

Connected West

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

Briefing Presentation

September 2024

Prepared for:



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.

Technical Review Committee

Ben Fitch-Fleishmann, Interwest Energy Alliance
 Biju Gopi, California Independent System Operator
 Branden Sudduth, Western Electricity Coordinating Council
 Chelsea Loomis, NorthernGrid
 Christina Hayes, Americans for a Clean Energy Grid
 Dave Angell, Independent Consultant
 Diane Brandt, Renewable Northwest
 Edward Smeloff, Consultant for Center for Energy Efficiency & Renewable Technologies
 Erik Aaboe, New Mexico Renewable Energy Transmission Authority
 Fred Heutte, Northwest Energy Coalition
 Heidi Pacini, WestConnect
 James Okullo, Energy Systems Integration Group
 Maury Galbraith, CO Electric Transmission Authority
 Nicole Hill, The Nature Conservancy
 Thomas Carr, Western Interstate Energy Board
 Tyler Farrell, Rocky Mountain Institute
 Vijay Satyal, Western Resource Advocates

Client Team

This work was commissioned by Gridworks and Gridlab.

Matthew Tisdale, Gridworks
 Cathy Boies, Gridworks
 Casey Baker, GridLab
 Ric O’Connell, GridLab

Authors

John Muhs, Sr. Consultant
 Kavita Sheno, Sr. Consulting Engineer
 Tyler Butikofer, Sr. Consulting Engineer
 Chris Hirsch, GIS Analyst
 Colby Johnson, Consulting Engineer
 Keegan Moyer, Principal
 Emily Leslie, Principal (Montara Mountain Energy)

Additional Support

Benjamin Preneta, Evolved Energy Research
 Ryan Jones, Evolved Energy Research
 Nels C. Johnson, The Nature Conservancy
 Deborah Shields, Gridworks
 Matt Jones, Gridworks

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

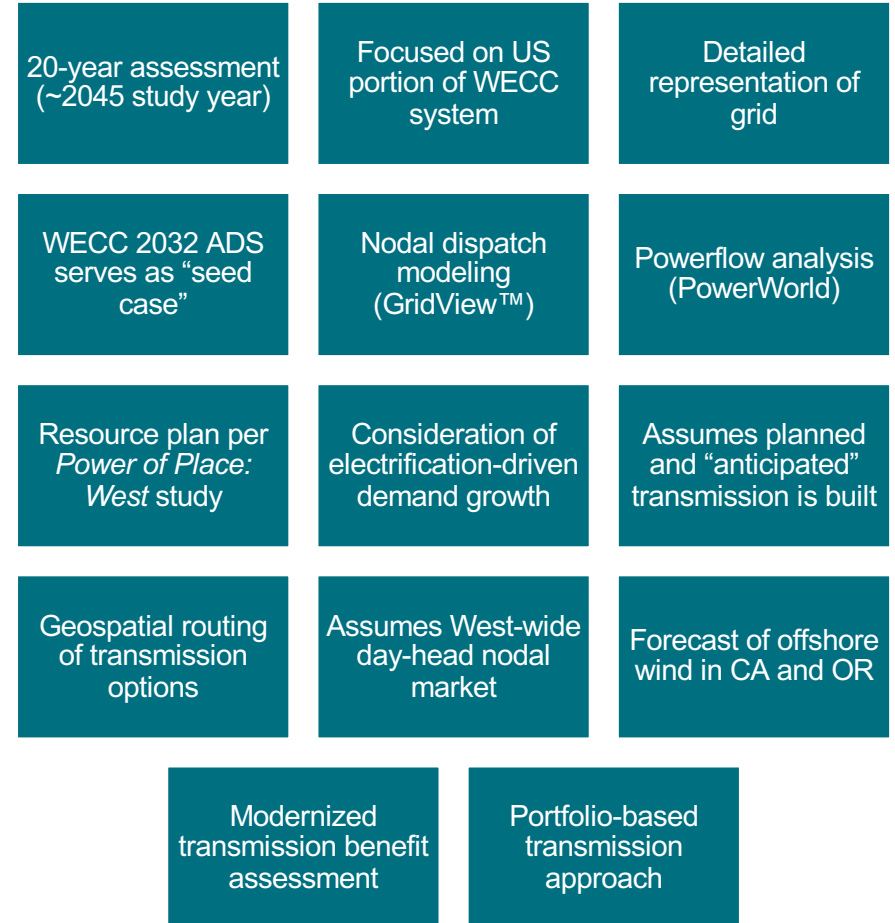
- 1. Motivation and Purpose**
- 2. Study Methodology & Assumptions**
- 3. Key Findings**
- 4. Other Results & Findings**
- 5. Appendices**
 - Additional Results from 2045 Connected West Reference Case
 - Deliverability Analysis Methodology
 - Transmission Project Lists

Motivation and Purpose of Connected West

Connected West Study: Motivation and Need

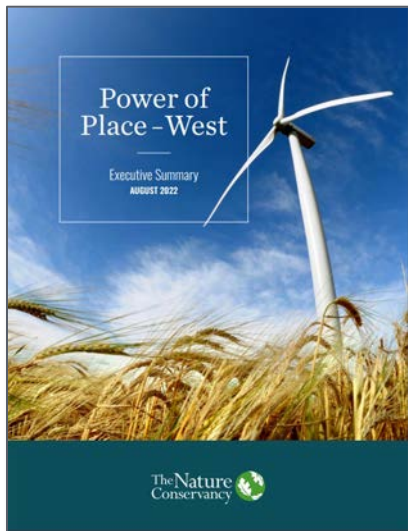
- In response to regional transmission planning gaps, fragmented transmission expansion, a lack of interregional project proposals, as well as federal initiatives identifying new transmission corridors, the Connected West study explores “next generation” transmission investments for the West
- The study 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

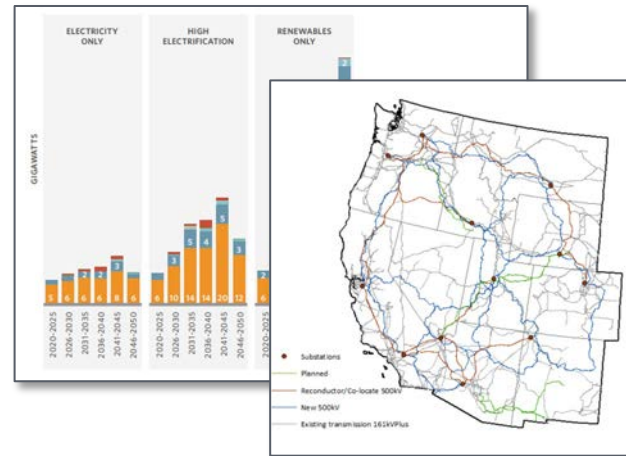


Connected West Study: Building from *Power of Place: West*

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



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



Connected West is transmission focused 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

- 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.

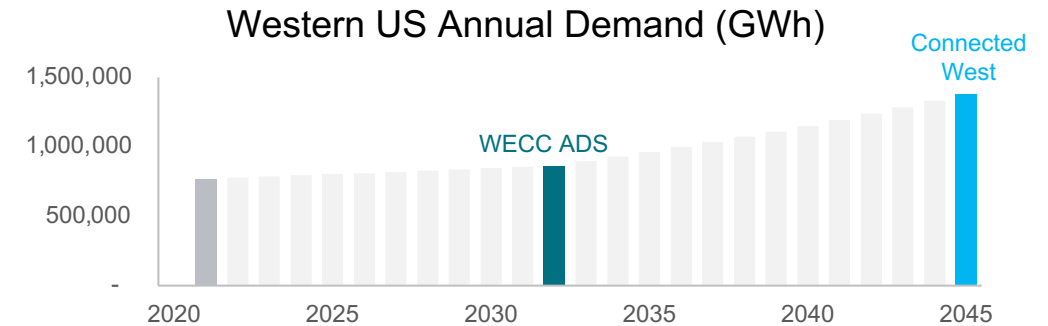
- Connected West Study builds on *Power of Place*.
- Specifically, the “High Electrification” scenario results relating to load forecasts, resource buildouts, and transmission expansions informed this study.
- In addition, extensive databases on land use and sensitivities informed the transmission routing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

- Connected West 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.

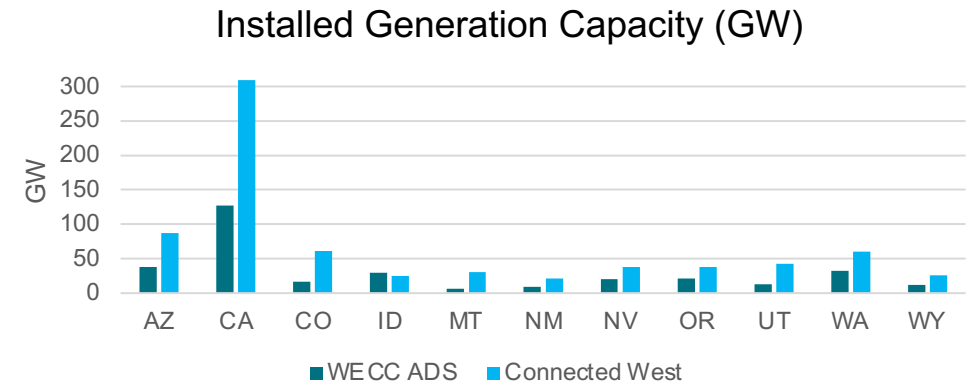
Connected West Overview

- **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



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



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?

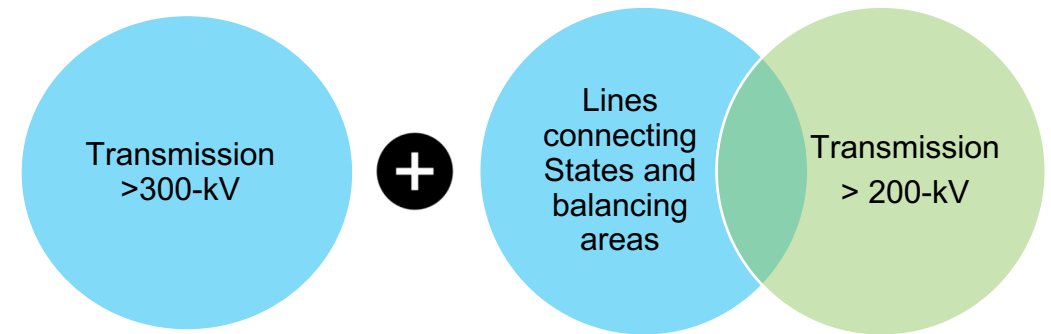


- The study uses transmission planning analyses, including powerflow studies and congestion assessments, performed on a 2045 “Reference Case” to help answer these questions.
- Geospatial analyses and assessments of the value proposition of each transmission portfolios further support the study’s efforts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



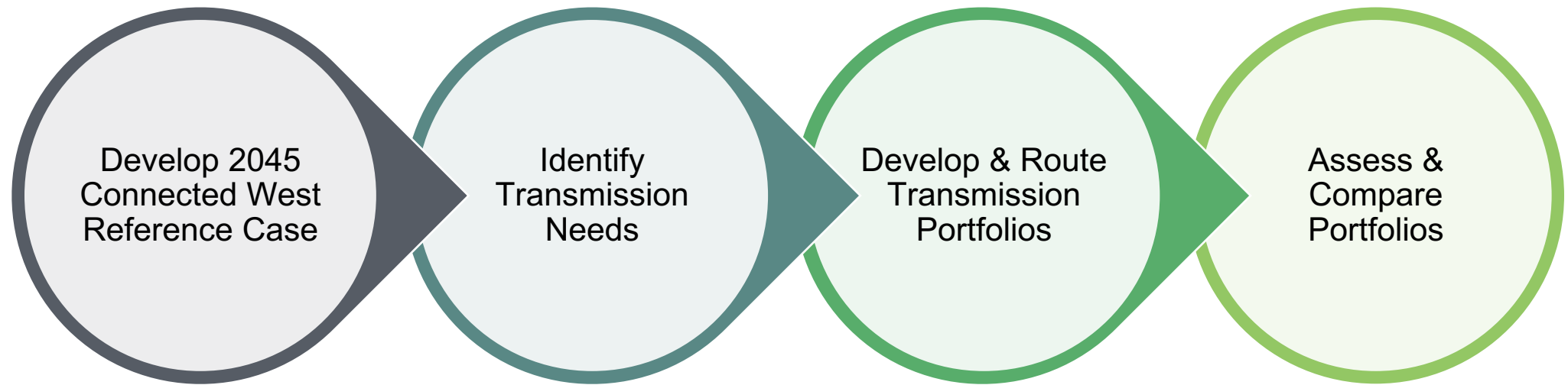
In addition to the upgrades above, some “regionally significant” lines were included in the scope

