Study Goals

Develop Actionable Portfolios: Create transmission portfolios addressing 10-year and 20-year needs, useful for planners, developers, and regulators.

Ensure Reliability: Meet NERC compliance, provide operational flexibility, and identify necessary transmission capacity for reliable operations.

Improve Efficiency: Reduce congestion and meet future energy needs, considering planning reserve margins for reliability.

Increase Affordability: Enable investment savings through coordinated transmission portfolios and better infrastructure utilization.

Enhance Visibility and Coordination: Provide a clear view of combined capabilities and requirements to support informed planning and solutions.

Support Cost Allocation: Offer regional-level information to assist in cost allocation discussions for future projects.

Ensure Fairness: Develop an unbiased plan that aligns with regulations and benefits all resource types and stakeholders.

What will make this study actionable?

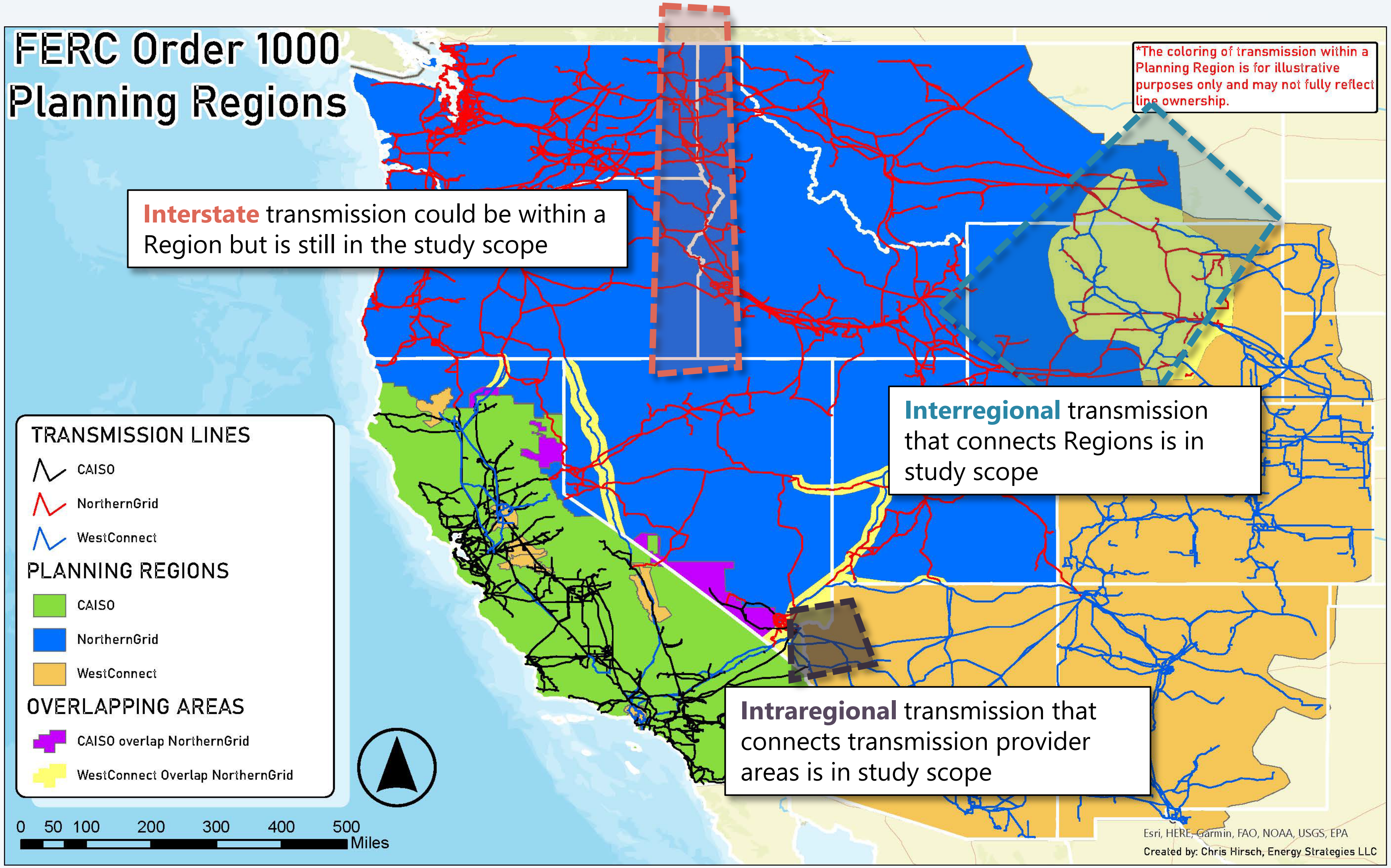
How will it be used…

- **Inform Planning:** Serve as inputs for local and regional planning, enabling coordinated transmission solutions.
- **Facilitate Development:** Support transmission developers and utilities in initiating and refining projects.
- **Engage Stakeholders:** Promote engagement with communities, tribal nations, and regulators.
- **Evaluate Benefits:** Provide data for assessing benefits and their distribution.
- **Guide Decisions:** Offer context for planning and investment decisions.
- **Optimize Siting:** Help identify optimal transmission paths for resource siting.
- **Support Regulation:** Assist regulators in evaluating utility transmission projects for approval and cost recovery.

