ENERGY STRATEGIES

Western Flexibility Assessment

Investigating the West's Changing Resource Mix and Implications for System Flexibility

Webinar Summary of Final Report

December 11, 2019

Prepared by Energy Strategies for submission under Agreement with the Western Interstate Energy Board

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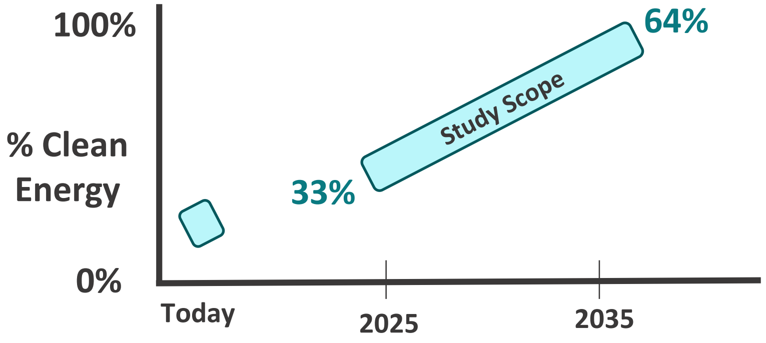
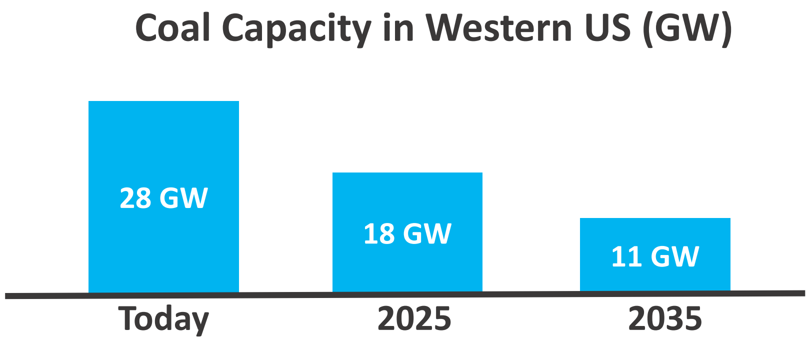
Western Flexibility Assessment motivated by surge in Western state policy that will impact future generation mix

- **New state policies, most of which expand renewable portfolio standards (RPS) and are generally designed to reduce carbon emissions, will change the West's resource mix, which will impact the operational and transmission dynamics of the grid**
- **The Western Interstate Energy Board (WIEB) engaged Energy Strategies to investigate a high-renewable future driven by state policy goals, investigating potential demand for renewables, resulting operational/transmission challenges, inter-region power flows, capacity issues in the Northwest, and effectiveness of integration strategies**
- **Voids the study sought to fill through independent study work:**
  - ☑ Is the power system flexible enough to operate with penetrations of variable renewable generation consistent with state/provincial policies?
  - ☑ If not, what steps can be taken to make the system more flexible?





Project Team and Structure

Project Steering Committee

Western Interstate Energy Board

State of Oregon 1859

Invenergy

AWEA American Wind Energy Association

EDF renewables

NextEra Energy

nationalgrid ventures

ORION Renewable Energy Group LLC

AVANGRID

Technical Advisory Committee

- 16 industry experts from across the West, representing utilities, regional planning bodies, NGOs, states, and National Labs

WIEB Project Manager

Tom Carr, WIEB Staff

ENERGY STRATEGIES

Ben Brownlee, Gary Simonson, Kathleen Fraser, Daniel Ramirez, Caitlin Liotiris, Keegan Moyer

- **Study benefited from technical support and data provided by WECC, BPA, and the Northwest Power and Conservation Council (NWPCC)**
- **Cameron Yourkowski (EDPR) and Tony Usibelli (WA) were instrumental in developing the original project proposal and organizing funders and committee structure**

What makes this study unique?

- ✓ Incorporates significant **recent state energy policies** across the West
- ✓ Wide-ranging, investigating **flexibility challenges from multiple technical perspectives** over an extended study horizon
- ✓ Includes a **granular representation of the transmission system** and captures interregional **transmission flow effects**
- ✓ Considers both **institutional and physical strategies** for system flexibility needs

Assumed RPS and Clean Energy Policies for Western States:

Modeling western policies to help investigate system flexibility needs

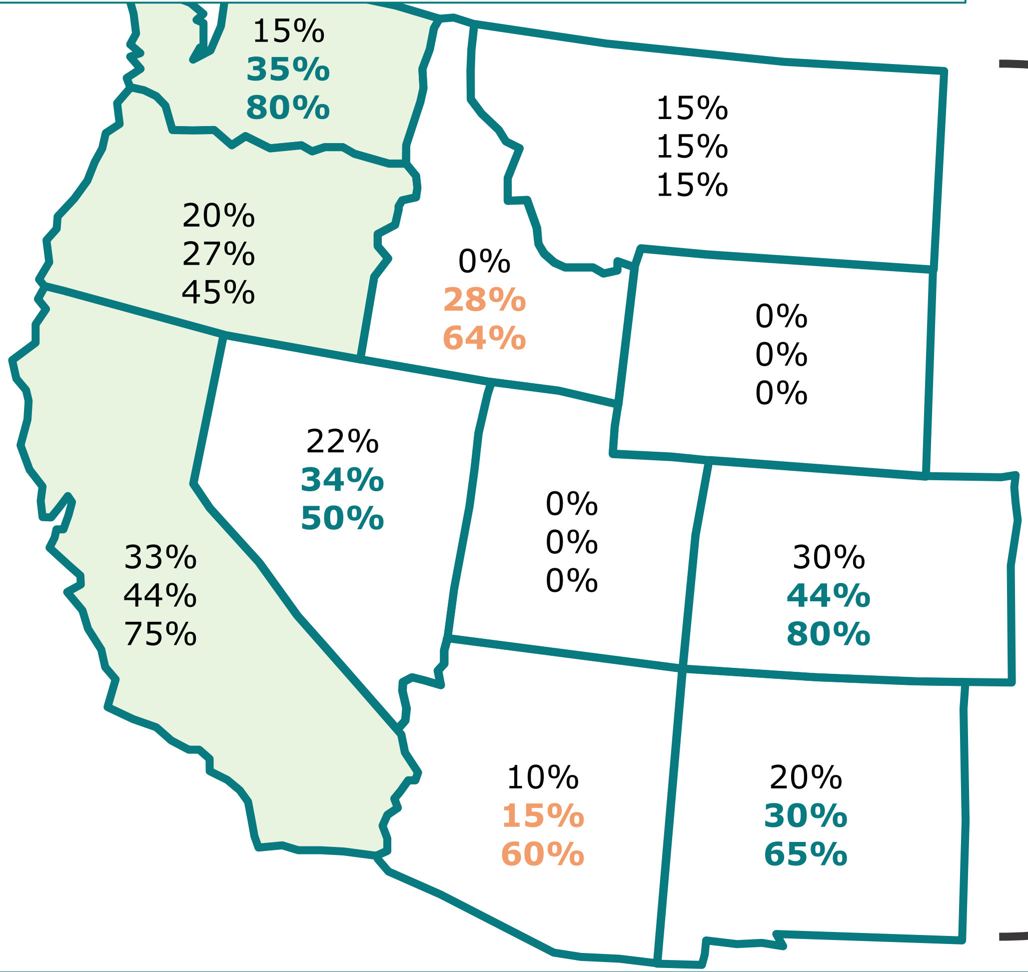
Clean/Renewable Penetration Requirements in Baseline Case

Key

- Existing policy
- Recently enacted policy
- Conceptual policy

Study year: 2020, 2026, 2035 → 22% / 34% / 50%

Assumed coordinated cap-and-trade in 2026



Clean Energy Target Based on Assumed Policies

2026	2035
33%	64%

Core Questions:

Study designed to address a number of topics related to system flexibility

- **Long-run Resource Needs**
  - Given recent policies enacted across the West, how much and what types of generation resources may be required to achieve policy goals?
  - To what degree are thermal generation retirements expected to occur?
  - Does the achievement of the state policies, as modeled, appear to be feasible on a regional basis?

- **Northwest Adequacy**
  - What is the nature of the Northwest's long-term capacity challenge?
  - How much new gas-fired generation is necessary to ensure future adequacy as renewable resources are added to the system?
  - Can energy storage and demand-side resources defer the need to construct thermal resources in the Northwest? Are these resources capable of meeting long-duration capacity needs?