Transmission Planning Needs Not Captured

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

Study Methods & Key Assumptions

Study Process



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

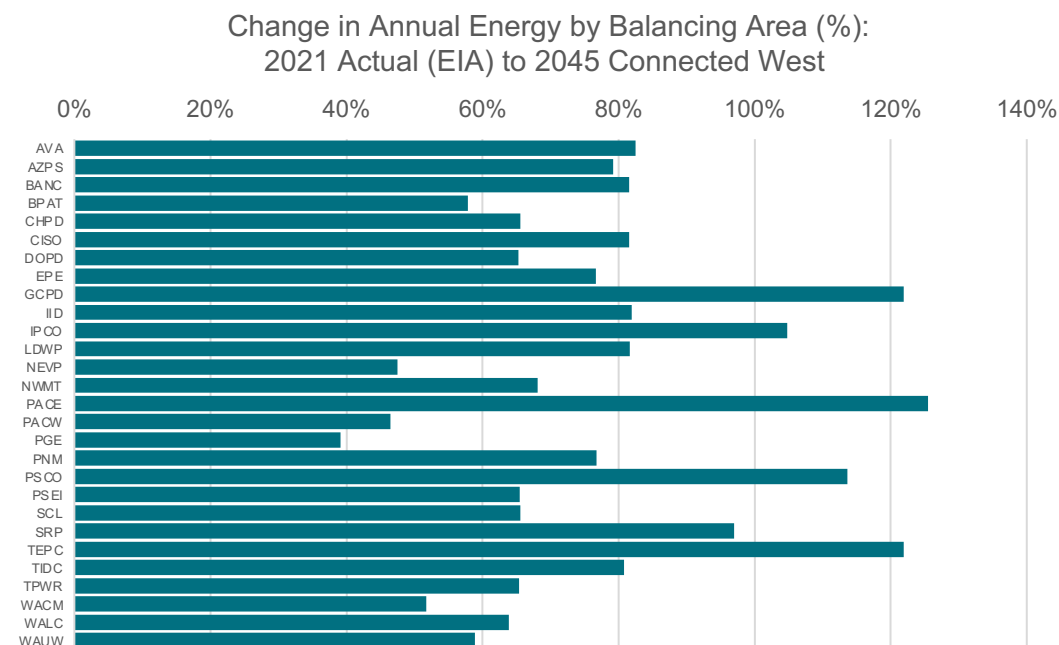
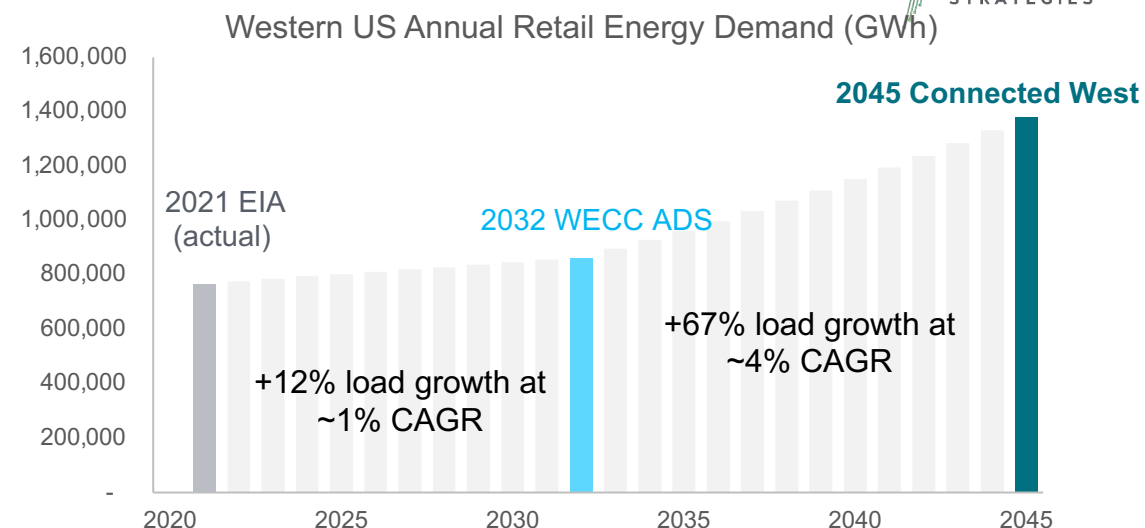
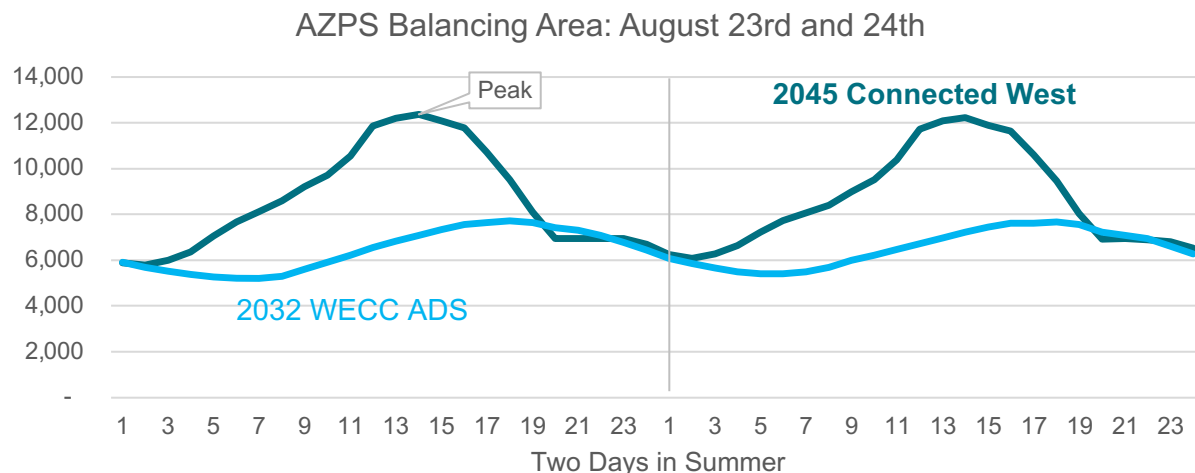
- The 2045 Connected West Reference Case serves as the study's basis for identifying transmission need under this scenario-driven assessment
- The Reference Case features a resource mix that is both deeply decarbonized and sufficient to power a heavily electrified economy
 - 95% of western US generation 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



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



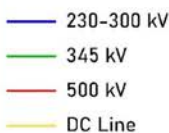
Generator Additions by Technology



Sum of selected Fields



WECC Transmission Lines



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

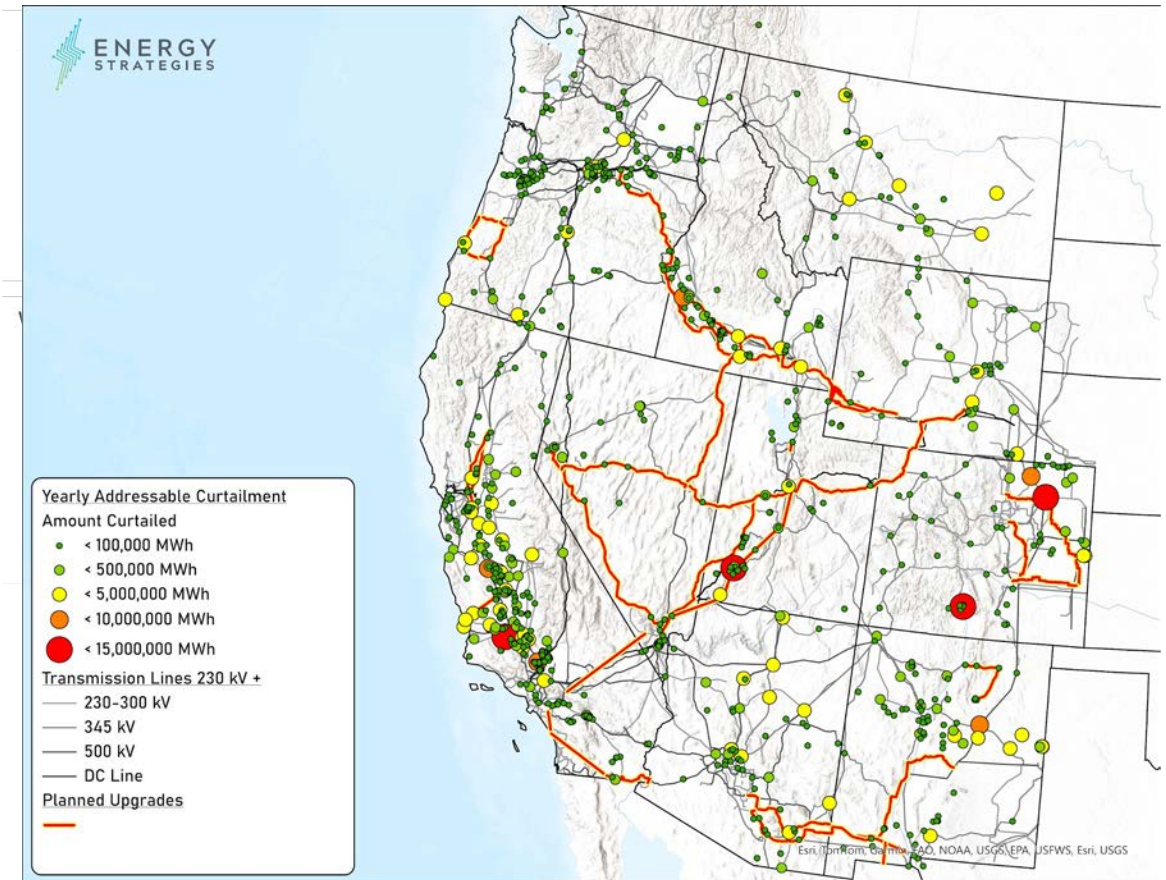
35 GW of new capacity

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

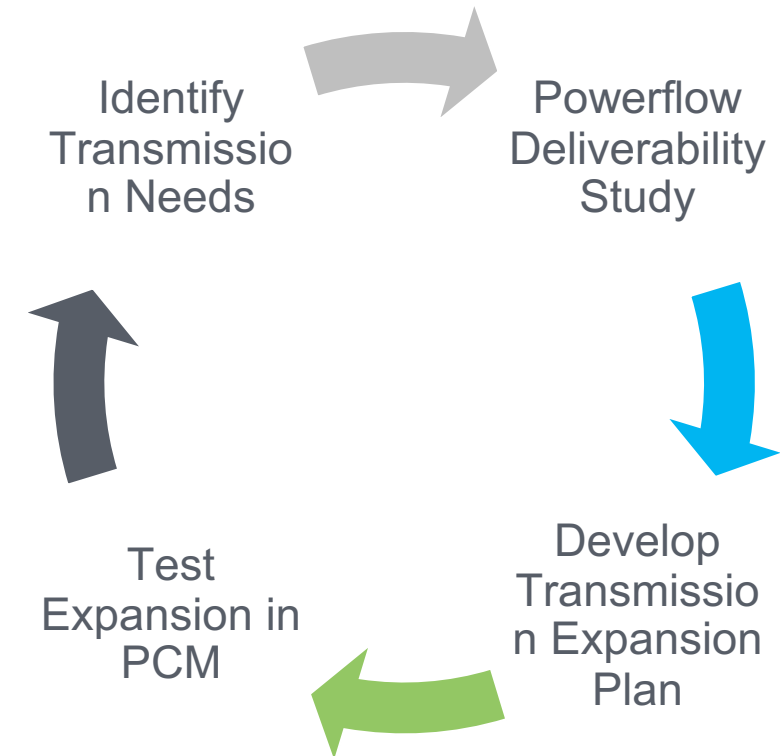
Connected West Reference Case “Addressable Curtailment”



Identifying Transmission Needs & Solutions

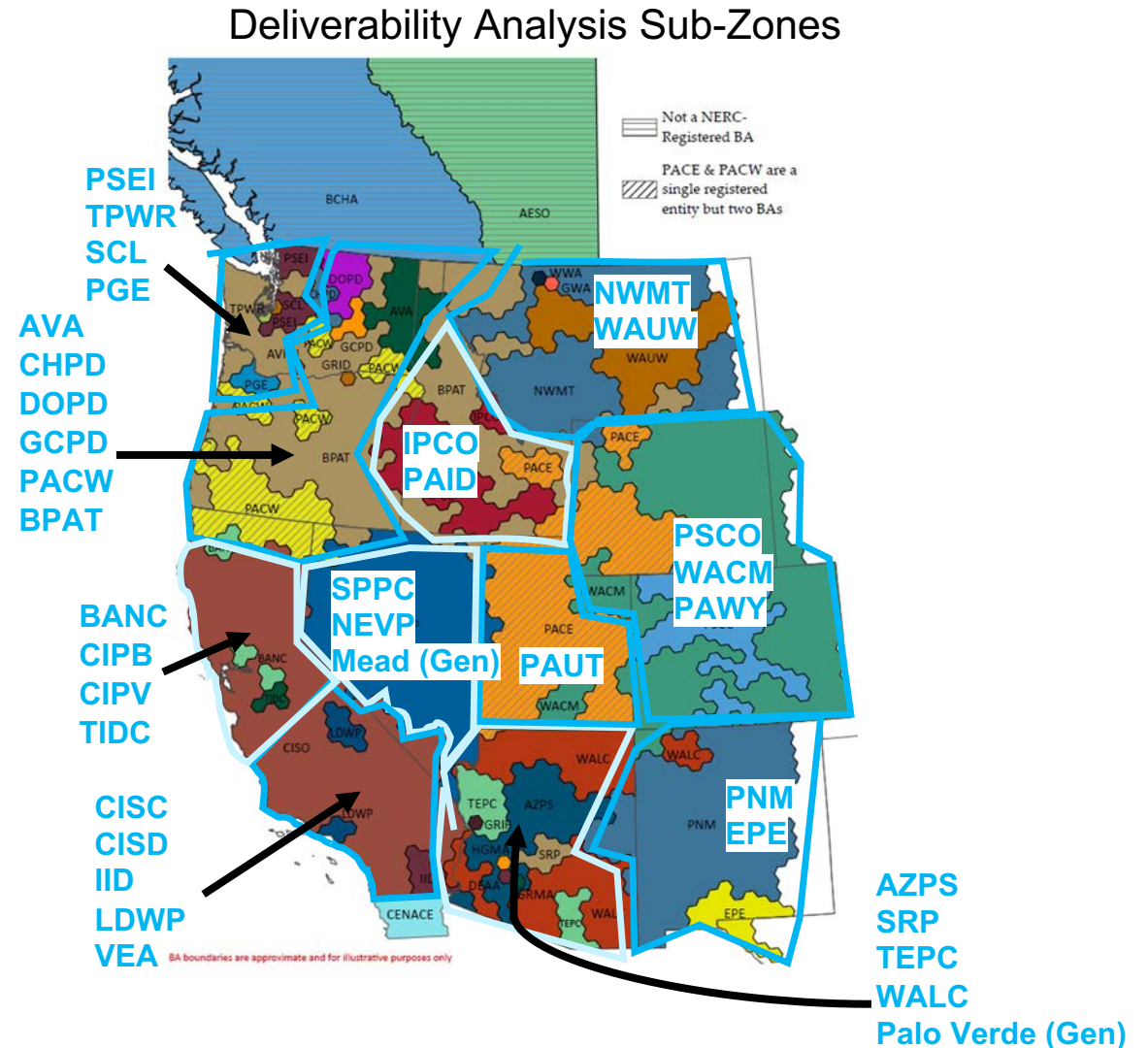
- **Energy Strategies identified transmission solutions using an iterative process:**
 - **Identify Transmission Needs:** Review LMPs, curtailment, and branch & path congestion to identify areas in need of transmission upgrades
 - **Power flow Deliverability Study:** Developed and studied several “zonal” 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