What it will include…

- Assessment based on **credible and transparent methodologies**, reflecting regional partners' input.
- **Detailed descriptions** of required infrastructure, including locations, technologies, and upgrades.
- Clearly articulated **drivers and dependencies** justifying each transmission solution or portfolio.
- Comprehensive **cost estimates** and qualitative and quantitative assessments of **benefits** for the broader Western region.
- **Preliminary routing options** to support permitting, siting, and construction feasibility studies.
- **Transmission alternative review**, highlighting trade-offs and reasons for selecting preferred options.

What transmission will the study address?



*The coloring of transmission within a Planning Region is for illustrative purposes only and may not fully reflect line ownership.

Interstate transmission could be within a Region but is still in the study scope

Interregional transmission that connects Regions is in study scope

Intraregional transmission that connects transmission provider areas is in study scope

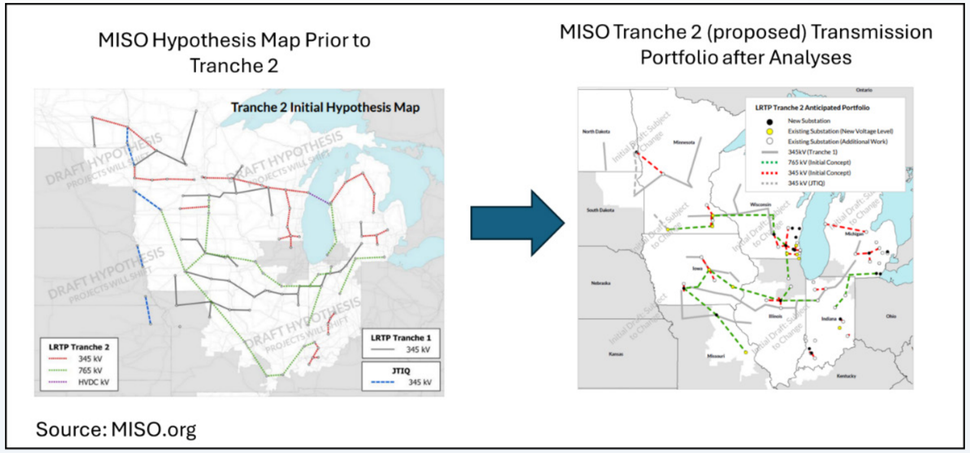
Source: WestConnect

Map highlights transmission associated with each Order 1000 Planning Region ("**Region**" in the Study Plan)

How will the study identify transmission portfolios?

- WATT has developed a complex 10-step study methodology encompassing:
    - Capacity expansion modeling
    - Busbar mapping of generation
    - Development of a “hypothesis map”
    - Powerflow and congestion assessments
    - Transmission solutioning
- The technical goal is to develop a transmission portfolio that **reliably** and **efficiently** moves power from where it is generated to where it is consumed
- Transmission portfolios will be developed for the Reference Case as well as Planning Scenarios (see next slide)

MISO Hypothesis Map Example



MISO Hypothesis Map Prior to Tranche 2

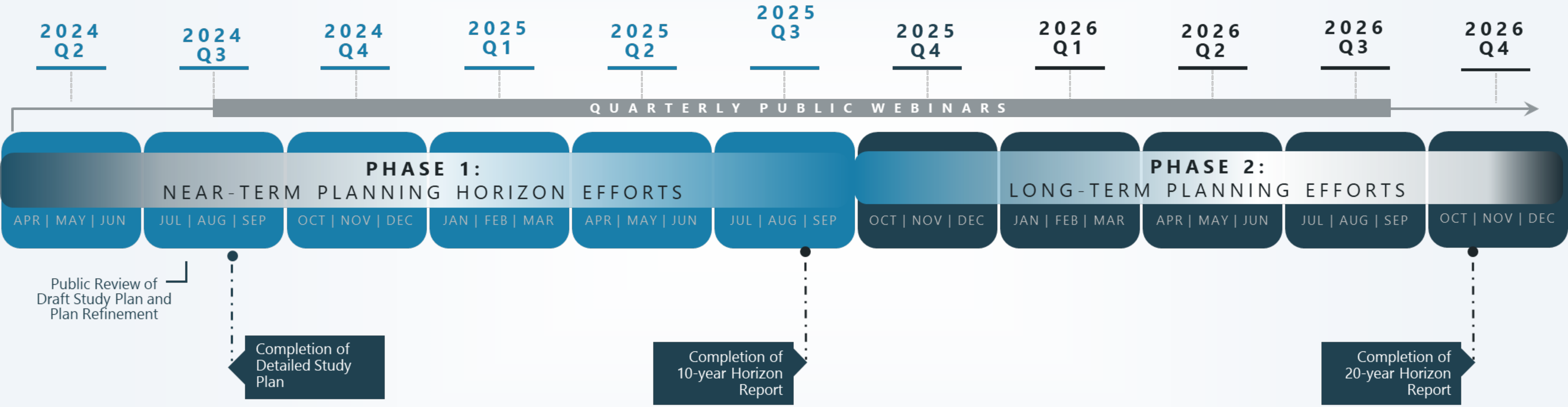
MISO Tranche 2 (proposed) Transmission Portfolio after Analyses

Source: MISO.org

What benefits, scenarios, and sensitivities will be considered?