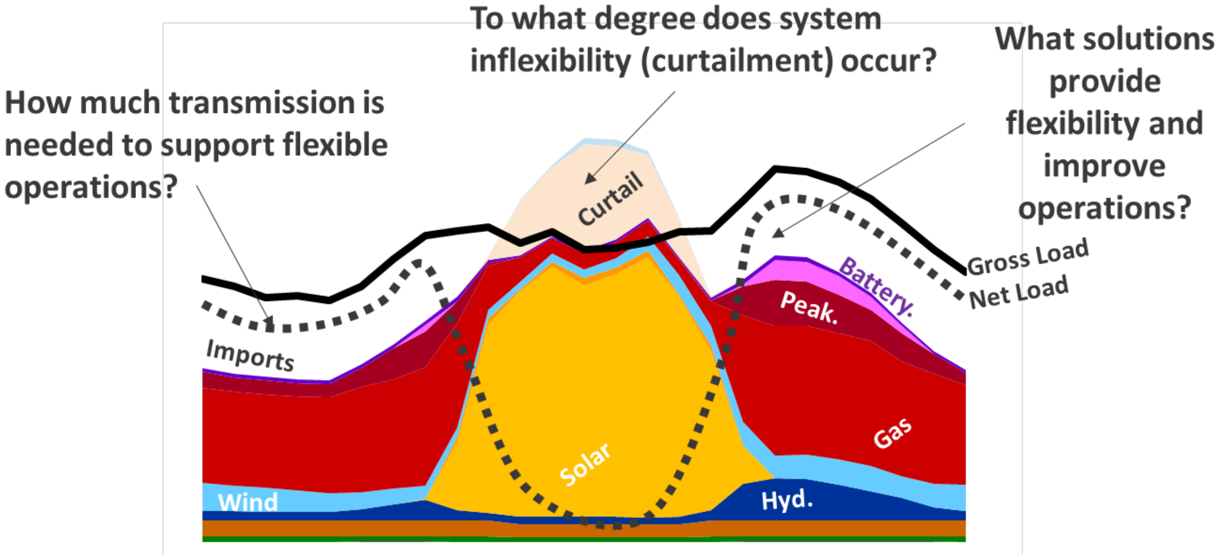
- **Operational Challenges**
  - How much renewable curtailment does the study forecast for different Western regions as state energy policies are met?
  - How much curtailment is driven by transmission limitations versus operational constraints?
  - How might clean energy policies impact capacity factors of the thermal fleet, and how might the thermal fleet operations change over time (e.g., ramping)?
  - When do the most difficult operating conditions occur, and how do those conditions change over time?

- **Transmission and Power flows**
  - As state policies are implemented, how might intra- and inter-regional transfers and/or congestion be impacted?
  - How might changes to inter-regional transfer capability (or flexibility) impact power flows?
  - How do transmission stress conditions change over time?

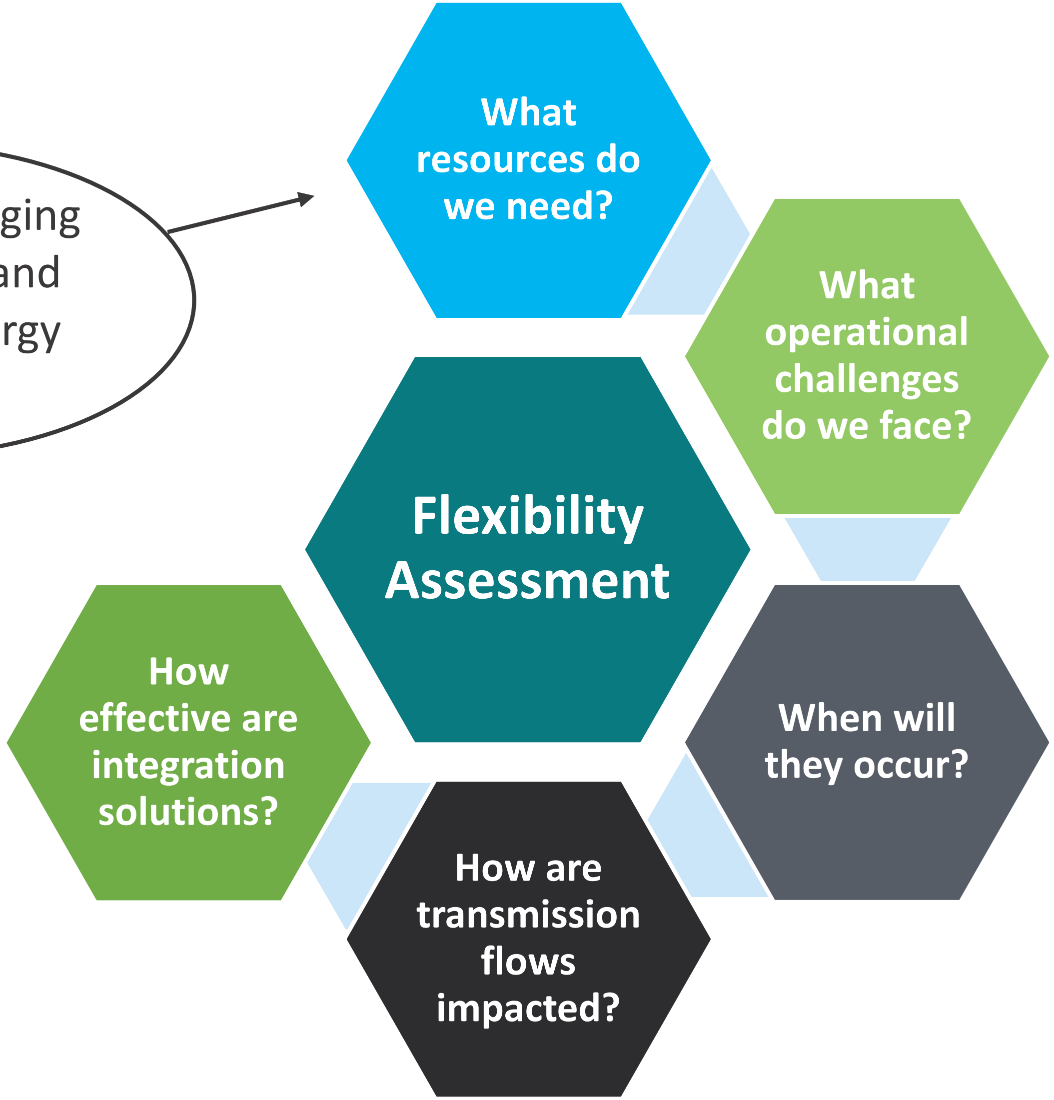
What does "flexibility" mean in the context of this study?

- **Study investigates long-run challenges in meeting recently enacted or anticipated public policy targets**
- **Takes a broad view of "system flexibility"**
- **More than just operational challenges – relates to what resources you choose, how you operate them, and what transmission limitations you might face**

Given the changing resource mix and new state energy policies…

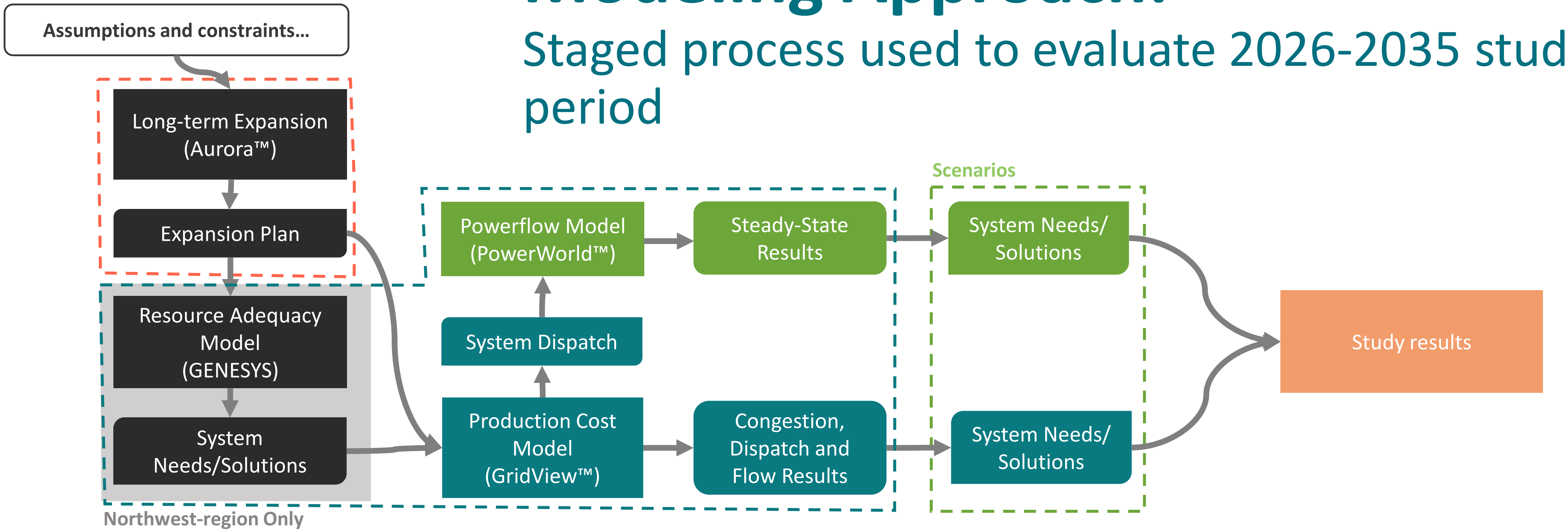


24-hour day on system with high solar output



Modeling Approach:

Staged process used to evaluate 2026-2035 study period



1. An expansion plan is developed to meet state policies and extra scrutiny is given to Northwest resource adequacy. The plan is adjusted based on this analysis.
2. Production cost modeling is performed to evaluate system performance. Solutions are evaluated and system L&R during stressed conditions are passed to powerflow model.
3. Powerflow modeling evaluates reliability performance for steady-state and dynamic studies. Needs and solutions are considered.
4. Results from all studies synthesized to draw conclusions regarding resource build, adequacy, integration challenges, and effectiveness of solutions

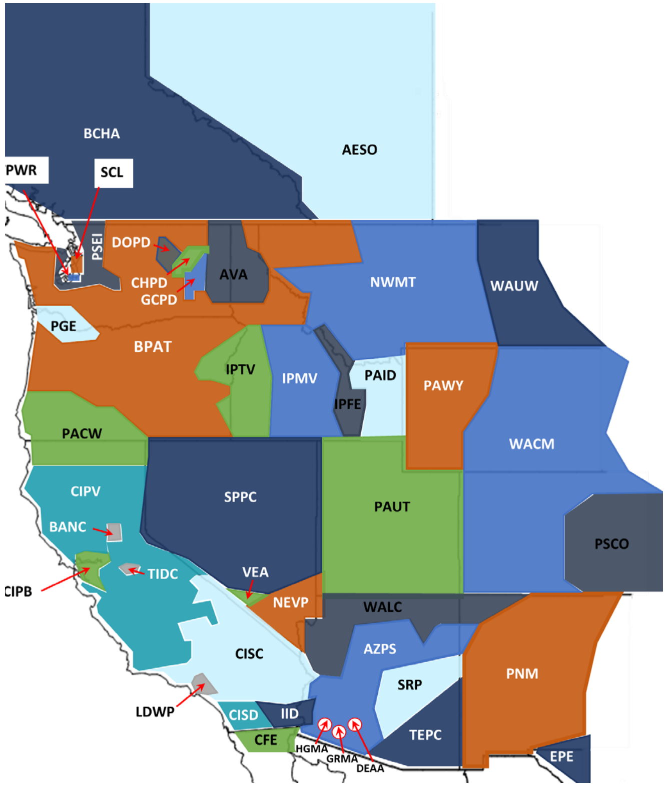
Four modeling tools used to answer specific questions…

	Aurora™	GENESYS	GridView™	PowerWorld™
Developer	Energy Exemplar	NW Power Council & utilities	ABB	PowerWorld Corp.
Purpose	Capacity expansion Price forecasting	NW-specific resource adequacy	Nodal operations and transmission congestion analysis	Transmission reliability analysis
Used by?	Numerous utilities/consultants	BPA, NWPCC, NW utilities	CAISO, WestConnect, ColumbiaGrid, NYISO	Many NW utilities, consultants, WestConnect
Features	Zonal topology for WECC Add/retire generation Minimize total system cost Reserve margins Capital cost trajectories Fuel forecasts Policy representation Ancillary services Hydro constraints	Hydro system constraints Hydro system budgets Zonal transmission Stochastic model Hourly operations ~6000 simulations 77-years streamflow 80 temperature years Forced outages	Security constrained dispatch Hourly supply-demand Nodal (bus) WECC grid Marginal loss Hydro constraints WECC Path represented Ancillary reserves modeled	System reliability Steady-state studies Full WECC system Transient stability Frequency response Full bus model Contingency analysis
Study metrics	Resource additions Retirements Emissions Market prices	Loss of load probability (LOLP) Expected unserved energy (EUE) Loss-of-load hours (LOLH) Loss-of-load events (LOLEV)	Generation dispatch Transmission congestion Generation curtailment Emissions Nodal pricing	Thermal overloads

Study Footprint:

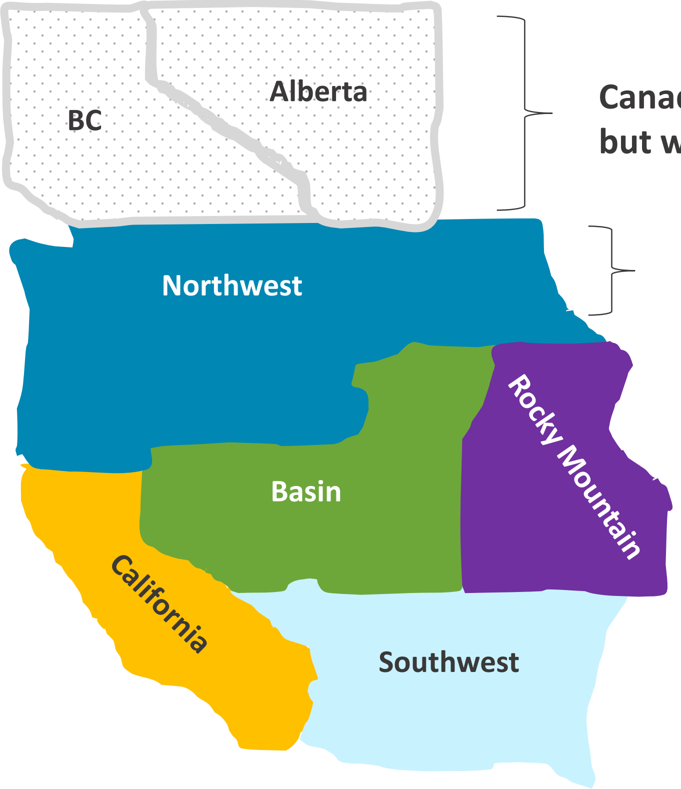
Results conveyed at regional-level, but modeling performed on full grid

WECC Balancing Areas



Full nodal analysis used in congestion and powerflow studies represent detailed system (no regional aggregation)

Study Regions



Canadian footprints are represented in modeling but were not focus of study – assumed BAU

Northwest region consistent with NW Power and Conservation Council footprint

Capacity expansion study captures transmission limitations between regions and limits inter-region resource selection based on inter-regional transmission limitations when appropriate

Study Considerations:

Study required a number of simplifying assumptions

- **Broad geographical scope means study is not positioned to address nuanced issues for a particular state or sub-area**
- **Mostly a deterministic analysis and did not have the benefit of robust sensitivity analysis**
  - ❖ Considers a narrow set of potential futures
  - ❖ Varying these assumptions will result in different study results
- **Does not address all aspects of renewable integration or system flexibility**
- **Study necessarily made numerous assumptions about the siting of new resources, retirement dates of existing resources, and other supply-side assumptions**
- **Transmission analysis imbedded in this study is not designed to replicate or supplant local, regional, or interconnection-wide planning efforts**
- **Model-derived forecasts around future resource portfolios is not sufficient to supplant modeling done on more granular scales, such as that performed in IRPs**

Study Metrics (Part 1)

Curtailment

- Used to characterize system inflexibility and is default flexibility solution – ensures generation = load
- Defined by NREL as **"a reduction in the output of a generator from what it could otherwise produce given available resources, typically on an involuntary basis"**
- Excess generation, transmission congestion, or general system inflexibility – such as operating constraints or "must-run" requirements – are all potential drivers of curtailment
  - When operational modeling results in pricing that is lower than the opportunity cost of renewable generation, curtailment occurs
- Study does not assume that curtailments are uneconomic, nor does it assume that all curtailments on the system should be eliminated. It does, however, use the existence of large numbers of curtailment system wide as an indicator of an inflexible system

Ramping

- Flexibility metric that gauges how system operations are changing under high penetrations of renewables
- Net load in a given hour for a given footprint = demand minus output from wind and solar production
- Net load ramps in this study can be met with local generation in a given region or state, or with neighboring generation imported on the transmission system
- This is one of the reasons why transmission is important to grid flexibility

Fuel Type	Installation Year or other description	Curtailment Cost (2018$/MWh)
Wind	Existing and Old, <=2015	-15
	Existing and New, >2015 & <=2020	-40
	New >2020	-15
Solar	Existing and New	-15

Resource Adequacy

- Northwest adequacy issues are addressed in this study
- Region is hydro/weather dependent and is home to increasing renewable penetrations
- Numerous recent studies on the topic – this one adds to the literature
- NWPCC is responsible for creating regional power plans and adopted a resource adequacy standard in 2011 that requires that the LOLP for the region be less than 5% for five years into the future
- The NWPCC is currently considering revisions to this standard, so this study uses the standard only as a reference point
- LOLP: loss of load probability

Study Metrics (Part 2)