Power Flow Deliverability Methodology

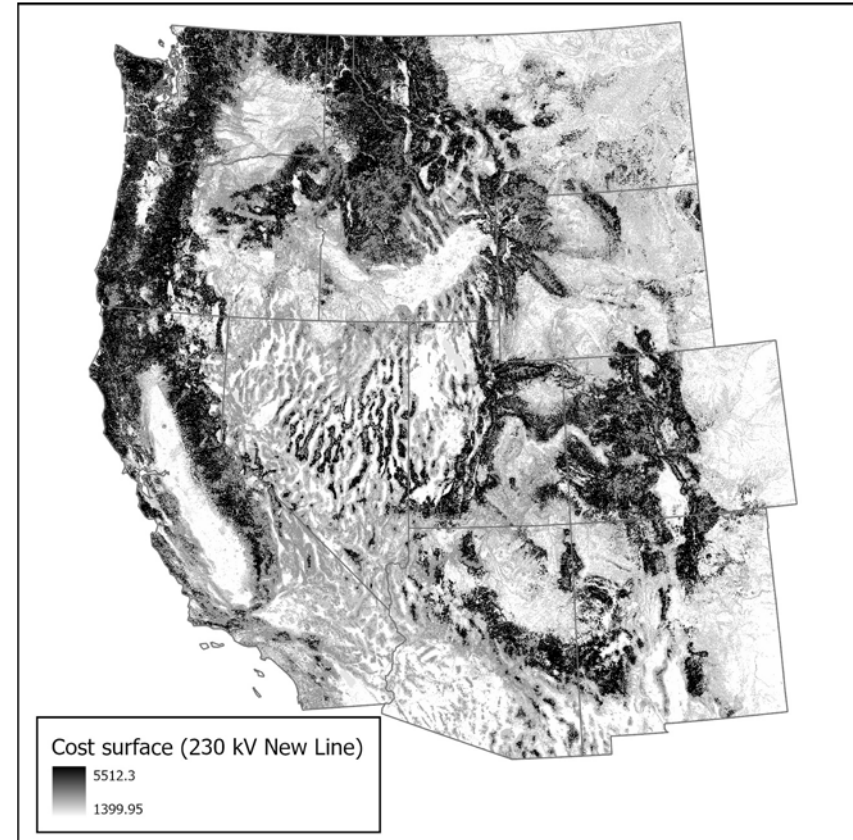
- **The WECC system was divided into 11 sub-zones each with a deliverability case**
 - Each sub-zone evaluated under stressed off-peak conditions
 - Sub-zones with significant generation analyzed as export zones, while those with large loads studied as import zones
- **Developed solutions to resolve issues within and associated with exports/imports from study zone**
 - Upgrades mitigate issues such as 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



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

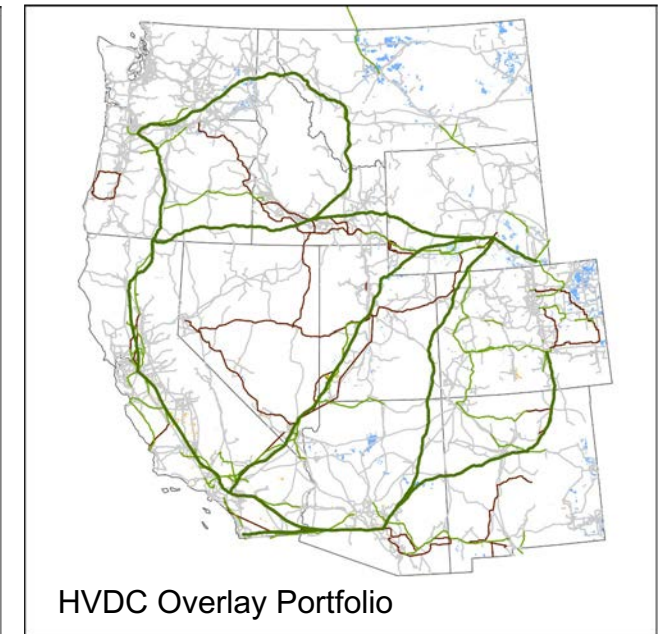
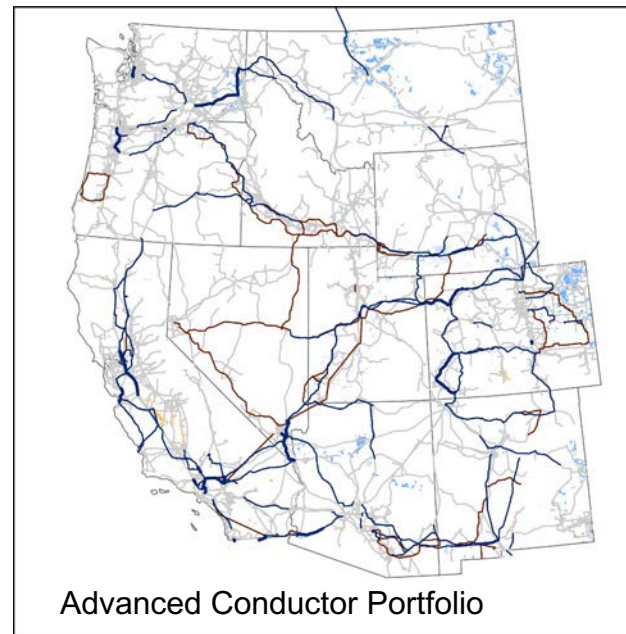
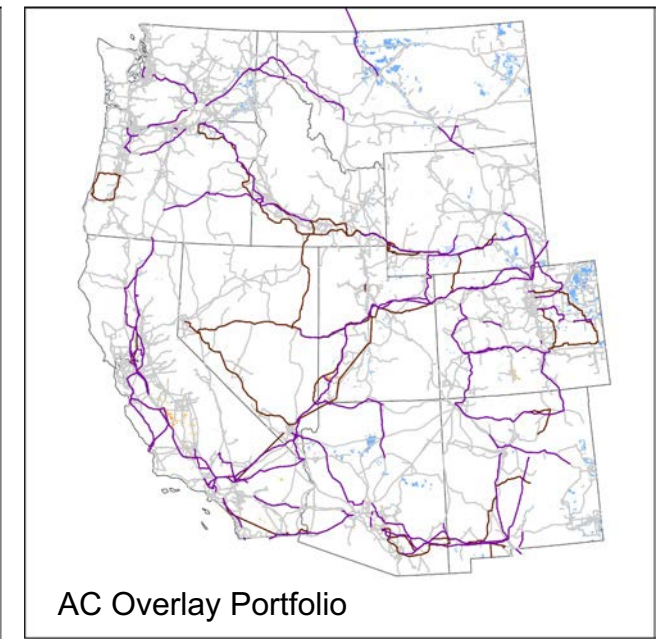
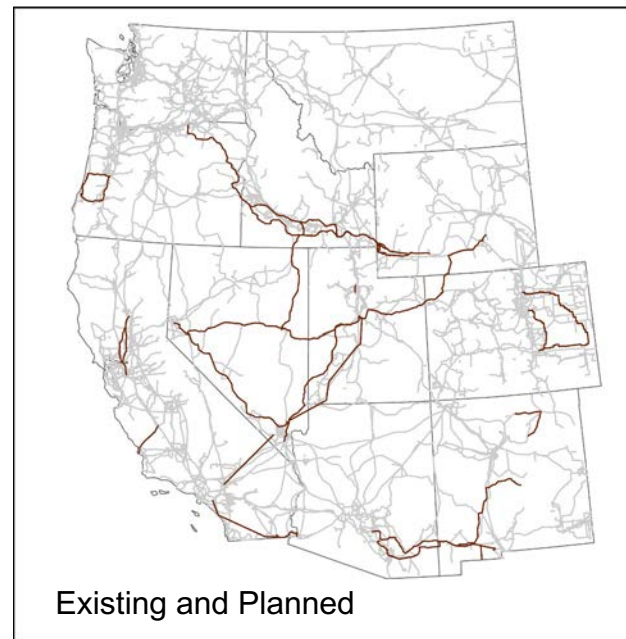
- **The study focused on evaluating the efficiency of transmission expansion within a series of corridors considered simultaneously (e.g., as a portfolio)**
 - To facilitate this evaluation the cost of the portfolio was compared to the benefits estimated for that portfolio
 - The resulting benefit-cost 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 and 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



Key Findings

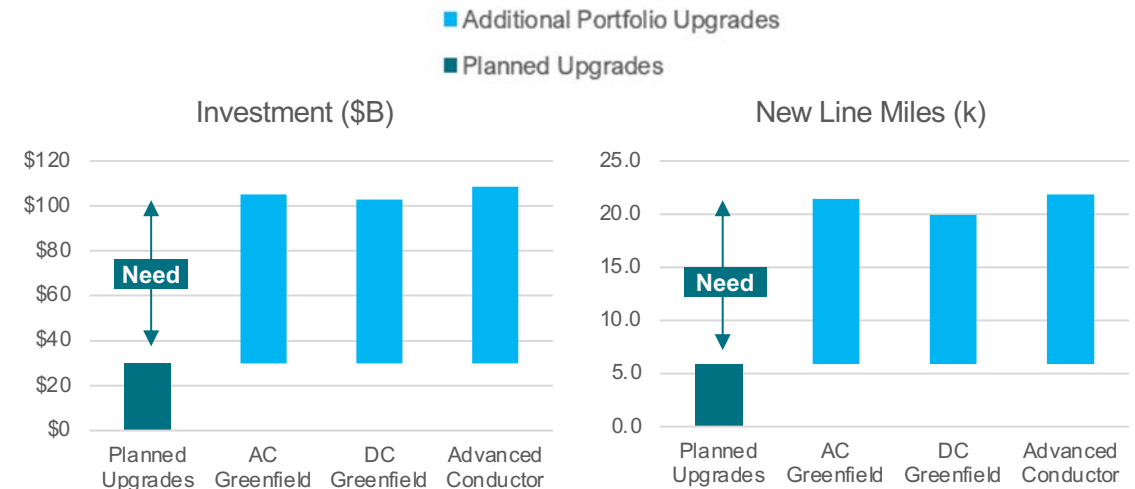
Key Findings #1: Continued Grid Expansion is Required

- **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
- **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

Planned transmission upgrades assumed in the study are insufficient



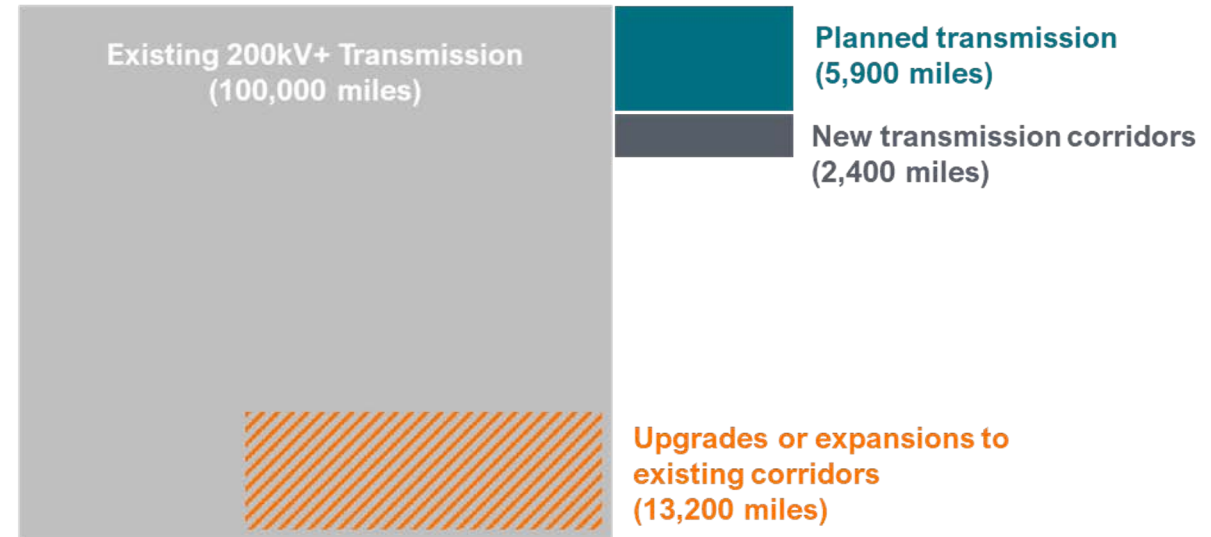
Transmission Expansion Gap Analysis



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
- **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

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.

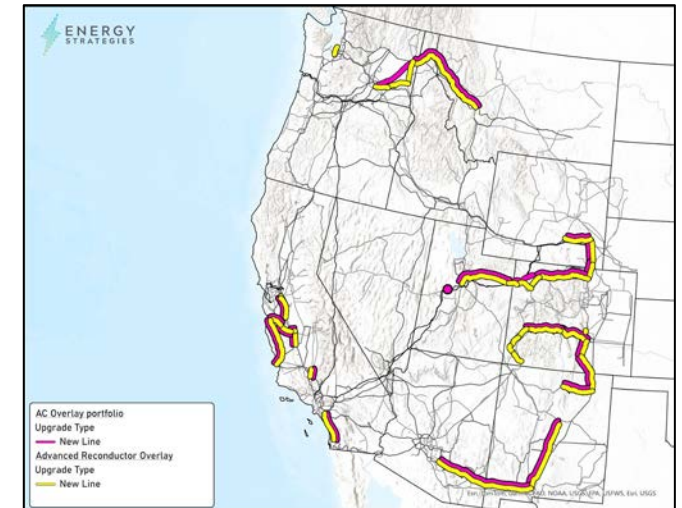
Key Findings #2: Reconductoring and Co-locating Transmission Lines is a Core Strategy for All Portfolios