- **Benefit assessment** will consider seven unique benefit categories, quantified for each transmission portfolio
  - **Operational efficiency, capacity savings, improved resource adequacy, resiliency benefits, increased resource access, avoided emissions, avoided/deferred reliability upgrades**
- **Planning Scenarios** will be used to help address planning uncertainties, providing a platform to assess how different futures could affect grid reliability and the need for transmission expansion
  - **Regional partners will be engaged in scenario development via facilitated workshops to help identify key drivers impacting energy landscape**
  - **Scenarios will enable a synthesis of transmission needs across varying futures**
- **Extreme event scenarios** will be constructed to test the performance of transmission portfolios under extreme weather events
- **Powerflow assessment sensitivities** will explore how transmission portfolios respond to alternative dispatch and load conditions (e.g., winter cold, calm, and dark event)

WestTEC Project Timeline



2024 Q2 — APR | MAY | JUN

2024 Q3 — JUL | AUG | SEP

2024 Q4 — OCT | NOV | DEC

2025 Q1 — JAN | FEB | MAR

2025 Q2 — APR | MAY | JUN

2025 Q3 — JUL | AUG | SEP

2025 Q4 — OCT | NOV | DEC

2026 Q1 — JAN | FEB | MAR

2026 Q2 — APR | MAY | JUN

2026 Q3 — JUL | AUG | SEP

2026 Q4 — OCT | NOV | DEC

QUARTERLY PUBLIC WEBINARS

PHASE 1:
NEAR-TERM PLANNING HORIZON EFFORTS

PHASE 2:
LONG-TERM PLANNING EFFORTS

Public Review of Draft Study Plan and Plan Refinement

Completion of Detailed Study Plan

Completion of 10-year Horizon Report

Completion of 20-year Horizon Report

About PGE

Quick facts

- We serve approximately 930,000 customers in 51 incorporated cities across Oregon.
- We have approximately 2,840 employees.
- Continued position as number 1 ranked renewable power program in the U.S. for 14 years according to the National Renewable Energy Laboratory (2023).(1)
- PGE was recognized in 2023 by the Bloomberg Gender-Equality Index for the company's commitment to creating a more equal, inclusive workplace.
- In 2023, PGE employees, retirees and the PGE Foundation donated nearly $4.6 million and volunteered over 23,000 volunteer hours to more than 400 nonprofit organizations.

Leading the way to a clean energy future for Oregon

- Our goals align with the 100% clean energy by 2040 framework. The targets to reduce baseline greenhouse gas emissions from power served to Oregon retail customers are:
    - 80% reduction in greenhouse gas emissions by 2030
    - 90% reduction in greenhouse gas emissions by 2035
    - 100% reduction in greenhouse gas emissions by 2040

3,500+ MWs of Generation

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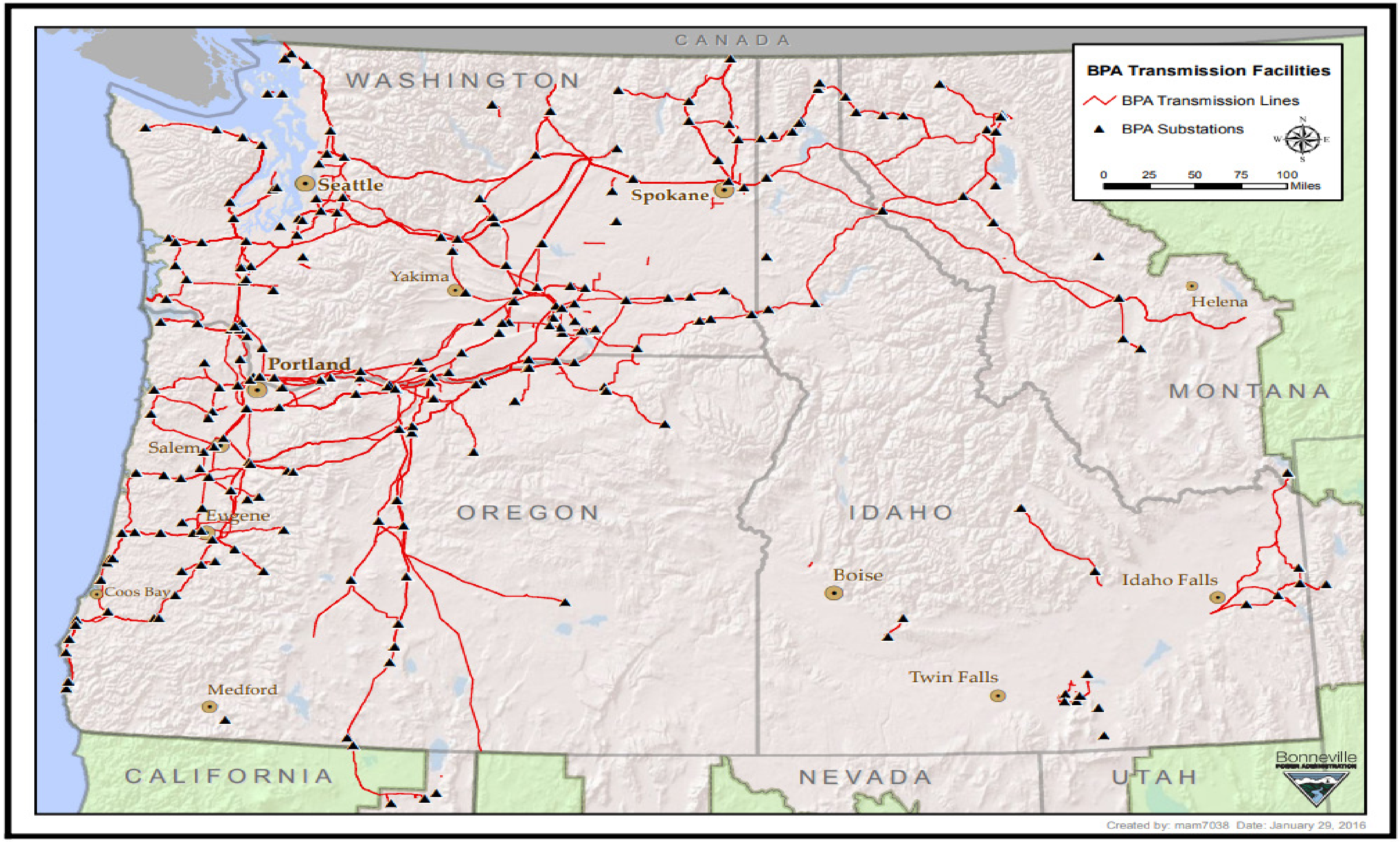
(1) NREL did not release rankings in 2011