Transmission metrics

- Study reports flows and congestion on WECC paths and between study regions
- Reliability evaluation included contingency analysis for critical system conditions

WECC Paths

Production costs

- Includes fuel costs, generator start-up costs, variable/fixed operations and maintenance costs, among others
- Study reports production costs for single study years (e.g., 2026), so they are presented as annual values
- Production cost changes do not capture all system costs, including those associated with transmission. They also do not include capital costs

CO_2 emissions

- Metric is important to this study because many of the policies driving the change in resource mix at issue in this study were created to reduce CO2 emissions.
- Tells us how different flexibility solutions impact emissions

Clean Energy Targets

- Study attempts to reflect the nuances of each Western state's RPS and/or clean energy standard.
- In most instances, RPS resources include wind, solar, bio-fuel, and geothermal.
- Assumed modeling of clean energy standards adds certain hydro and nuclear generation serving Washington, and nuclear generation serving Arizona
- To simplify reporting, we refer to the aggregate demand for these "policy compliant" resources as a west-wide "clean energy target"

Baseline Case Assumptions:

Defining an expected future scenario with “default” levels of system flexibility

- **Renewable resources are deployed to meet clean energy policy requirements;**
- **Regionalization of energy markets occurs and there is a market platform that allows for fully-optimized day-ahead and real-time trading between all Western Balancing Areas, free of transmission service charges;**
- **Near-term resources identified in integrated resource portfolios (IRPs) are constructed;**
- **Only transmission projects with a direct path to cost recovery are built;**
- **Load growth occurs consistent with recent forecasts;**
- **Resource costs change over time consistent with recent forecasts;**
- **8.3 million new electric vehicles (EVs) are deployed by 2035 (3.7 GWa of added load).**

WECC-wide modeling is at the core of study, with goal of reasonably estimating high-level grid implications of Western state policy

2019	2026	2030	2035

Pre-study Period

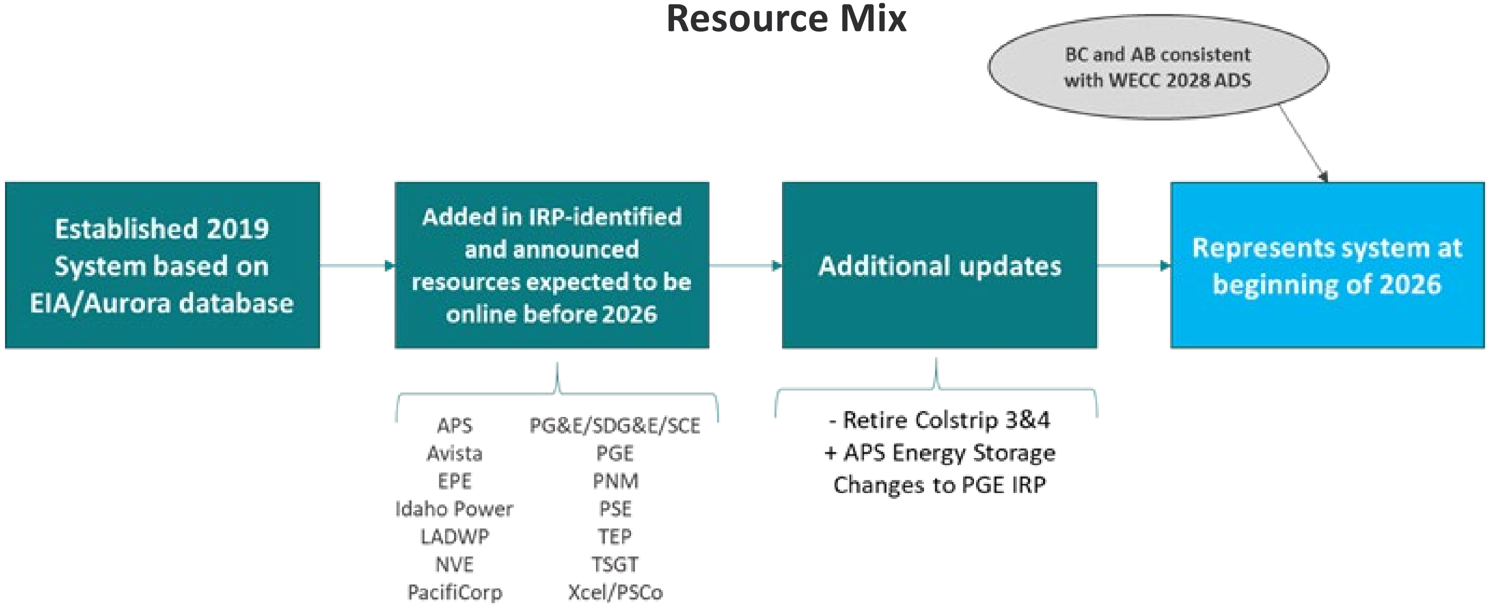
- ✓ Assume that resources identified in IRPs are constructed, including energy storage
- ✓ Approved transmission included in models
- ✓ Planned/announced generation retirements through end of 2025 are assumed to take place
- ✓ Regional market development achieved and day-ahead power trading is optimized

10-year Study Period

- Key study assumptions implemented over study period
  - ✓ GHG/RPS policy targets are enforced
  - ✓ Load growth projections
  - ✓ DR/EE potential forecasts and implementation
  - ✓ Anticipated DG penetration
  - ✓ Changes in resource/storage capital costs
  - ✓ Certain generation retirements and additions hardwired
  - ✓ No incremental transmission unless it is approved
- Determined through modeling for study period:
  - Resource additions
  - Operational dynamics and curtailments of renewable resources
  - Compliance with state policies (regionally)
  - Generation retirements
  - Power flows and congestion
  - Detailed study of adequacy of Northwest system

Approach to Define Resource Mix:
Existing + Plans + Modeled Capacity Expansion

Analytical Process to Develop Starting Point Resource Mix



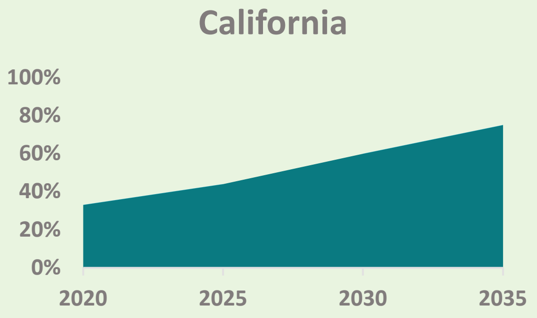
Summary of Existing and Planned Resources in Western U.S. (MW)

Resource Type	2019	2025	Change
Coal	34,336	23,863	(10,473)
Natural Gas	100,105	98,044	(2,062)
Geothermal	3,181	3,268	87
Bio-Fuel	3,359	3,465	106
Hydro/PS	71,822	72,627	805
Nuclear	7,443	6,908	(535)
Solar	19,144	24,522	5,378
Wind	28,230	32,607	4,377
DG	11,774	18,741	6,967
Other	2,354	4,957	2,603
TOTAL	281,750	289,002	7,252

- Baseline Case existing resource assumptions, including announced retirements, were sourced from multiple databases
- Assumptions for planned resource additions were also incorporated into the Baseline Case
- Capital expansion modeling determined incremental resources additions (beyond existing and planned) and economic retirements for Baseline Case during the 2026-2035 study period

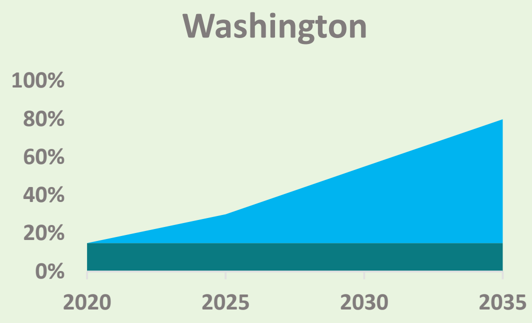
Baseline Case GHG Reduction Policy Assumptions by Region and State (2020 – 2035)

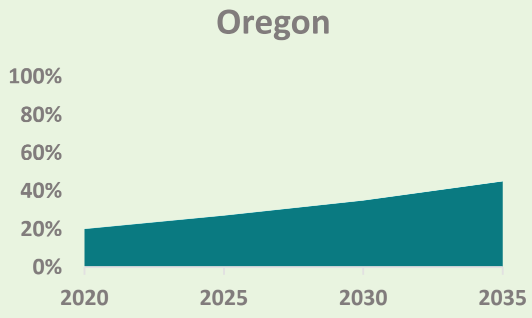
California

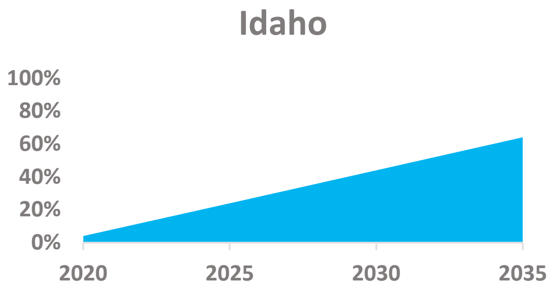


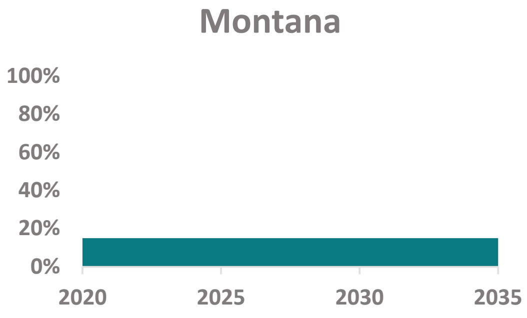
Baseline case assumes CA, WA, OR have carbon cap and trade program by 2025 with common allowance trading platform