- **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



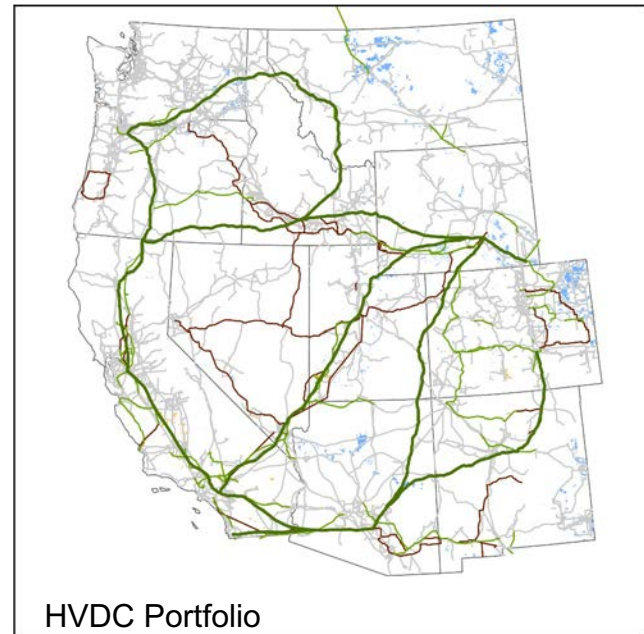
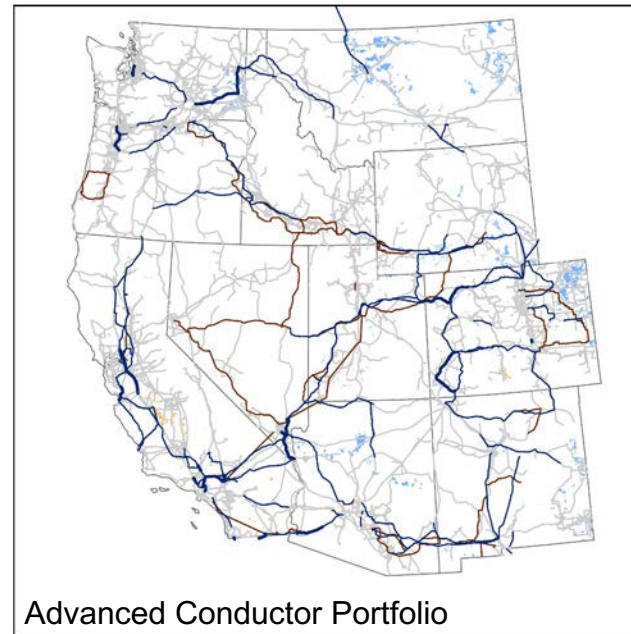
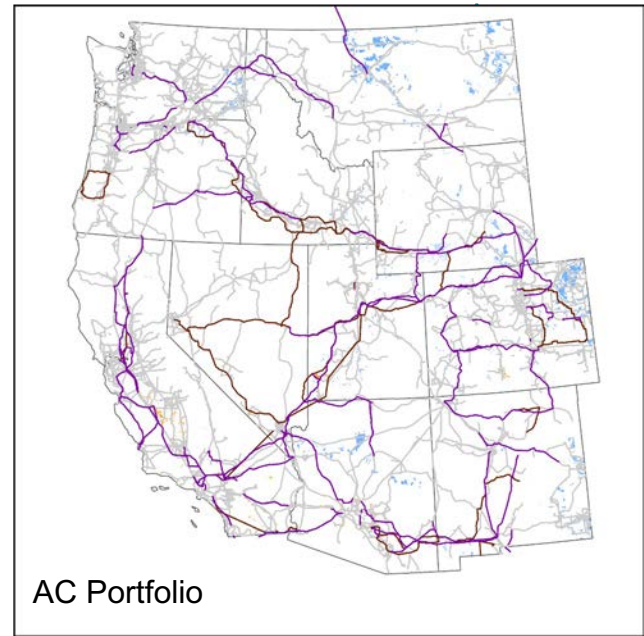
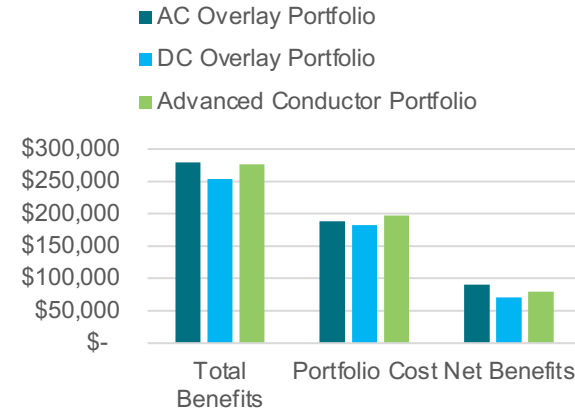
Priority Greenfield Corridors Identified



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)



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

Findings and Results

Part I: Reference Case Results & Observations

Part II: Transmission Expansion Portfolios

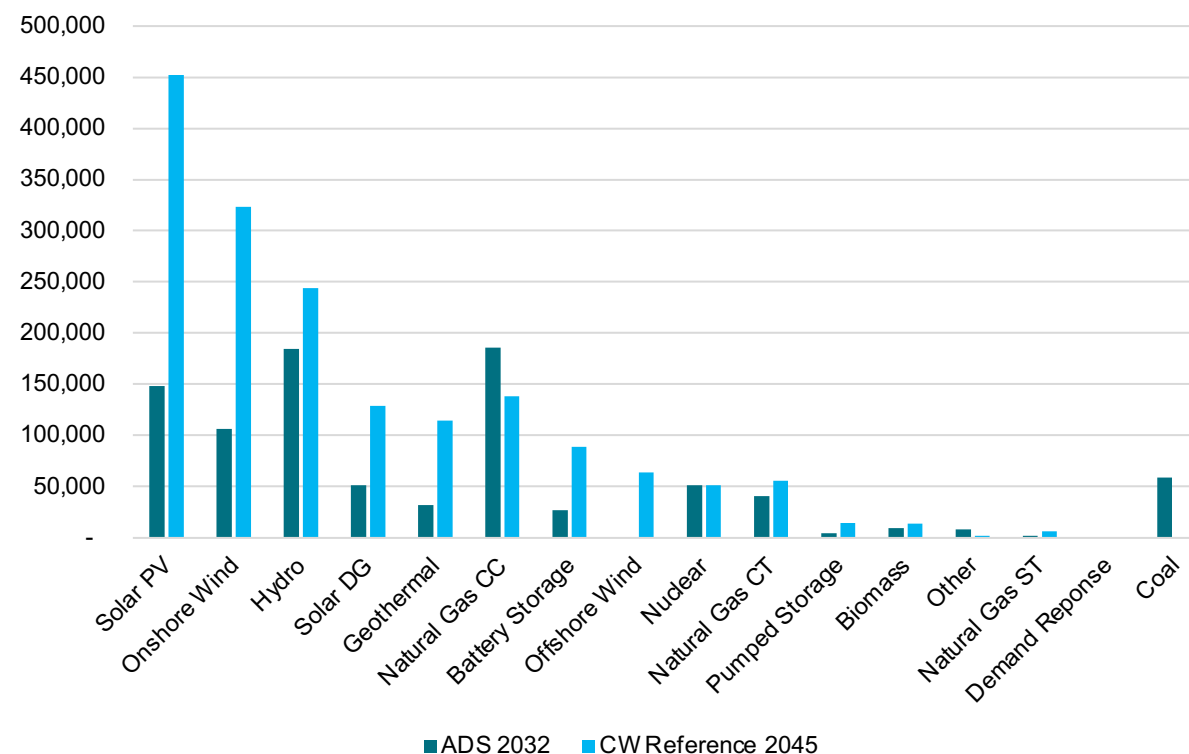
Part III: Answers to Key Questions

Part IV: Additional Findings

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 (%)

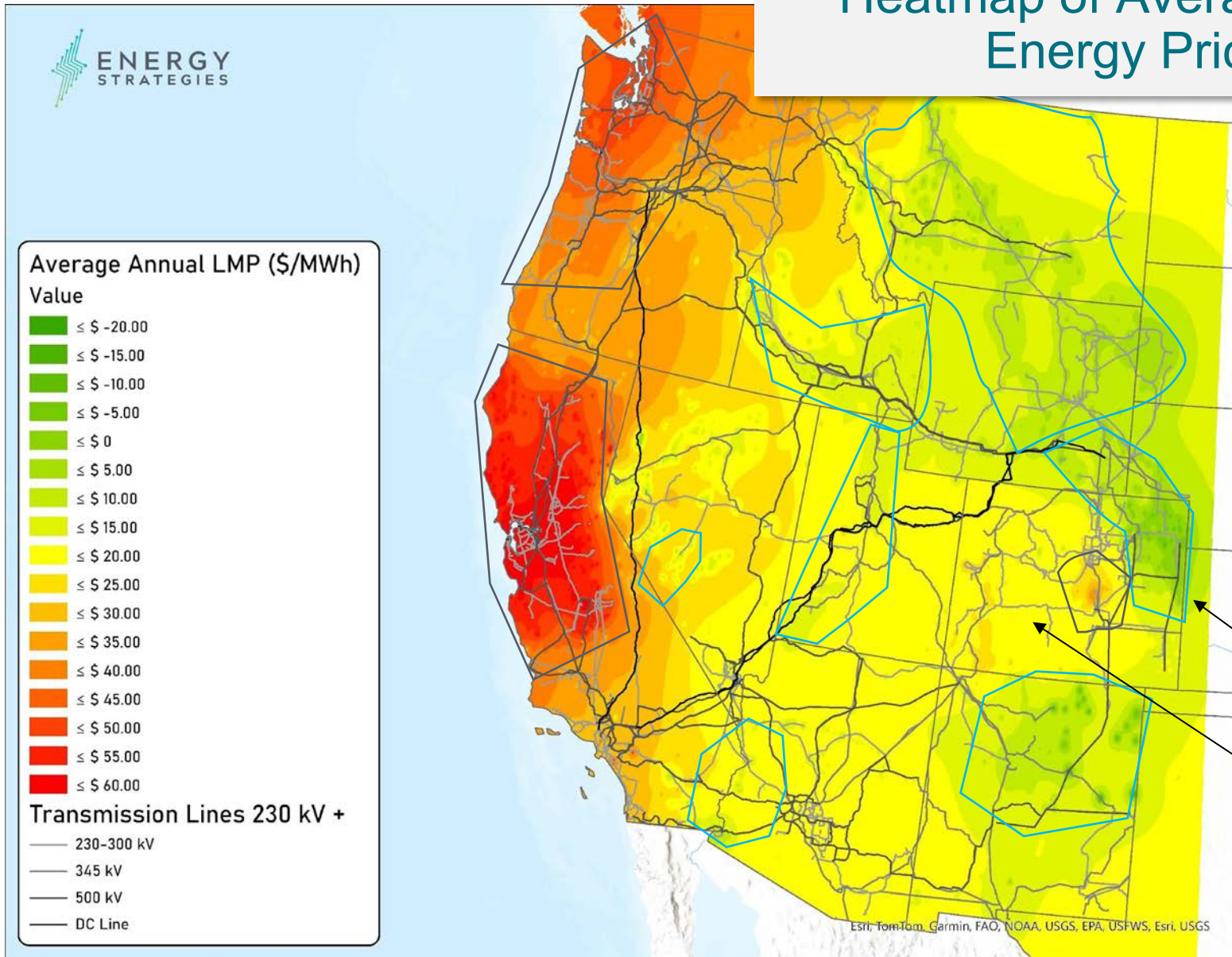
2032 ADS:
67%

2045 Connected West:
92%



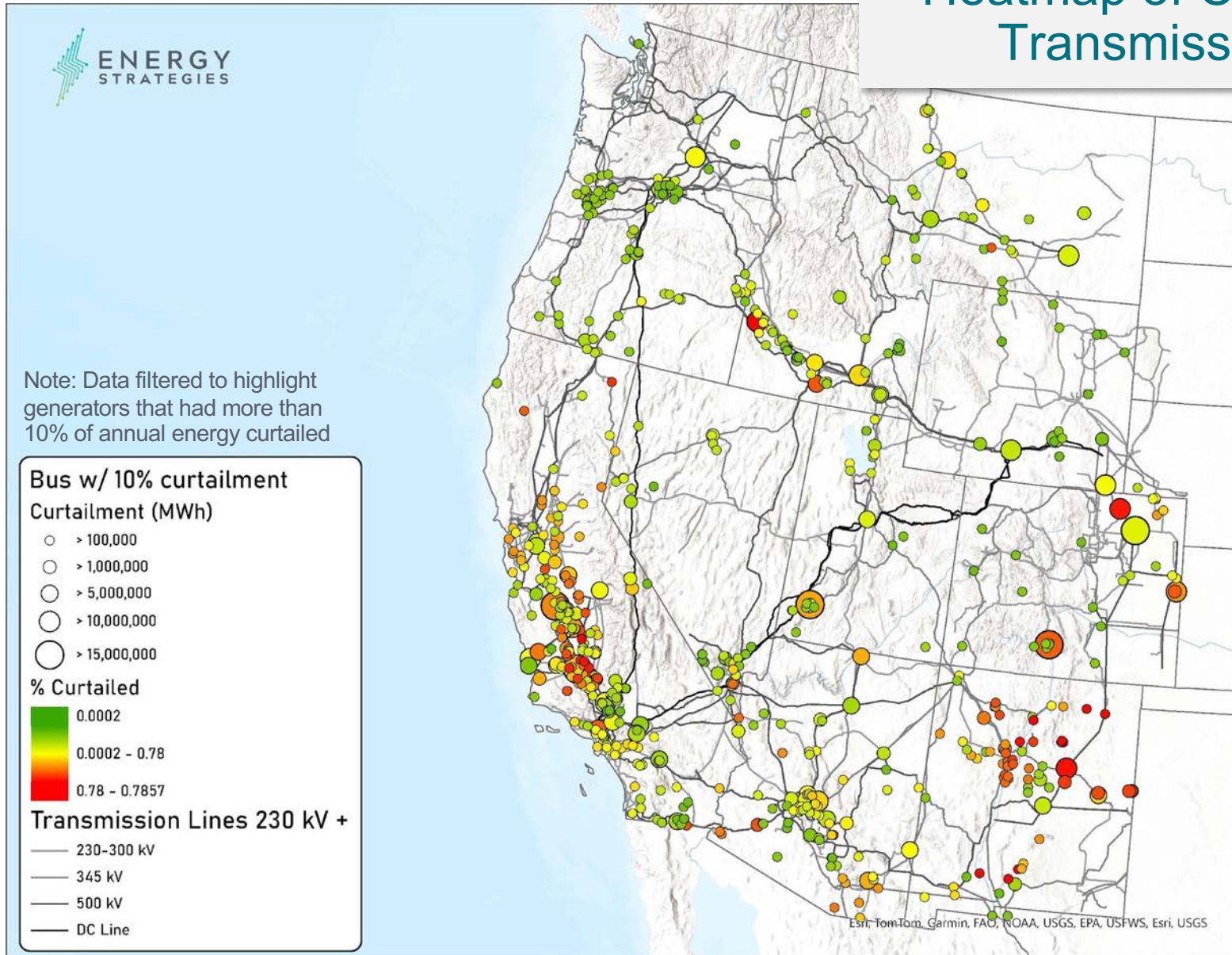
Connected West achieved a **95% clean energy mix** once transmission limitations were addressed. This is on track with Power of Place which targeted a net-zero emission 2050 future.