Evolving Grid Project Portfolio Update

Northwest Power and Conservation Council

November 14, 2024

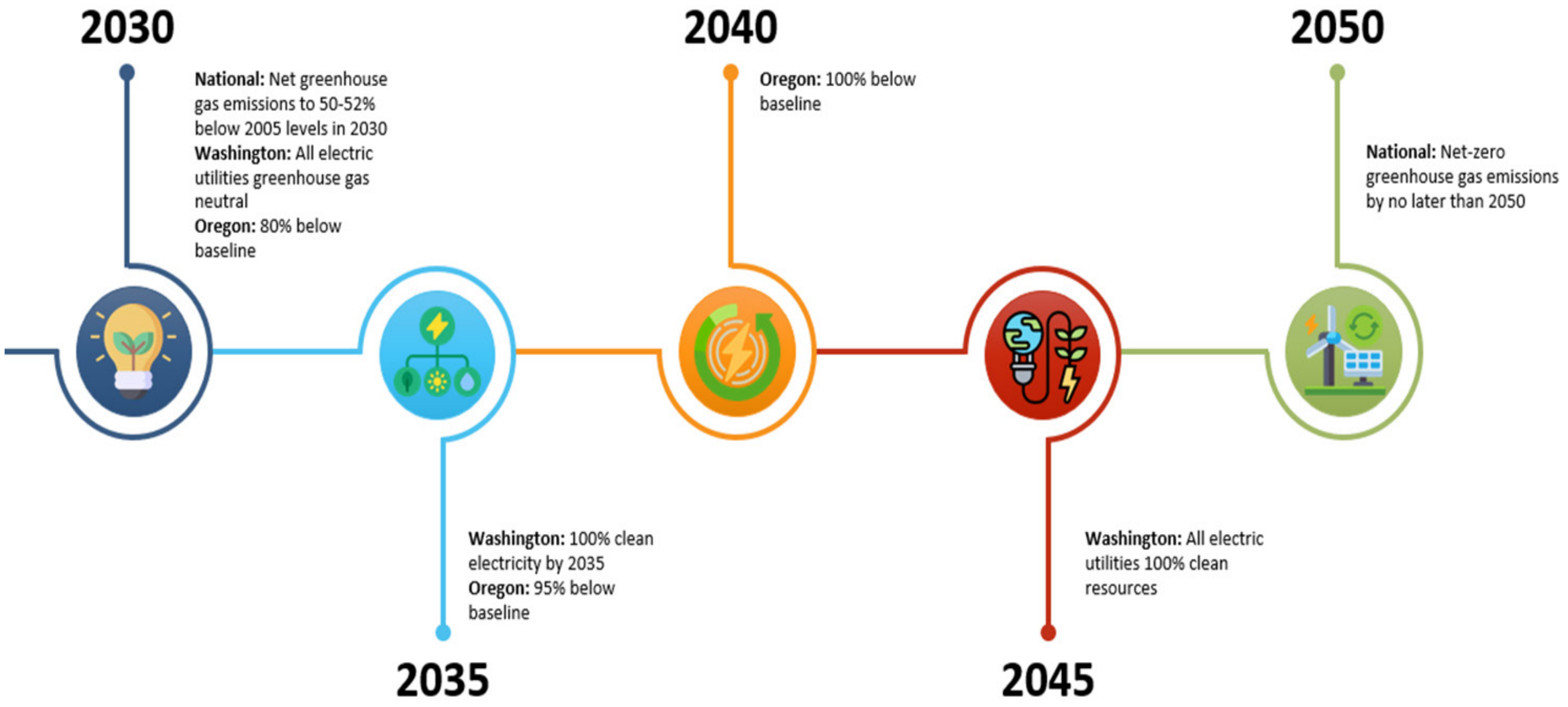
BPA Infrastructure



Created by: mam7038 Date: January 29, 2016

Overview

- EGP 1.0 is supporting the region’s 2030 goals
- EGP 2.0 is supporting the region’s 2030+ goals



2030

National: Net greenhouse gas emissions to 50-52% below 2005 levels in 2030
Washington: All electric utilities greenhouse gas neutral
Oregon: 80% below baseline

2035

Washington: 100% clean electricity by 2035
Oregon: 95% below baseline

2040

Oregon: 100% below baseline

2045

Washington: All electric utilities 100% clean resources

2050

National: Net-zero greenhouse gas emissions by no later than 2050

The Objective of BPA’s Evolving Grid Initiative

A variety of factors are creating a need for a transformational shift in the Transmission industry. Bonneville Transmission wants to raise awareness of recent efforts and initiatives, those underway and yet to come, and what customers and the region can expect in the future as we navigate the changing landscape.