Northwest

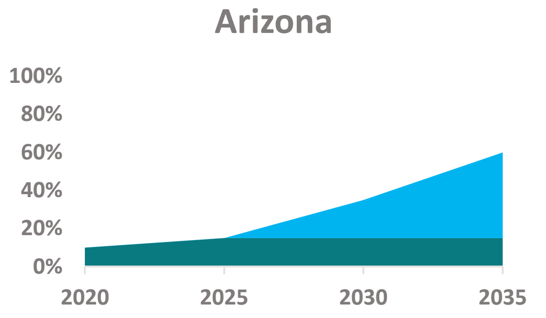


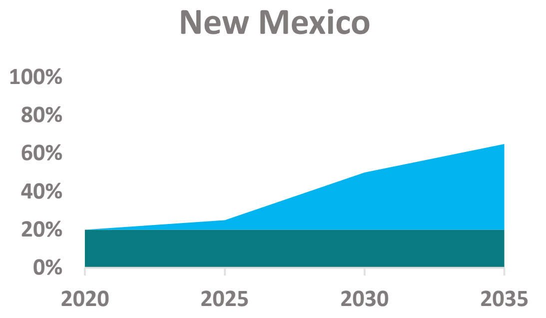




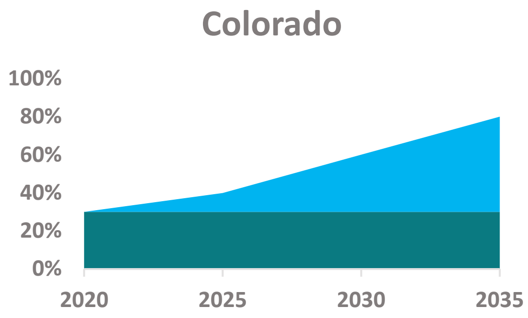


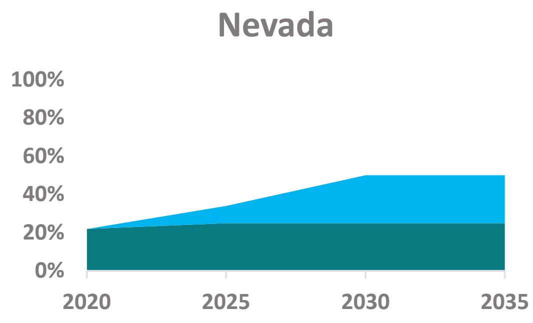
Southwest





Intermountain/Basin





= Baseline Case

= Business as Usual

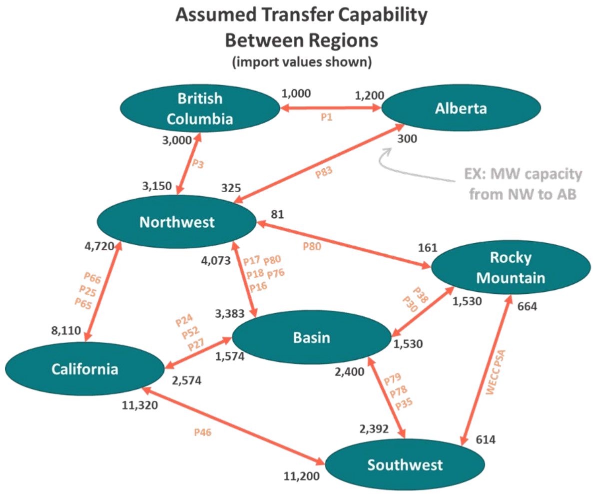
- Wyoming and Utah have no new policy assumed in Baseline Case.
- Washington and Arizona policies are "clean" and count Nuclear

West-wide RPS% in 2035 Baseline: ~64%
Increase from BAU: ~60% increase

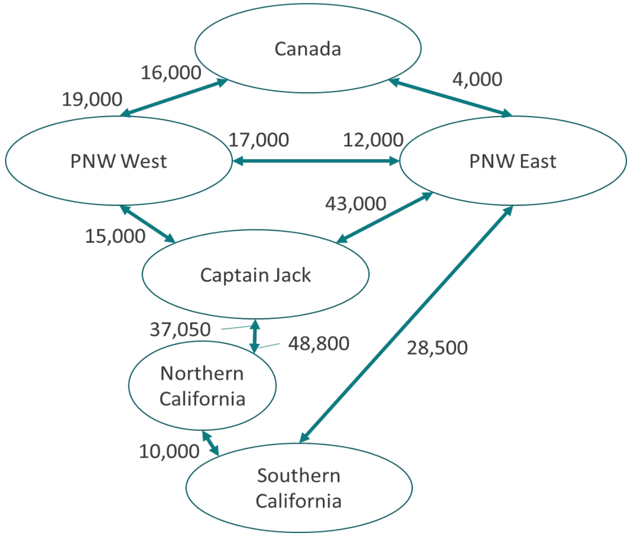
Each model required different transmission granularity

- **Included only "approved" transmission projects**
- **Production cost and power flow modeling were nodal and included extensive representations of the Western Interconnection's transmission system**
  - ❖ The production cost and capital expansion models assumed zero transmission service wheeling charges to represent that a regional, WECC-wide market had been achieved by 2026
- **Capital expansion and GENESYS modeling used zonal topologies:**

Topology of capital expansion modeling



Topology of GENESYS modeling



New resource options developed for every state and region

- **New resource types included:**
  - Biomass
  - Natural gas aero-derivative combustion turbine
  - Natural gas frame combustion turbine
  - Natural gas combined cycle
  - Geothermal
  - Solar photovoltaic (PV)
  - 4- and 8-hour lithium-ion storage
  - 12-hour pumped storage
  - Wind (onshore and off-shore)
- **Resource capacity values were based on regional or sub-regional location, the location's peak load season, and resource type**

- **Each new resource option had a fixed cost (capital cost, property tax, and insurance) and fixed O&M cost trajectories for the entire study period based on their location and the load each resource might serve**
- **The capacity value for new wind, solar, and storage resource options was assumed to decrease commensurate with their energy penetration in each portion of the Western system, to represent the decline in capacity value for the marginal**

- **Cost assumption data sources:**
  - WECC/E3 Capital Cost Calculator.
  - NREL 2018 Annual Technology Baseline (ATB).
  - PacifiCorp 2019 IRP Resource Table.
  - PacifiCorp 2017R RFP Results and subsequent regulatory filings.
  - Xcel regulatory filings for Colorado Energy Plan.
  - Lazard Levelized Cost of Storage 4.0.
  - "Projecting the Future Levelized Cost of Electricity Storage Technologies"; Schmidt, o. et. Al.; January 2019.
  - Cost and Performance Characteristics of New Generating Technologies; EIA; January 2019.
  - 2018 U.S. Utility-Scale Photovoltaics-Plus-Energy Storage System Costs Benchmark; Fu, Ran et. al., November 2018.
  - 2017-18 CPUP IRP Input Assumptions (RESOLVE Model Documentation).