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

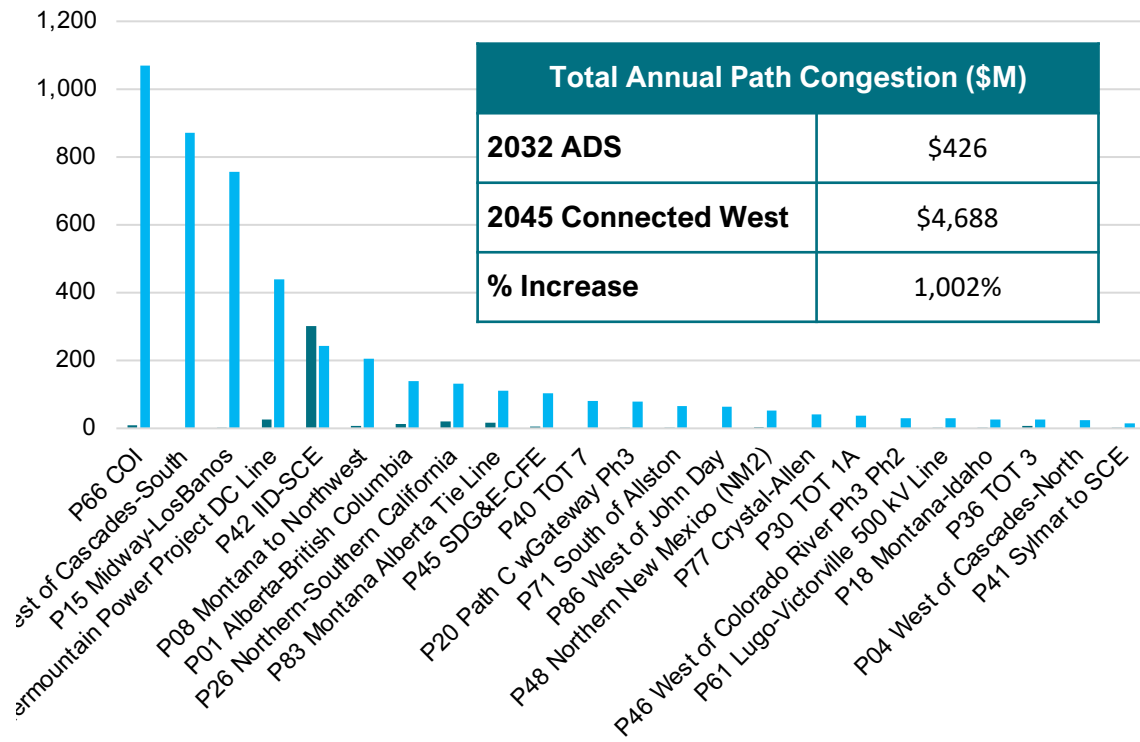


- **Curtailment data can provide insights into where and when the grid is unable to handle the full available generation**
 - While the 2045 grid is likely to experience some curtailment due to “system level” overgeneration events or inflexibility, locational transmission-driven curtailments are frequent 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



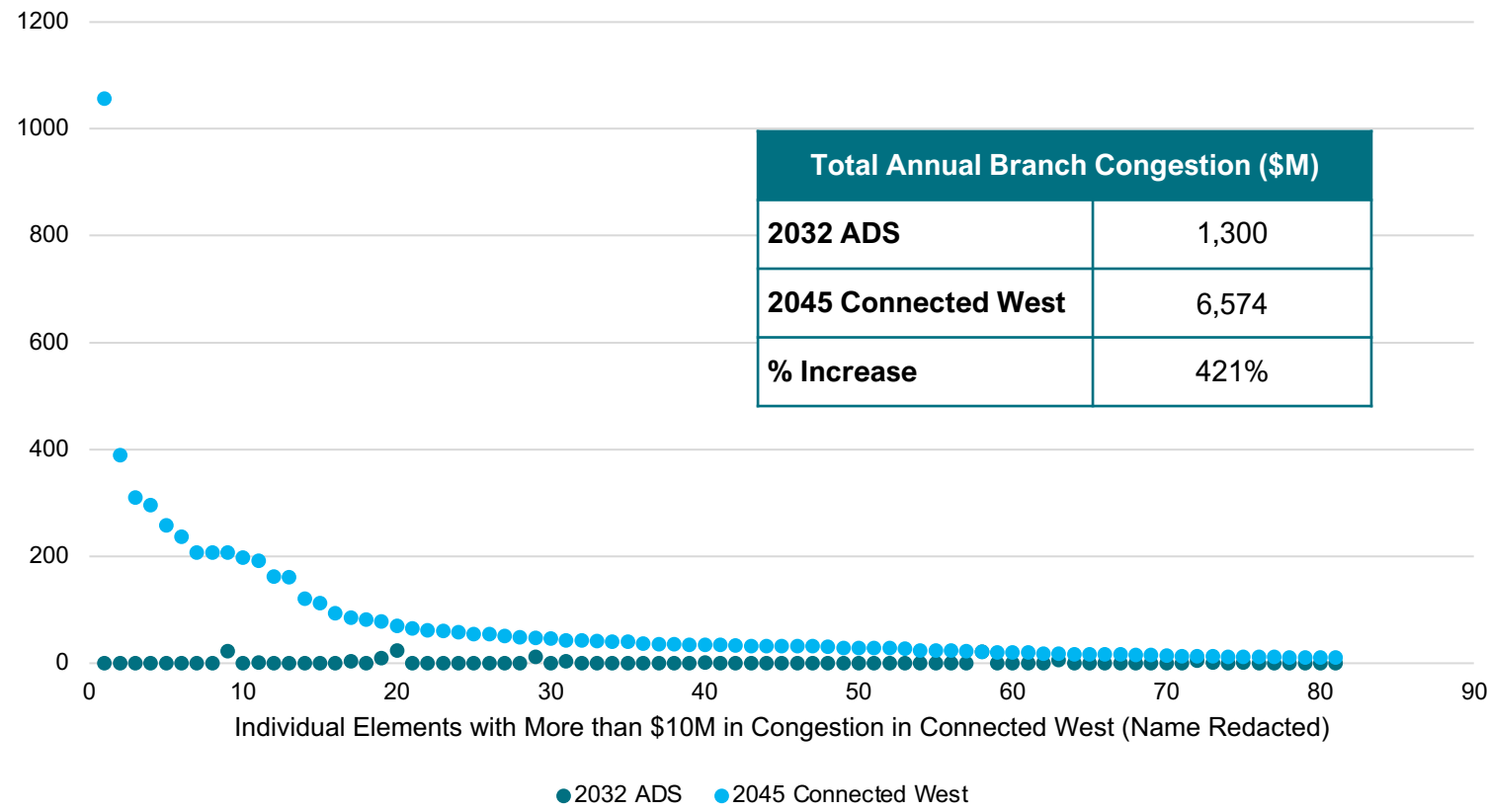
WECC Paths with more than \$10M of Congestion

■ 2032 ADS ■ 2045 Connected West

Transmission Congestion on High-voltage Branches is Severe

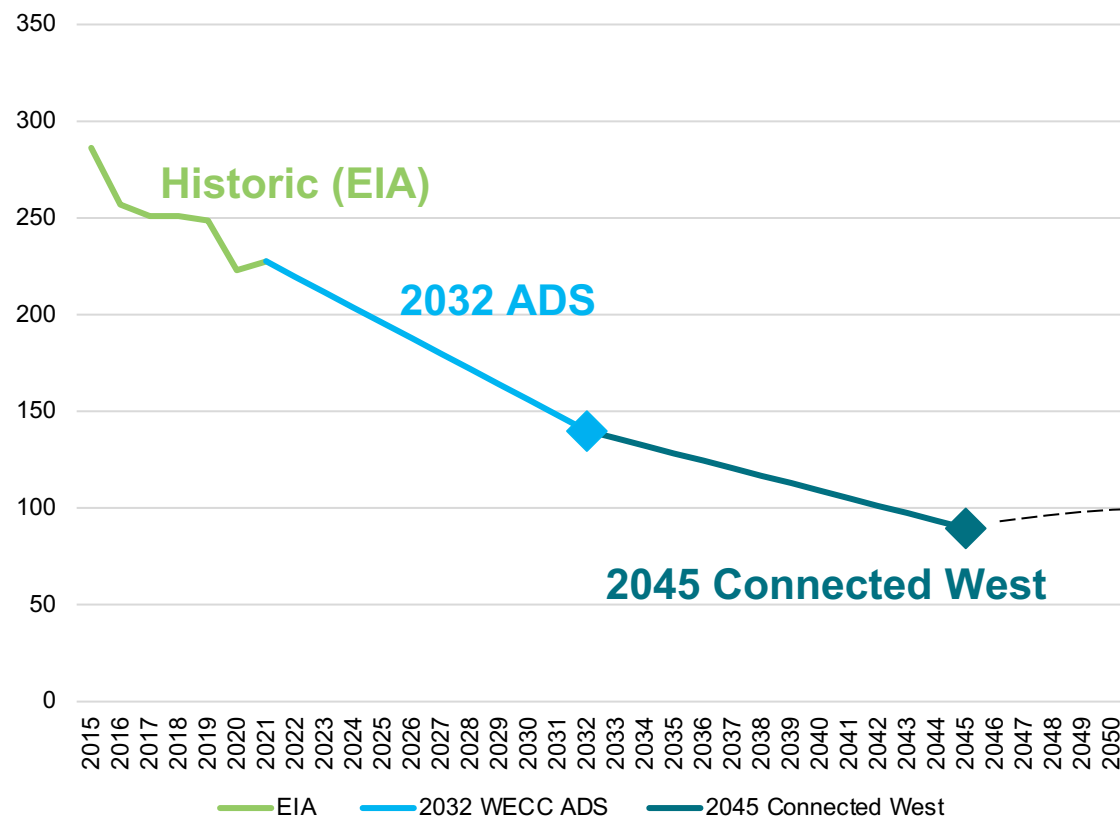
- **Transmission congestion on high-voltage elements, which includes lines and transformers, increased by 406% in the 2045 Connected West Reference Case relative to the 2032 ADS**
 - Note this does not capture ALL transmission congestion as the study limited transmission monitoring to high-voltage lines 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**

Branch Congestion (\$M):
2032 ADS vs. 2045 Connected West



Relative to 2032 ADS, 2045 Connected West reduces annual CO₂ emissions by 64 million metric tons

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



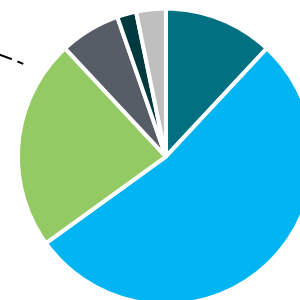
- The 2045 Connected West Reference Case, even without needed transmission upgrades, achieves 36% reduction in CO₂ emissions from WECC 2032 ADS, and 72% reduction from 2005 levels

○ Electric sector emissions only!

- Emissions in 2045 are mainly driven by combined cycle units located in DSW market (Arizona, California)

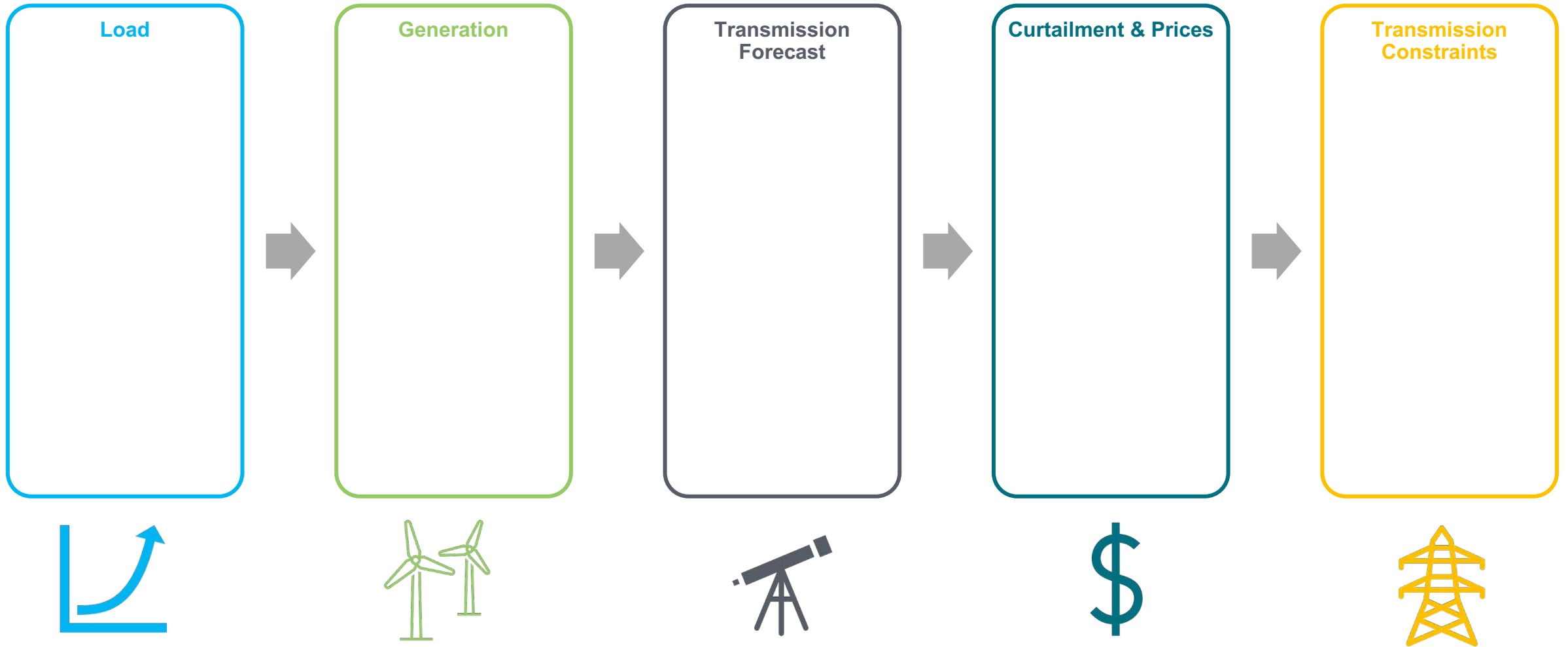
○ This study assumes fuel carbon contents consistent with WECC ADS. This may understate the usage of clean fuels or other carbon reduction methods represented in the PoP study.