Evolving Grid Projects Background

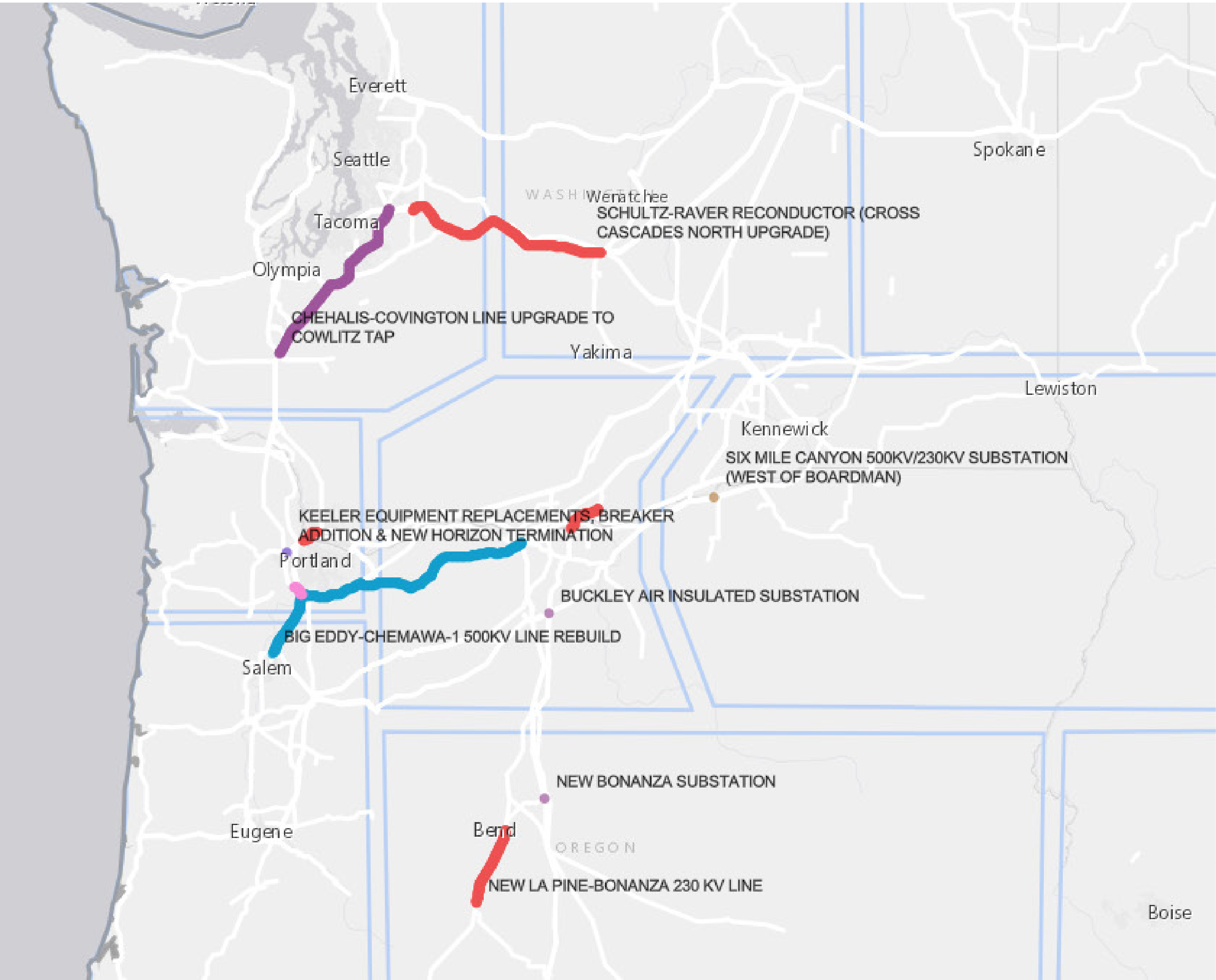
- Progressive de-carbonization policies in the states of Washington and Oregon, accelerated need for carbon-free resources, load growth accelerating due to high-tech industries, and operational challenges due to extreme temperatures are creating a rapidly evolving Northwest landscape.
- Last year, BPA brought forward a set of capital projects called the 'Evolving Grid Projects" to respond to this increasing demand of BPA for forward looking Transmission projects. With the next set of projects, BPA is continuing to pull commitment decisions forward in time to provide more certainty to the region regarding critical projects.
- Evolving Grid Projects are just one aspect of the larger BPA's Transmission Plan to meet the needs of our customers by investing in our infrastructure and enabling economic growth in the region.