Out-of-State New Resource Options & Transmission Availability Assumptions

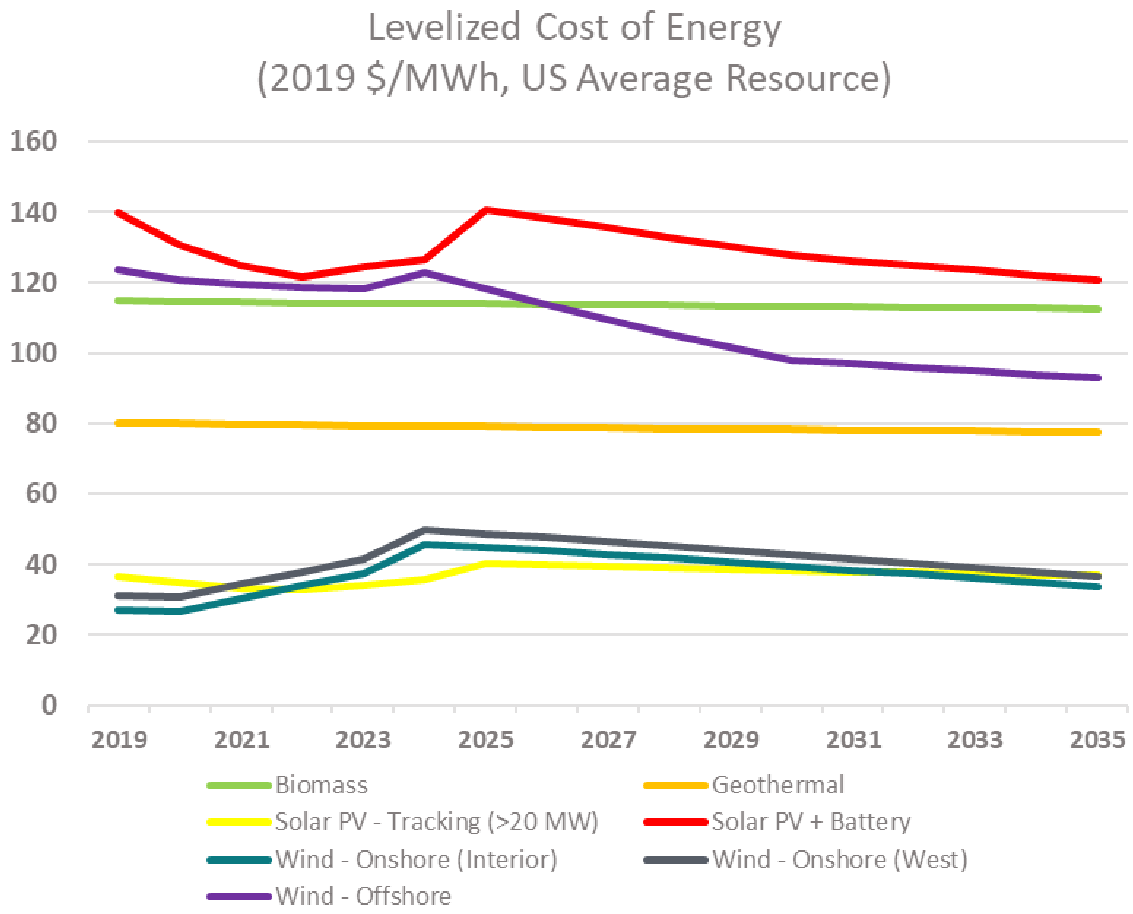
- Considered plausible out-of-state resource options
- Study considered transmission cost adders for these options
- Technical potential was determined by state and/or resource type

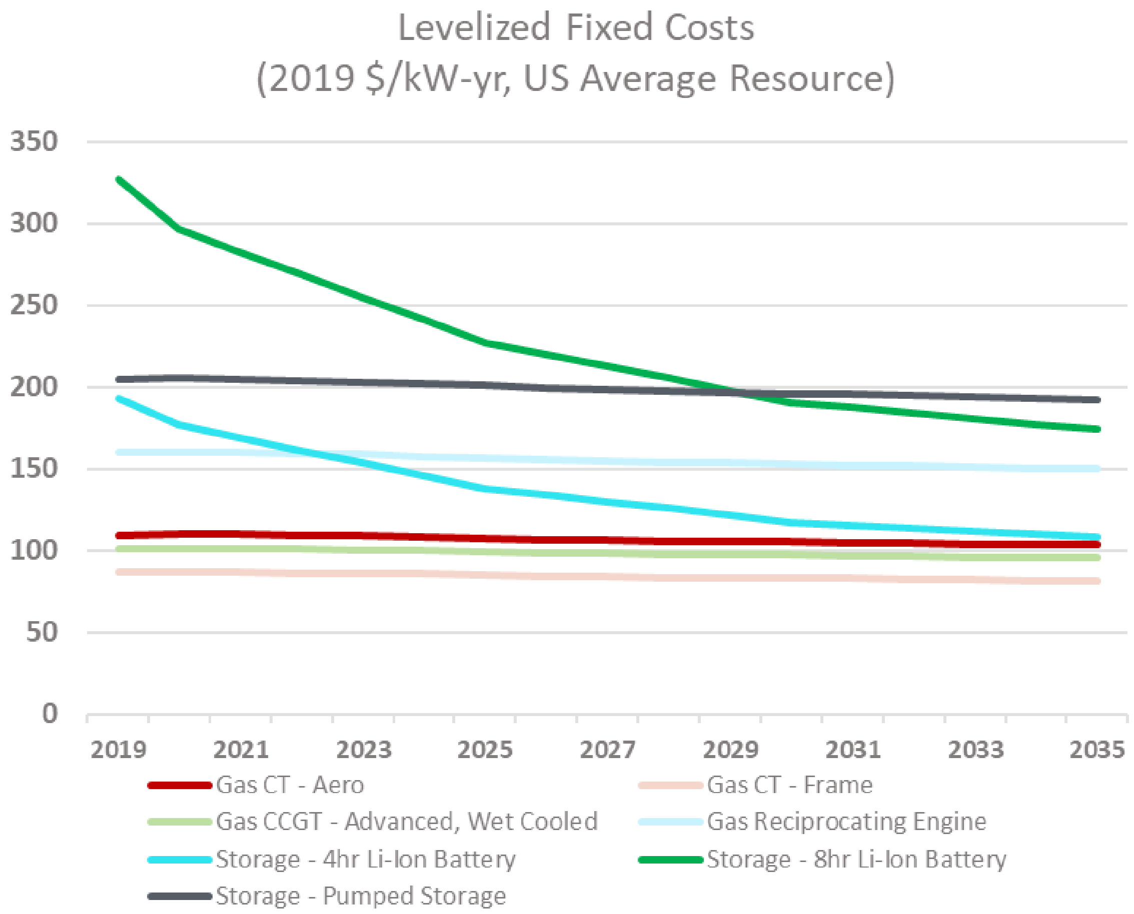
Out-of-State Resource Options in Capacity Expansion

Resource Location & Type	Out-of-State Load Location
Arizona pumped storage and solar PV	California
Idaho wind and solar PV	California, Oregon, and Washington
Montana wind and pumped storage	Oregon and Washington
Nevada geothermal and solar PV	California
New Mexico wind	Arizona and California
Oregon wind, solar PV, and pumped storage	California and Washington
Washington wind and pumped storage	Oregon
Wyoming wind	California, Colorado, Oregon, and Washington

Expected capital cost reflected in Baseline expansion plan decisions:

Cost trajectories by resource type benchmarked to today's prices





*Levelized cost values are generic and do not adjust for regional capacity factor difference or differences in regional construction costs

GHG Reduction Policy Modeling:

Oregon and Washington were assumed to join California's cap-and-trade program

- **Policy represented by:**
  - ❖ Carbon emissions price on thermal generation in California, Oregon, and Washington
  - ❖ Carbon adder wheeling charge on flows into the combined footprint of California, Oregon, and Washington
- **Assumptions based on California PUC IRP modeling for 2018 Reference System Plan ("42 MMT Case")**

GHG Reduction Policy Modeling

Carbon Emission Price and Carbon Adder Wheeling Charge Assumptions, by Year

Assumption	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035
Carbon Emission Price (2019$/Ton)	23.02	24.22	25.49	26.83	28.24	29.72	31.27	32.91	34.63	36.44
Full Carbon Adder Wheel (2019$/MWh)	9.83	10.34	10.89	11.46	12.06	12.69	13.36	14.06	14.79	15.57

Curtailment Cost Assumptions

- **Production tax credit (PTC) and the market for renewable energy credits (REC) provide incentives for certain wind and solar to "ride through" and generate during negative pricing without curtailing**
- **Hydro also had negative curtailment costs so as not to adversely disrupt its constrained operation**
  - ❖ Hydro bounded by NWPCC operating limits had the lowest curtailment prices

Fuel Type	Installation Year or other description	Curtailment Cost (2018$/MWh)	Reasoning
Wind	Existing and Old, <=2015	-15	$15/MWh REC value, assumes PTC period has expired
	Existing and New, >2015 & <=2020	-40	$15/MWh REC and $25/MWh PTC valuations provide incentive to generate during negative pricing
	New >2020	-15	REC value provides incentive to generate during negative pricing
Solar	Existing and New	-15	REC value provides incentive to generate during negative pricing
Hydro	NWPCC	-300	This hydro is already bounded to the NWPCC GENESYS operating limits so there shouldn't be any curtailment of that operation
	Non-NWPCC	-50	Use assumptions from 2028 CAISO Default PCM