Source of 2045 Connected West CO₂ Emissions



■ Biomass ■ Combined Cycle ■ Combustion Turbine ■ Geothermal ■ ICE ■ Steam

Takeaways from Reference Case Modeling



Findings and Results

Part I: Reference Case Results & Observations

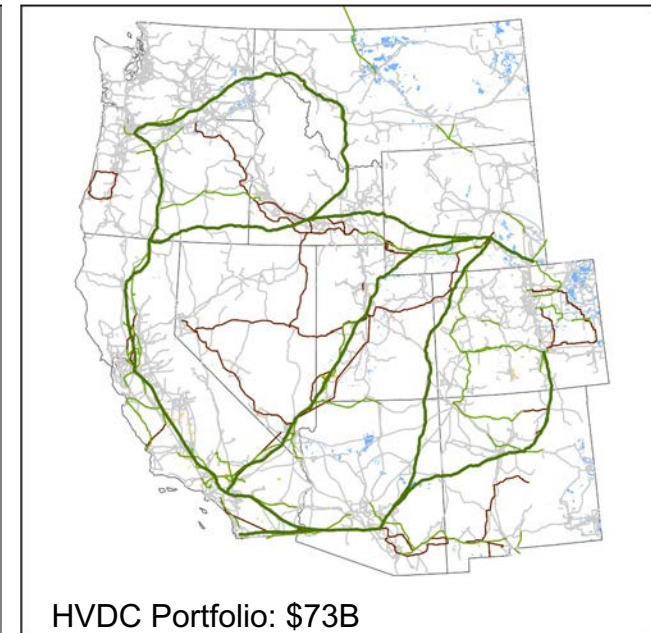
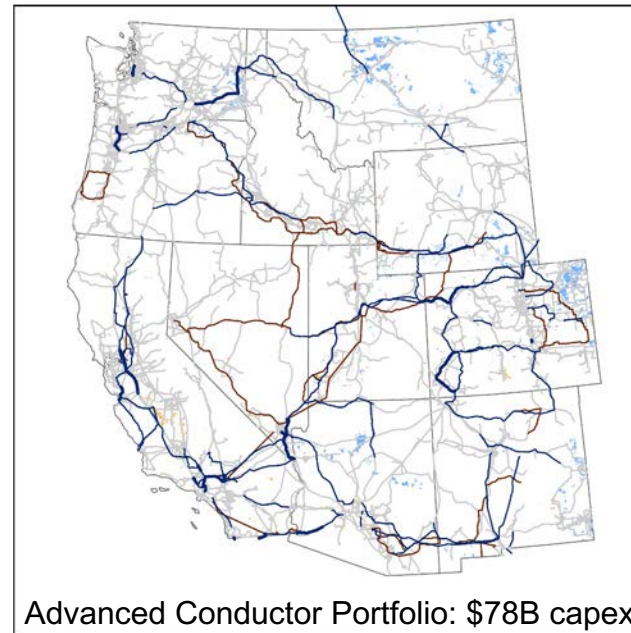
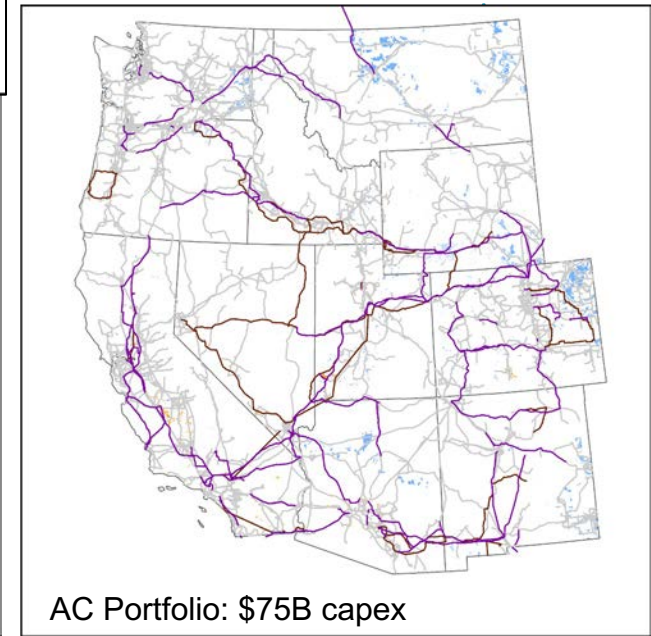
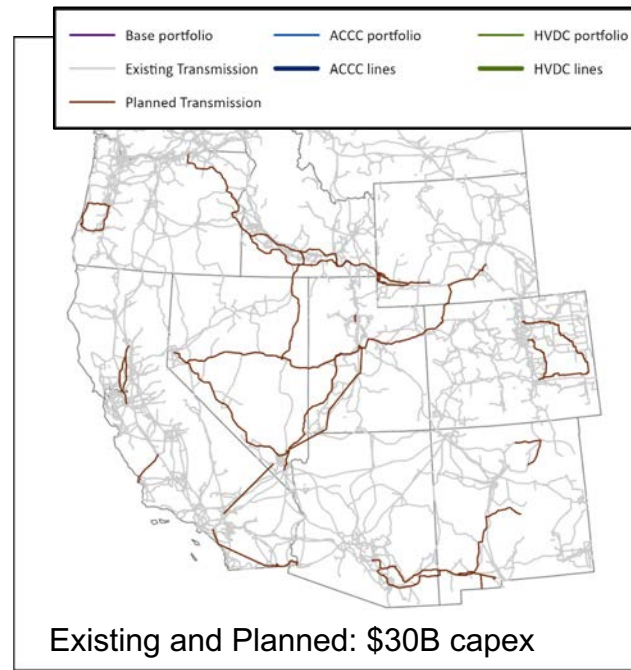
Part II: Transmission Expansion Portfolios

Part III: Answers to Key Questions

Part IV: Additional Findings

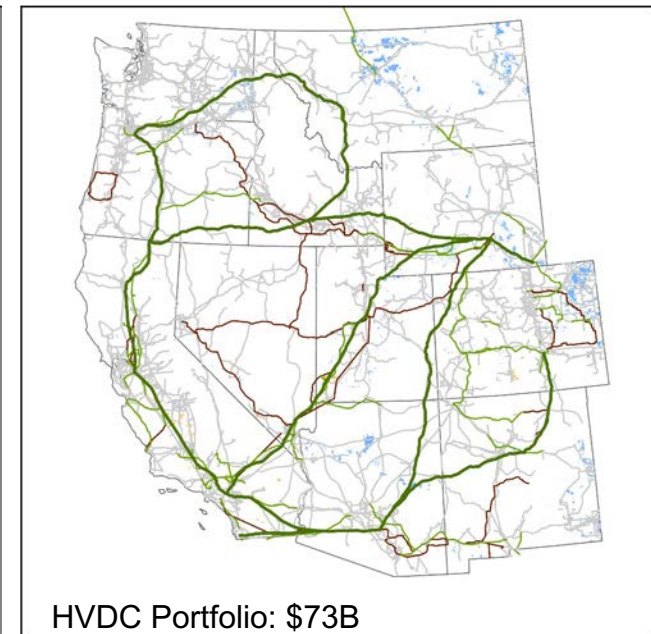
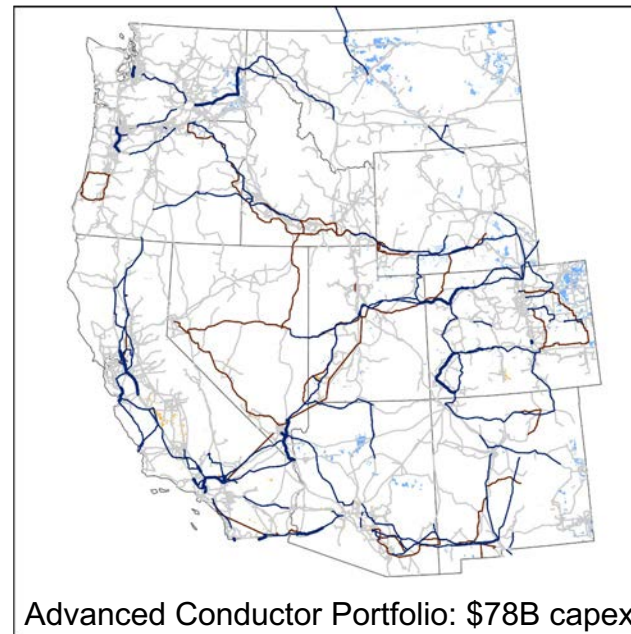
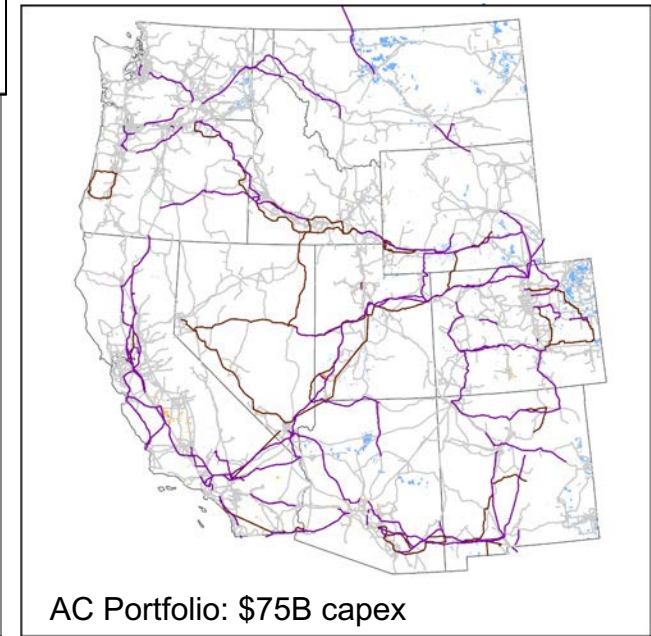
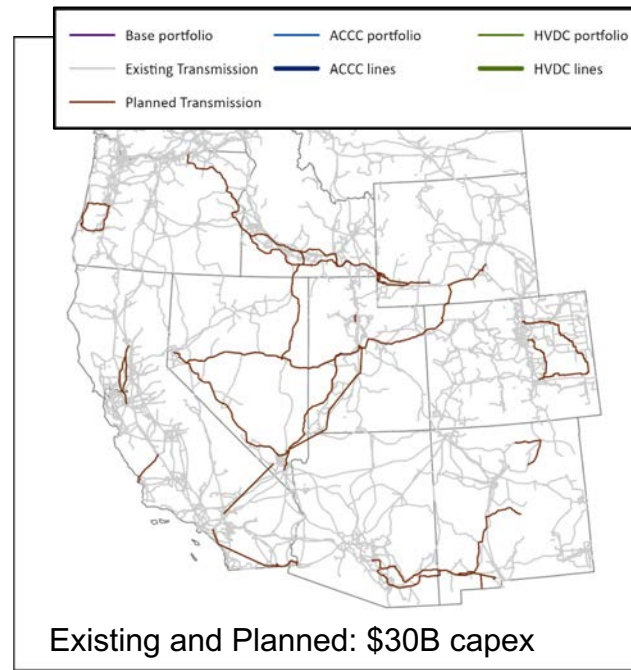
Connected West Transmission Portfolios

- **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**



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**

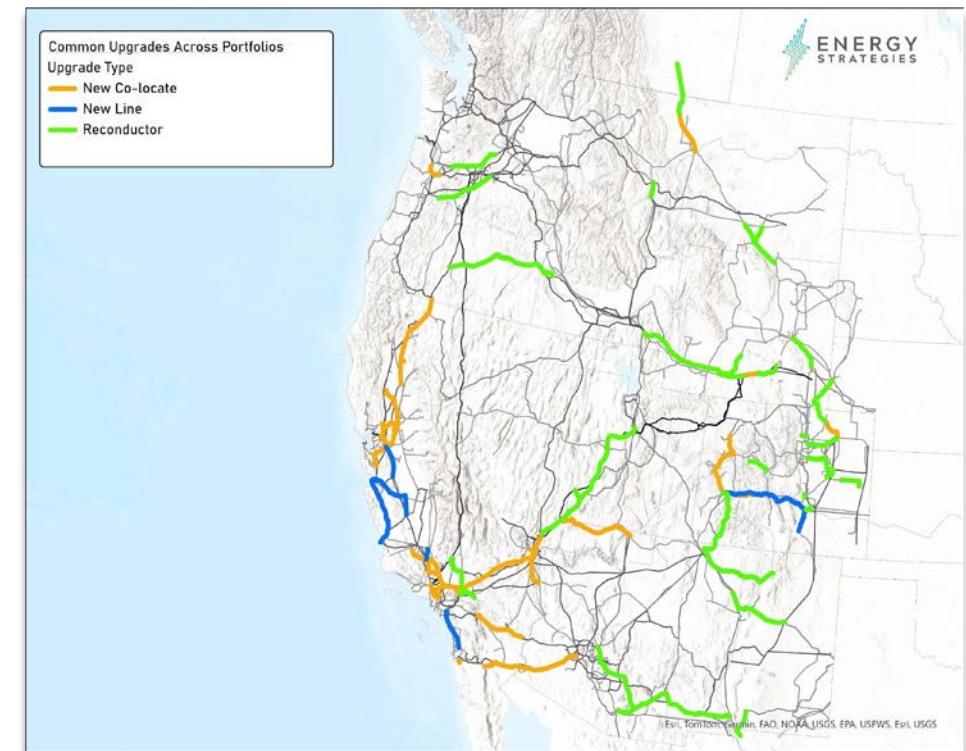


Transmission Portfolio Summary: Comparison of Buildouts

- 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



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		Technical Details		Portfolio Costs & Benefits (present value)		AC Greenfield Portfolio
Annual curtailment (%)	22%	Total Length (mi.)	15,749	Total Cost (\$M)	\$188,366	
Average energy price (LMP)	\$23	Reconductoring miles	5,779	Total Benefit (\$M)	\$278,851	
US Clean energy penetration (%)	94.4%	Co-located miles	7,444	Net Benefit (\$M)	\$90,486	
US CO ₂ reduction from Ref Case (%)	23%	New build miles	2,385	Benefit-Cost Ratio	1.48	
Transmission congestion cost (\$M)	\$2,277	HVDC miles	140			
Branches with > \$50M of Congestion	11	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			

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		Technical Details		Portfolio Costs & Benefits (present value)		DC Greenfield Portfolio
Annual curtailment (%)	21.5%	Total Length (mi.)	14,008	Total Cost (\$M)	\$182,522	
Average energy price (LMP)	\$25.6	Reconductoring miles	3,531	Total Benefit (\$M)	\$253,365	
US Clean energy penetration (%)	94.2%	Co-located miles	3,805	Net Benefit (\$M)	\$70,843	
US CO ₂ reduction from Ref Case (%)	21%	New build miles	890	Benefit-Cost Ratio	1.39	
Transmission congestion cost (\$M)	\$3,081	HVDC miles	5,783			
Branches with > \$50M of Congestion	17	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			