Evolving Grid Portfolio Review

- BPA has now developed two distinct portfolios of projects
    - 10 projects currently underway make up the EGP 1.0 portfolio
    - 13 projects in the initiation phase make up the EGP 2.0 portfolio

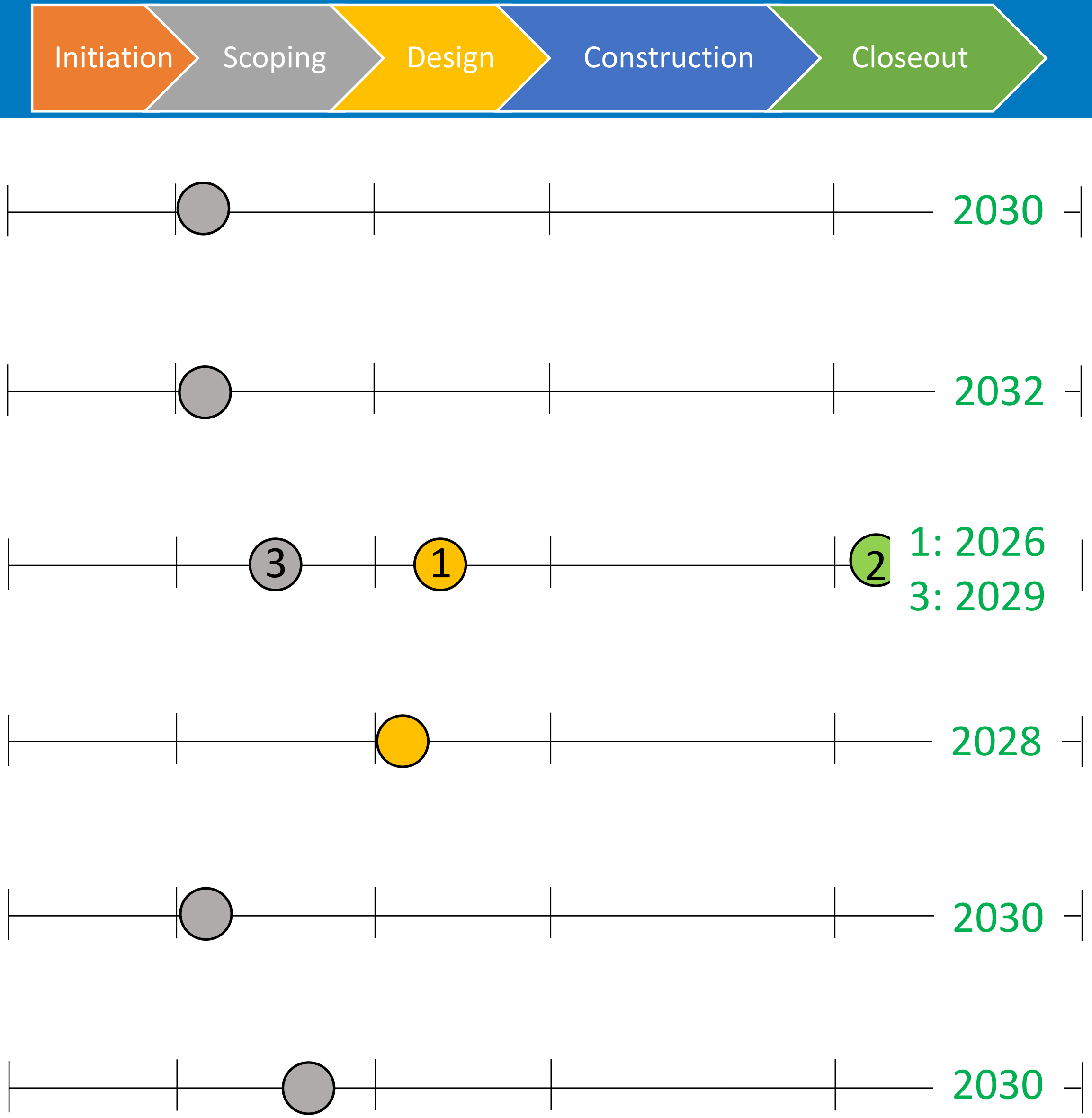
BONNEVILLE POWER ADMINISTRATION

Evolving Grid 1.0 Projects



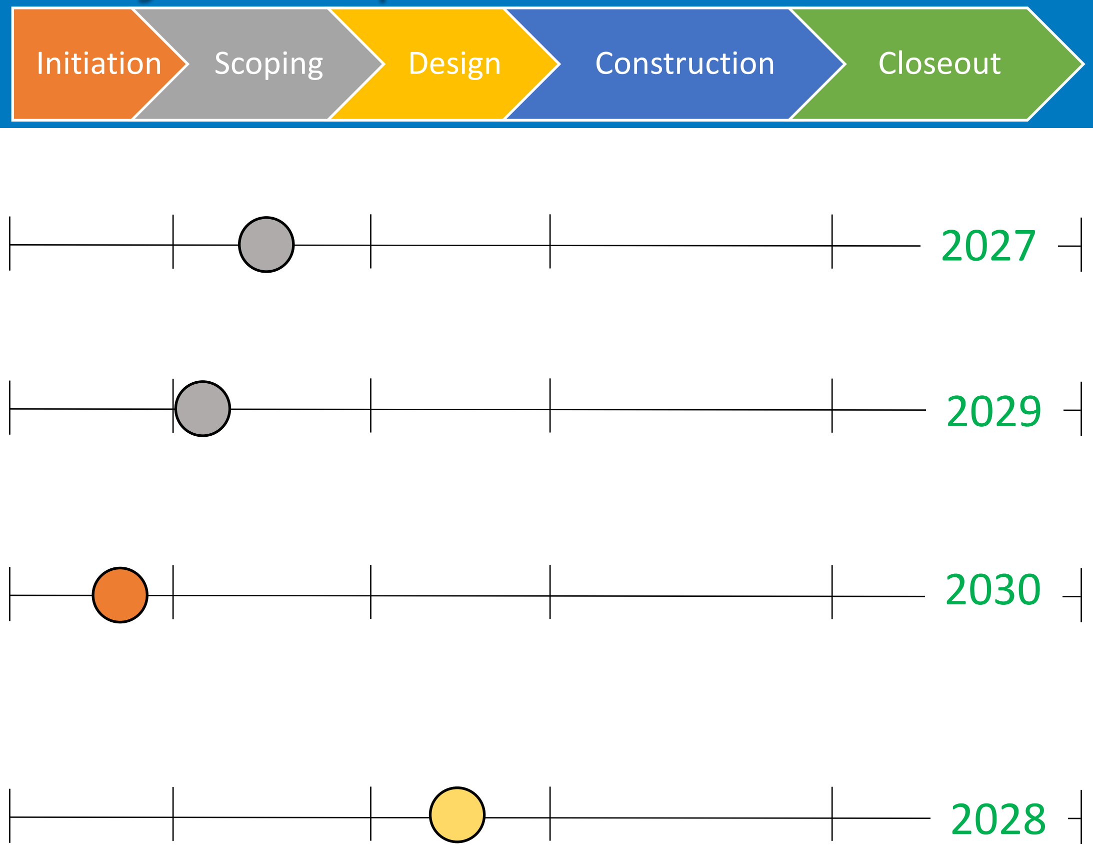
#	Project Name	Expected Energization	Estimated Costs
1	SCHULTZ-RAVER SERIES CAPS	2030	$50,000,000.
2	BIG EDDY-CHEMAWA-1 500KV LINE REBUILD	2032	$670,000,000.
3	PORTLAND AREA: MULTIPLE PROJECTS		
	PEARL-SHERWOOD-MCLOUGHLIN UPGRADE	2026	$10,000,000.
	KEELER EQUIPMENT REPLACEMENTS, BREAKER ADDITION & NEW HORIZON TERMINATION	2028	$12,000,000.
	KEELER 500KV EXPANSION AND TRANSFORMER ADDITION	2029	$36,000,000.
4	CHEHALIS-COVINGTON LINE UPGRADE TO COWLITZ TAP	2028	$95,000,000.
5	ROSS-RIVERGATE-1 230KV LINE UPGRADE	2030	$50,000,000.
6	ROCK CREEK-JOHN DAY 500KV LINE UPGRADE	2030	$37,000,000.
7	SIX MILE CANYON 500KV/230KV SUBSTATION (WEST OF BOARDMAN)	2027	$250,000,000.
8	NEW BONANZA SUBSTATION	2029	$300,000,000.
9	NEW LA PINE-BONANZA 230 KV LINE	2030	$150,000,000.
10	BUCKLEY AIR INSULATED SUBSTATION	2028	$150,000,000.
	PROJECT INFORMATON AS OF NOVEMBER 2024		