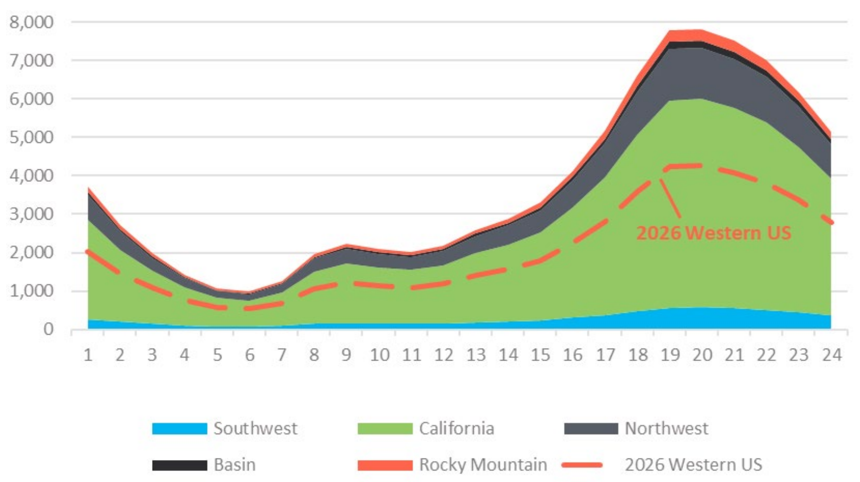
Baseline Case accounts for incremental electric load growth due to increasing penetration of electric vehicles

Electric Vehicle-driven Load across West

EV Load Energy (MWa)	2026	2030	2035	CAGR (%/yr) 2026-2035
California	1,474	1,897	2,592	5.8%
Northwest	360	511	638	5.9%
Basin	45	70	107	9.1%
Rocky Mountain	55	89	141	10.0%
Southwest	101	164	258	9.8%
Total	**2,034**	**2,731**	**3,736**	**6.3%**

- Majority of incremental EV charging load is assumed to be located in the Northwest and California
- Shape based on weekday- and weekend-specific profile developed by the CEC and NREL using the Electric Vehicle Infrastructure Projection Tool (EVI-Pro)

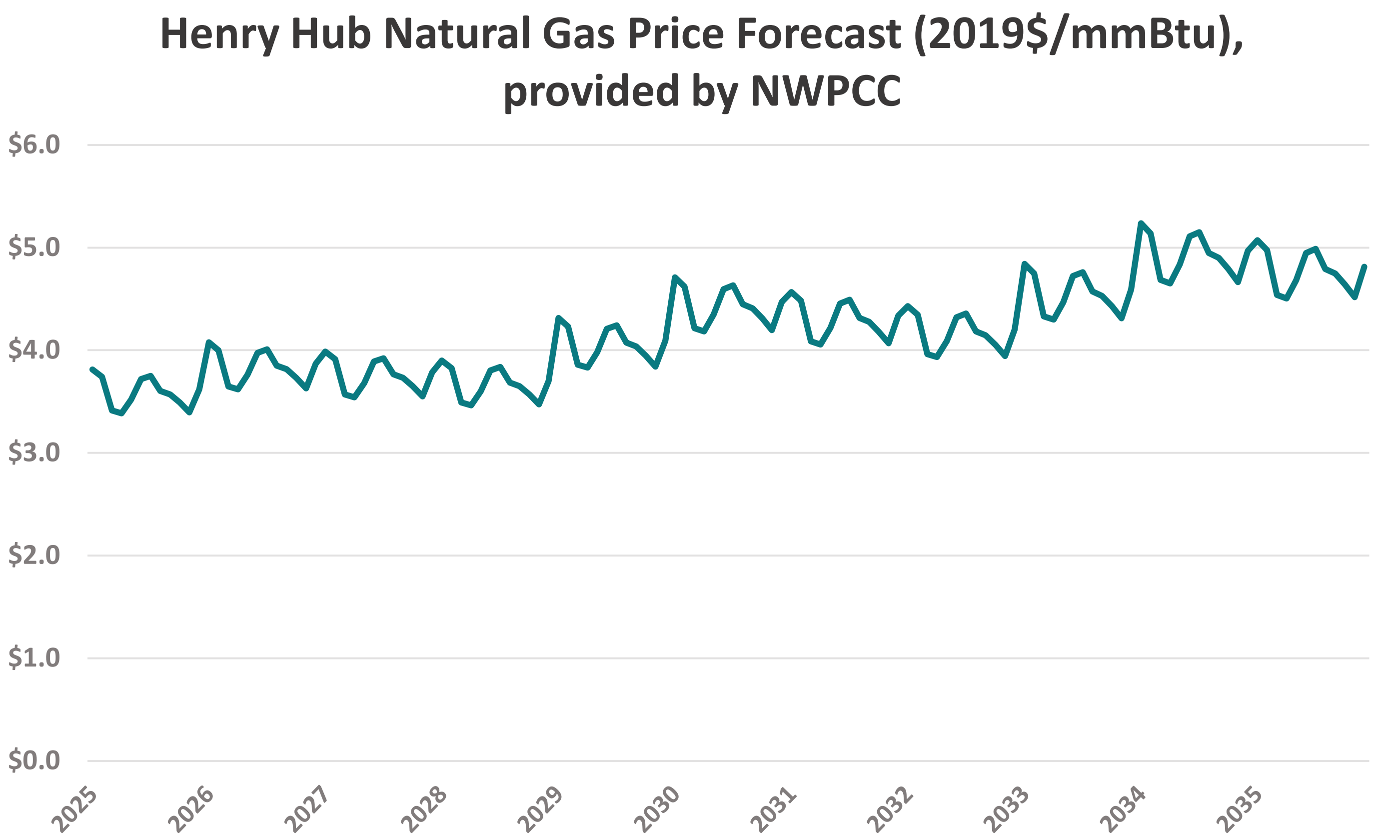
Assumed Charging Shape (Average day, MW)



Cumulative EV Population Growth

Region	New EV Population (cumulative in thousands)				Source
	2020	2025	2030	2035	
California	1,000	2,500	3,900	5,400	CEC - 2018 IEPR High Demand
Northwest	234	611	1,096	1,500	NWPCC - Mid-Demand Scenario
Southwest, Rocky Mountain, Basin	108	455	880	1,418	Calculated by ES using EIA AEO 2019, CEC
Total	**1,342**	**3,566**	**5,876**	**8,318**	Energy required and shapes based on CEC tools

Gas prices based on forecasts developed by the NWPCC



- **Forecasted Baseline case coal prices using data from the 2018 EIA Annual Energy Outlook (AEO)**

Baseline Case Summary

- **What it is:** Assumes that planned or potential RPS or GHG reduction policy is implemented in certain states; intended to represent an expected future
- **What it is NOT:** An endorsement or prediction of any specific policy or a determination around specific infrastructure needs

Western Mix (MW): Forecast for Baseline Case in 2025

Resource Type	2019	2025	Change
Coal	34,336	23,863	(10,473)
Natural Gas	100,105	98,044	(2,062)
Geothermal	3,181	3,268	87
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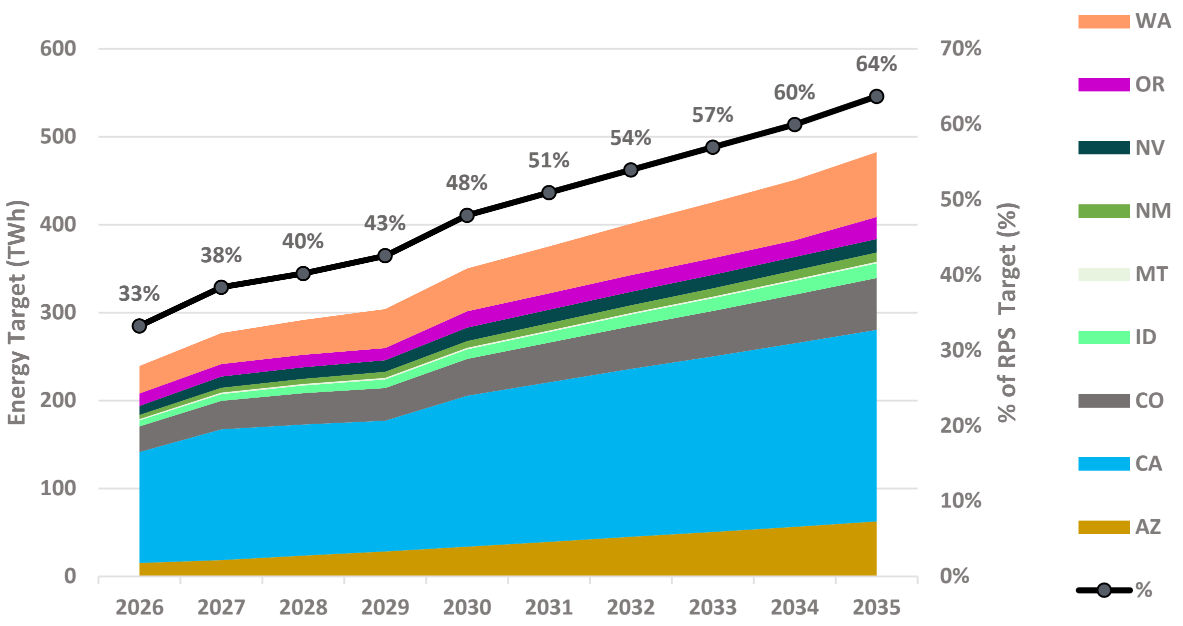
DG	11,774	18,741	6,967
Other	2,354	4,957	2,603
TOTAL	**281,750**	**289,002**	**7,252**