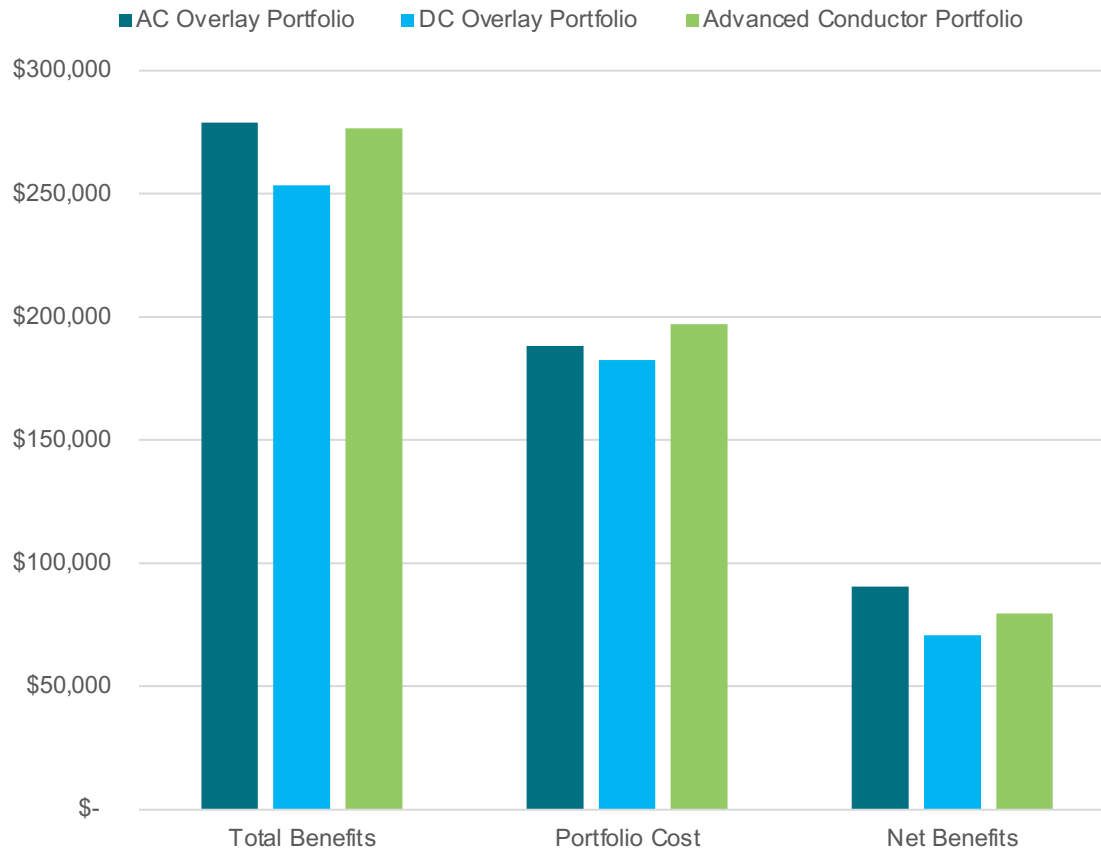
Transmission Portfolio Summary: Advanced Conductor

- 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		Technical Details		Portfolio Costs & Benefits (present value)		Advanced Conductor Portfolio
Annual curtailment (%)	22%	Total Length (mi.)	16,313	Total Cost (\$M)	\$196,958	
Average energy price (LMP)	\$21.6	Reconductoring miles	6,397	Total Benefit (\$M)	\$276,527	
US Clean energy penetration (%)	94.4%	Co-located miles	7,554	Net Benefit (\$M)	\$79,569	
US CO ₂ reduction from Ref Case (%)	23%	New build miles	2,222	Benefit-Cost Ratio	1.40	
Transmission congestion cost (\$M)	\$2,094	HVDC miles	140			
Branches with > \$50M of Congestion	7	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			

Transmission Portfolio Summary: Benefit Analysis Comparison

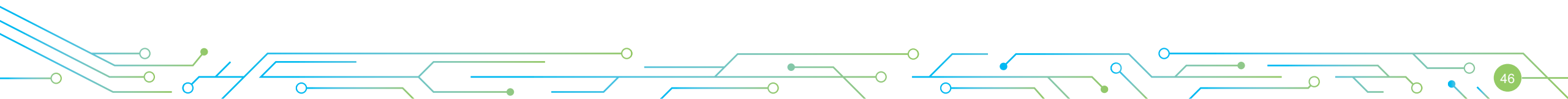
Portfolio Economic Performance:
40-year Present Values (2023\$, millions)



- **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**

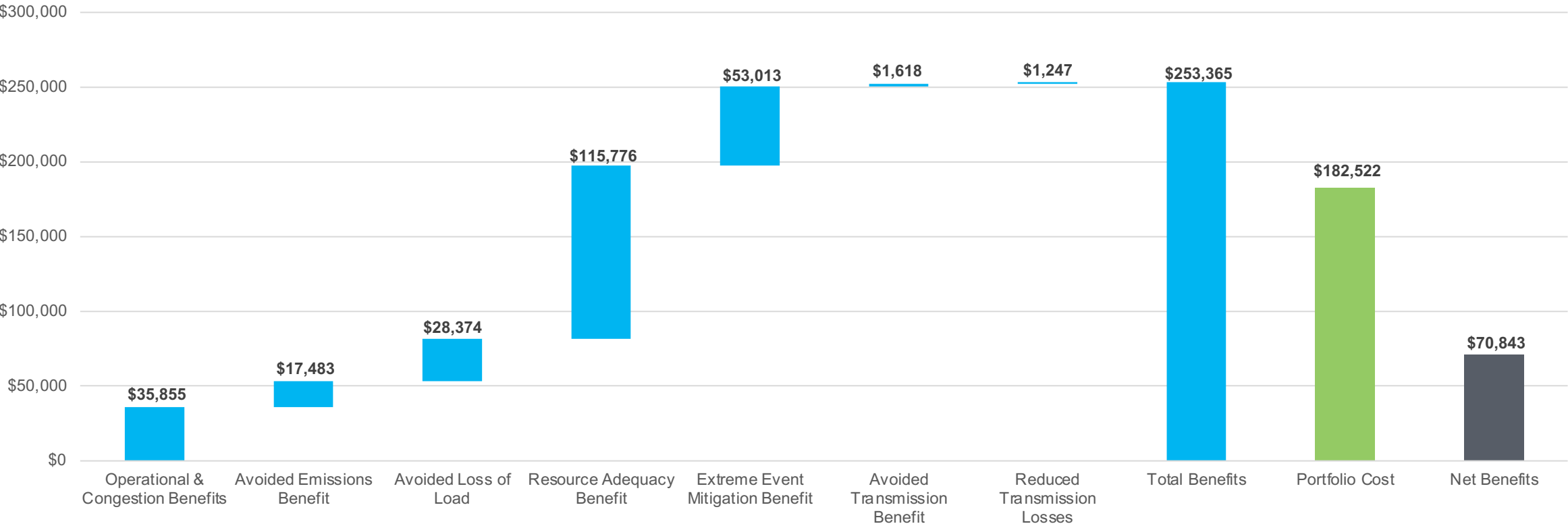
Transmission Benefits Summary: AC Greenfield

AC Overlay Portfolio:
Present Value Benefits, Costs, and Net Benefits
(2023\$, millions)



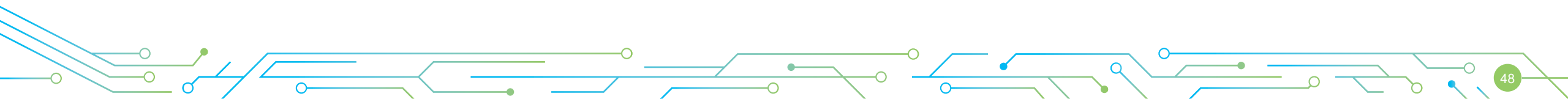
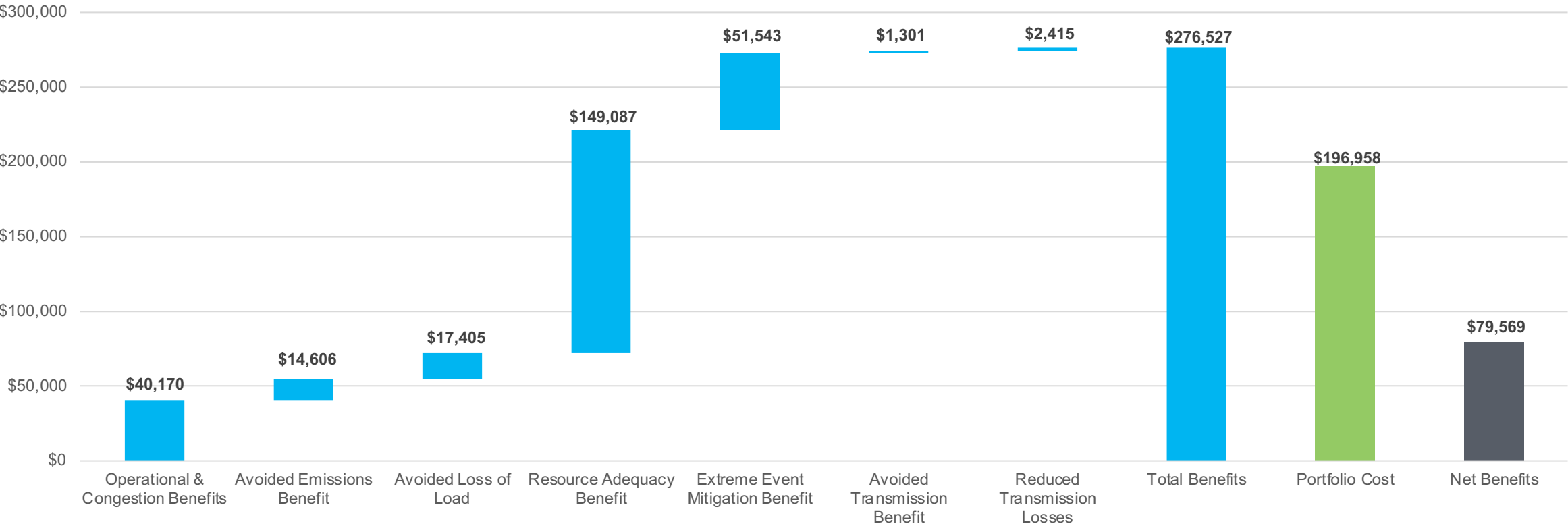
Transmission Benefits Summary: DC Greenfield

DC Overlay Portfolio:
Present Value Benefits, Costs, and Net Benefits
(2023\$, millions)



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 CO₂
- **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

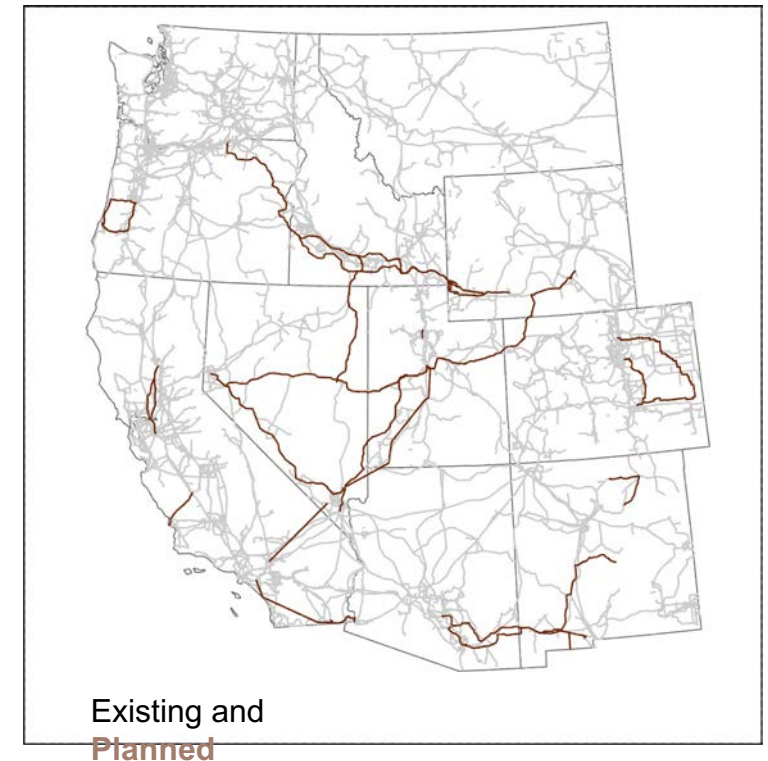
Part III: Answers to Key Questions

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 with existing and planned upgrades alone:
 - 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



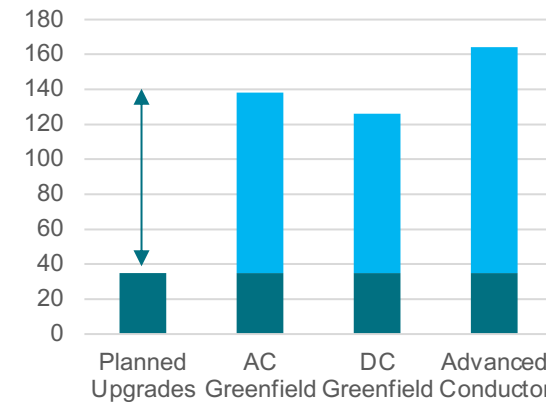
Transmission Gaps: If the planned projects do not fully meet the 2045 needs, what is the remaining transmission gap in terms of investment (\$) and additional transmission capacity (MW)?