EGP 1.0 Project Update



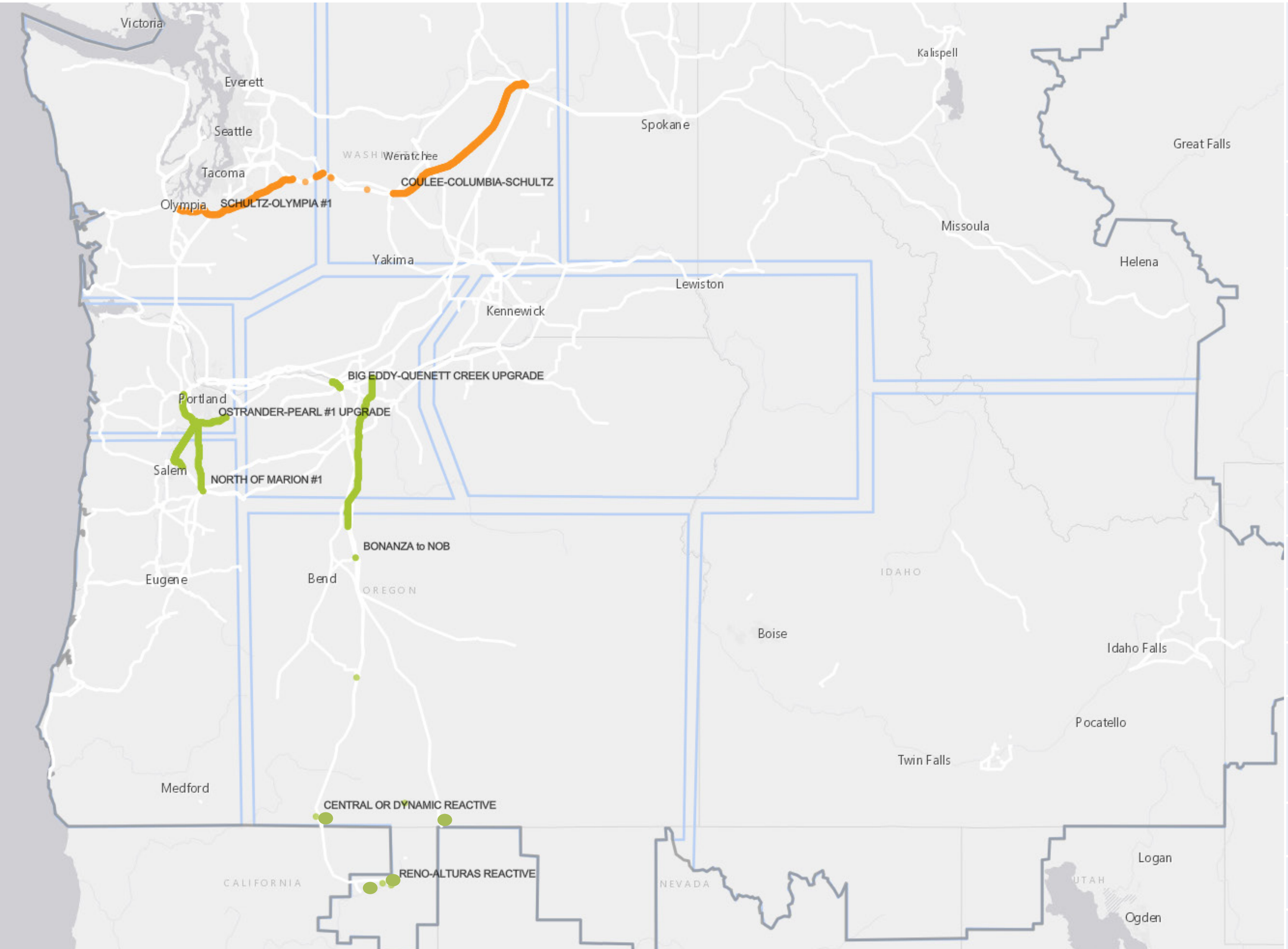
Project		Next Milestone
Cross-Cascades North: Schultz – Raver #3 & #4	2030	Project is moving into Scoping with the OC later this summer. ISD 2030
Cross-Cascades South: Big Eddy – Chemawa Rebuild	2032	Project will be starting Scoping with the OC later this summer. ISD 2032
Portland Area: Multiple projects	1: 2026 3: 2029	1. Pearl-Sherwood-Mcloughlin: Project is in Design with an estimated energization in early 2026. 2. Keeler-Horizon#2: Energized. 3. Keeler Transformer Addition: Project is in Scoping.
Raver-Paul: 230 kV Line Upgrade	2028	Project has finished Scoping and will be starting Design later this summer. ISD 2028
Ross - Rivergate 230 kV Line Upgrade	2030	Project will be starting Scoping with the OC later this summer. ISD 2030
Rock Creek – John Day 500 kV Line Upgrade	2030	Project will be completing Scoping with the OC later this summer. ISD 2030

EGP 1.0 Project Update



Project	Next Milestone
SixMile 500/230kV Sub	Project is in Scoping. A feasible site has been selected. Longest Lead Material have been placed on order. Estimated energization in late 2027.
Bonanza 500/230 kV Sub	Project will be starting Scoping with the OC later this summer. ISD 2029
La Pine – Bonanza 230 kV Line	Plan of Service is in development. ISD 2030
Buckley Sub Rebuild	Project is in Design. Estimated energization is 2028.

Evolving Grid 2.0 Projects



#	Project Name	Expected Energization	Estimated Costs
1	SCHULTZ-OLYMPIA #1	2035	$853,000,000.
2	COULEE-COLUMBIA-SCHULTZ	2035	$324,000,000.
3	NORTH OF PEARL	TBD	$127,000,000.
4	OSTRANDER-PEARL #1 UPGRADE	TBD	$44,000,000.
5	NORTH OF MARION #2	TBD	$105,000,000.
6	BONANZA to NOB	TBD	$800,000,000.
7	RENO-ALTURAS REACTIVE	TBD	$80,000,000.
8	NORTH OF MARION #1	TBD	$196,000,000.
9	NORTH OF GRIZZLY	TBD	$245,000,000.
10	CENTRAL OR DYNAMIC REACTIVE	TBD	$169,000,000.
11	NEVADA-OREGON BORDER SUBSTATION LAND ACQUISITION	TBD	$3,000,000.
12	BIG EDDY-QUENETT CREEK UPGRADE	TBD	$6,000,000.
13	BIG EDDY-THE DALLES #1 REBUILD	TBD	Included in #12
	PROJECT INFORMATION AS OF NOVEMBER 2024		

EGP 2.0 Project Update

- All EGP 2.0 project details are promising but preliminary at this point; scoping, analysis, and collaboration will occur before full project design and construction funding approval.
- Acquisition of long-lead items for EGP 2.0 projects is not forecasted until 2026.
- Currently, approvals for EGP 2.0 projects is for scoping only, full business case approval using preliminary engineering and scoping findings is estimated in FY26.
- Environmental analysis required before BPA can construct.

Helpful BPA Links

BPA Transmission Plan: https://www.bpa.gov/-/media/Aep/transmission/attachment-k/2022-bpa-transmission-plan.pdf

Transmission Availability : https://www.bpa.gov/energy-and-services/transmission/transmission-availability

Becoming a BPA Customer: https://www.bpa.gov/energy-and-services/transmission/becoming-a-transmission-services-customer

- *For assistance in the BPA application process, call BPA Transmission Sales (360) 619-6016 and request the assignment of a BPA Transmission Services Account Executive.*

Interconnection: https://www.bpa.gov/energy-and-services/transmission/interconnection

Transmission Service Request Study: https://www.bpa.gov/energy-and-services/transmission/acquiring-transmission/tsep

Questions

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Bonneville
POWER ADMINISTRATION