- **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%)**

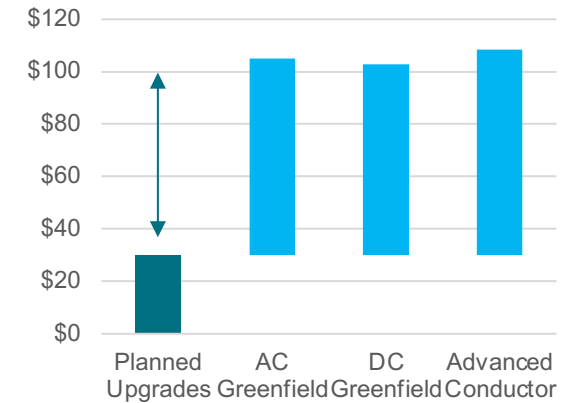
Transmission Expansion Gap Analysis: Need Beyond Planned Upgrades Assumed in Study

■ Additional Portfolio Upgrades
■ Planned Upgrades

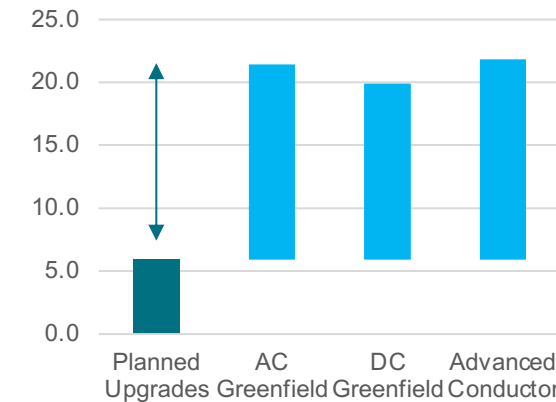
Total New Tx Capacity (GW)
through 2045



Total Tx Investment (\$B)
through 2045



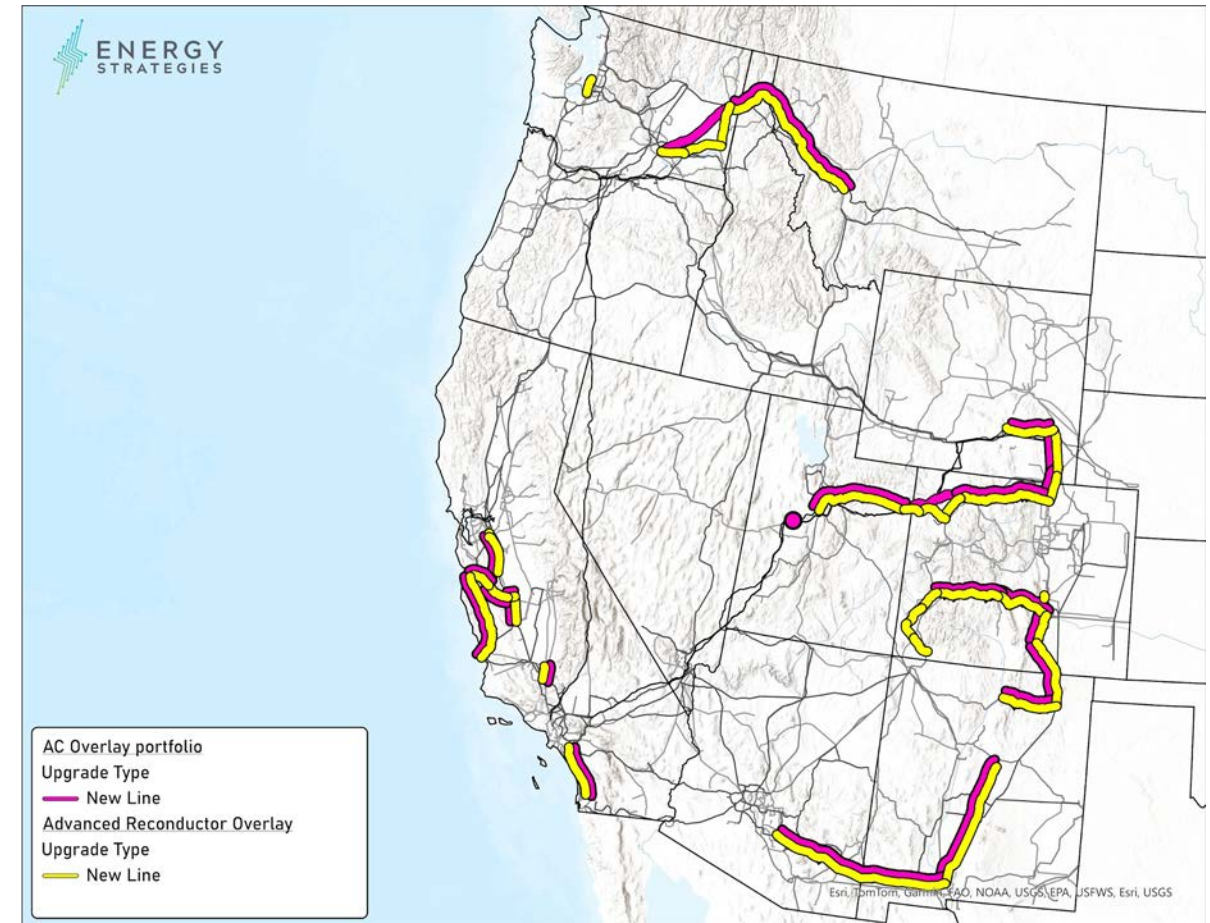
Total New Line Miles (k)
through 2045



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, **ranking** 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
- **Further diligence on the feasibility of reconductoring projects included in the portfolios will impact this conclusion**

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

Kavita Shenoi
Senior Consulting Engineer
kshenoi@energystrat.com

John Muhs, PE
Senior Consultant
jmuhs@energystrat.com

Keegan Moyer
Principal
kmoyer@energystrat.com

Tyler Butikofer, PE
Senior Consulting Engineer
tbutikofer@energystrat.com

www.energystrat.com

Christopher Hirsch
GIS Analyst
chirsch@energystrat.com

Colby Johnson
Consulting Engineer
cjohnson@energystrat.com

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

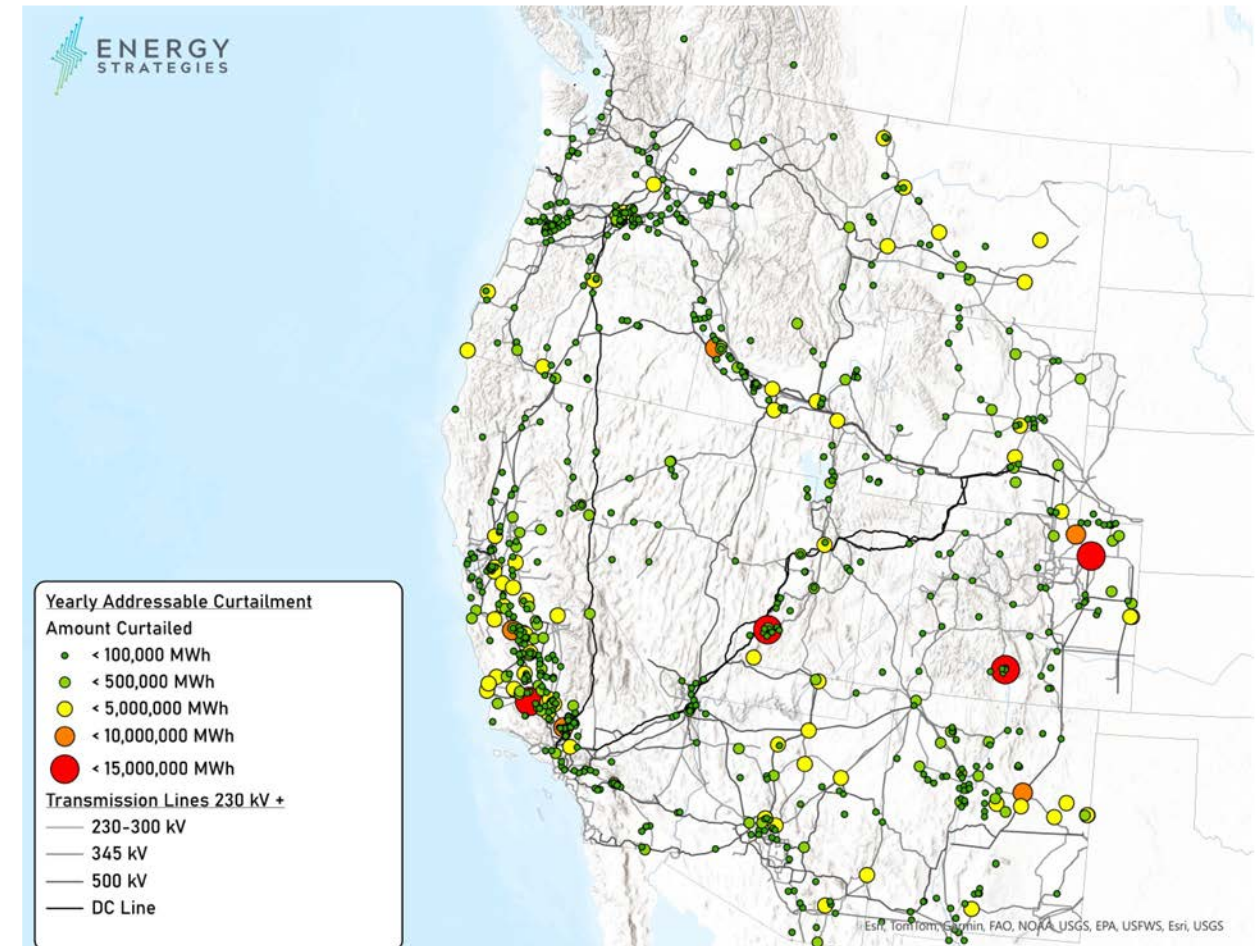
Benefit	Metric
Operational Savings	Change in WECC-wide production cost.
Avoided Emissions	Avoided emissions savings based on simulated emissions reductions and a forecasted carbon price
Avoided Loss of Load	Avoided loss of load valued at \$40,000/MWh, with the benefit calculated as the product of reduced loss of load in simulation and 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

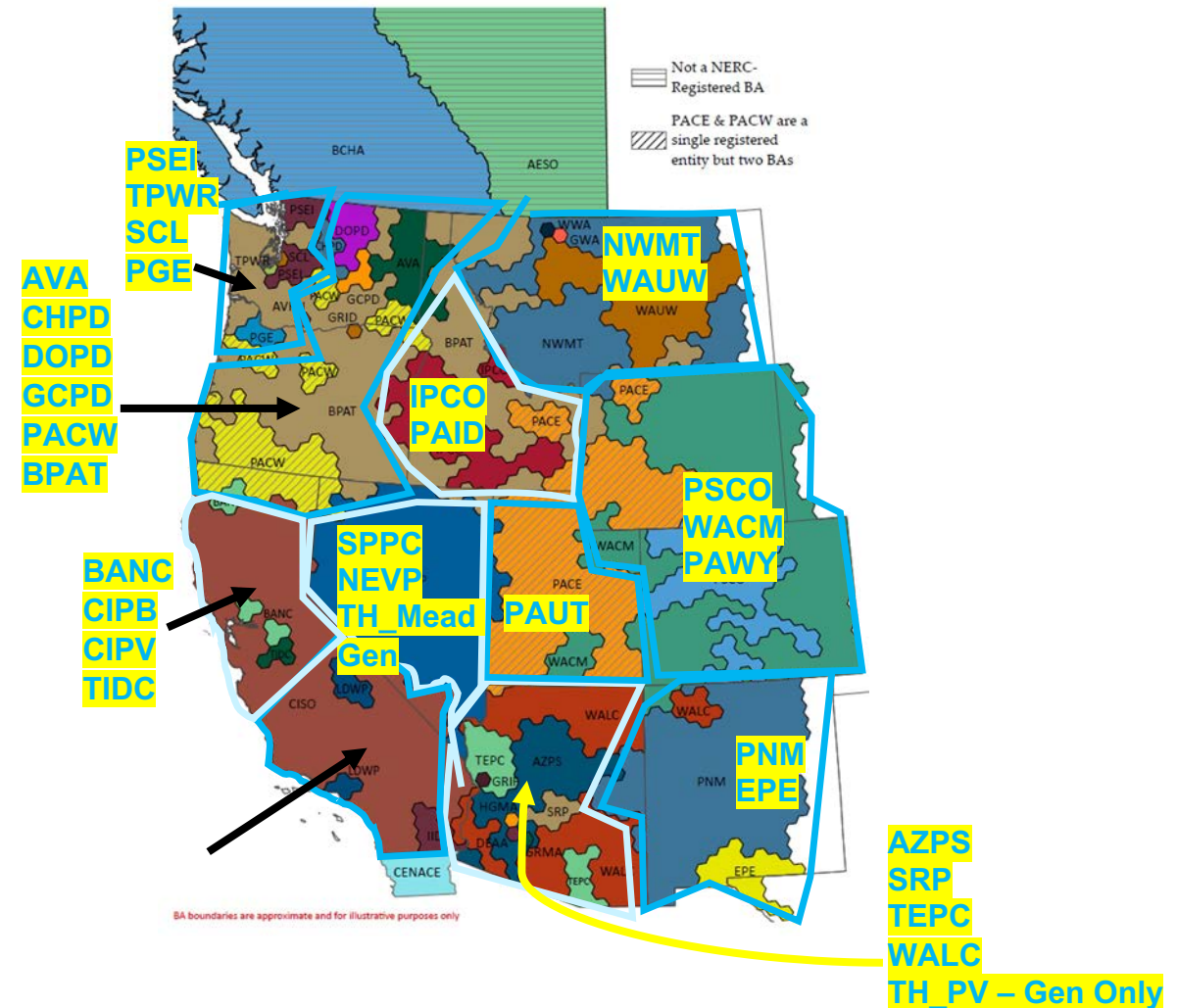
Connected West Reference Case “Addressable Curtailment”



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

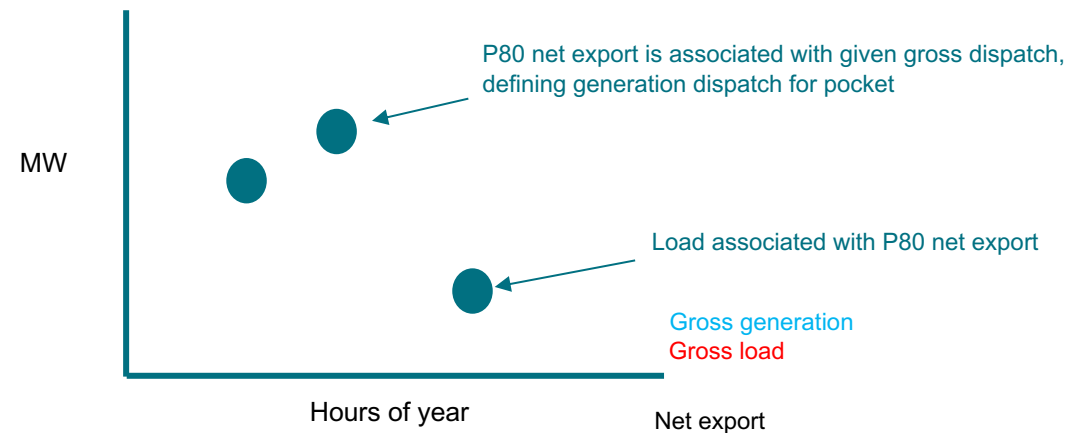
Deliverability Analysis Sub-Zones



Detailed Deliverability Study Assumptions

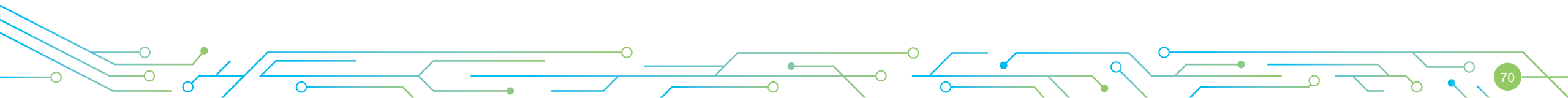
- Dispatch conditions were informed by a review of hourly data from the 2045 Connected West Copper Sheet Case.
- Identified average dispatch conditions that represented a P80 exceedance net export (or import) condition for the given study sub-zone.
- P80 was selected because addressing 100% of the deliverability 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%