Data sources: EIA, WECC Anchor Data Set, California PUC IRP (2017-18), utility IRPs

Baseline Case Clean Energy Target (%) and State Breakdown (GWh)

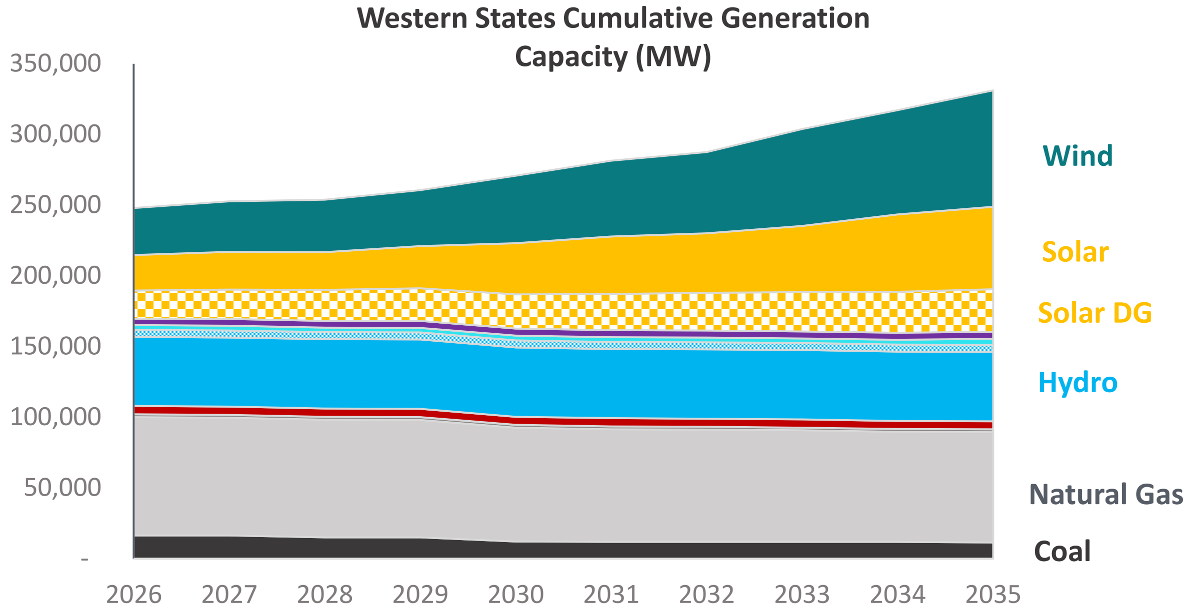


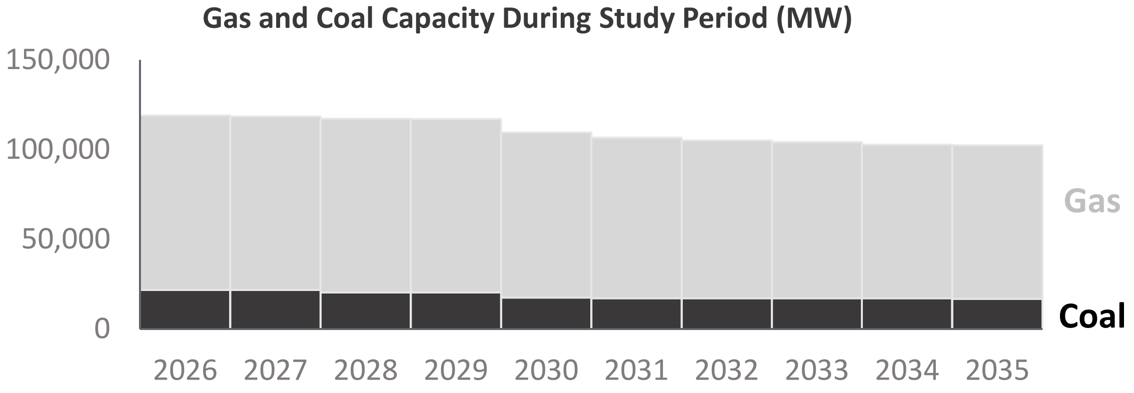
Load	Transmission	Generation	Other
WECC-wide gross load at **0.8% CAGR**	Only approved upgrades assumed in-service	Announced and anticipated coal retirements	DA market implemented by 2025
25 GW of distributed PV by 2035	No Full Gateway, B2H, other regional projects	2030 CA build consistent with 17-18 IRP	2035 carbon price based on CEC IEPR: $36.44/ ton (2019$)
8.3 GW of new demand from EVs by 2035	Montana transmission available in 2025	Resource potential capped at state-level	Henry hub (2019$/mmBtu) 2026: $3.83 2035: $4.77

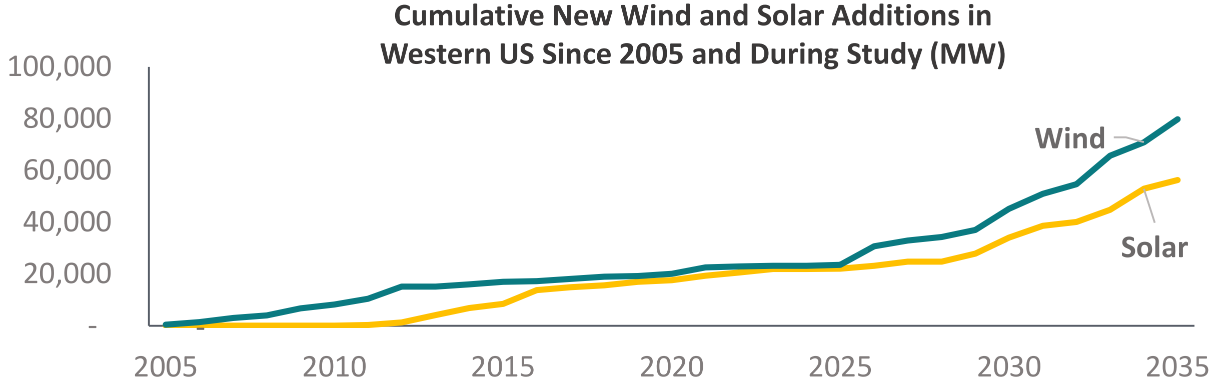
ENERGY STRATEGIES

Resource Expansion and Generation Mix

- **By 2035, zero-emission resources make up 72% of Western capacity**
  - Includes wind, solar, geothermal, hydro, and nuclear
  - Storage accounted for in separate studies
- **Zero-emission generation contributes nearly 80% of the system's energy needs by 2035**
- **Wind and solar additions from 2025 to 2035 total nearly 9 GW per year**
- **By 2035, coal nearly eliminated from the generation fleet, but gas continues to provide significant capacity (although its energy output is limited)**

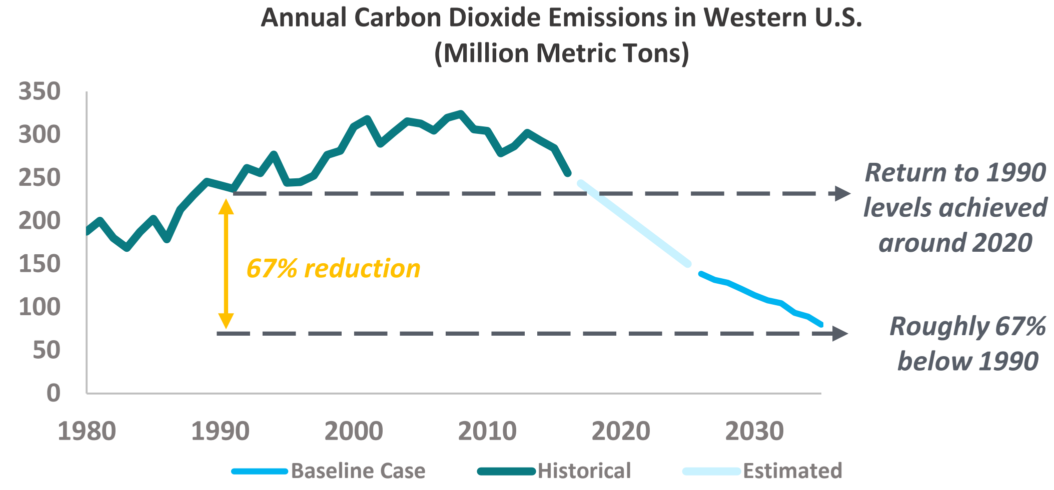


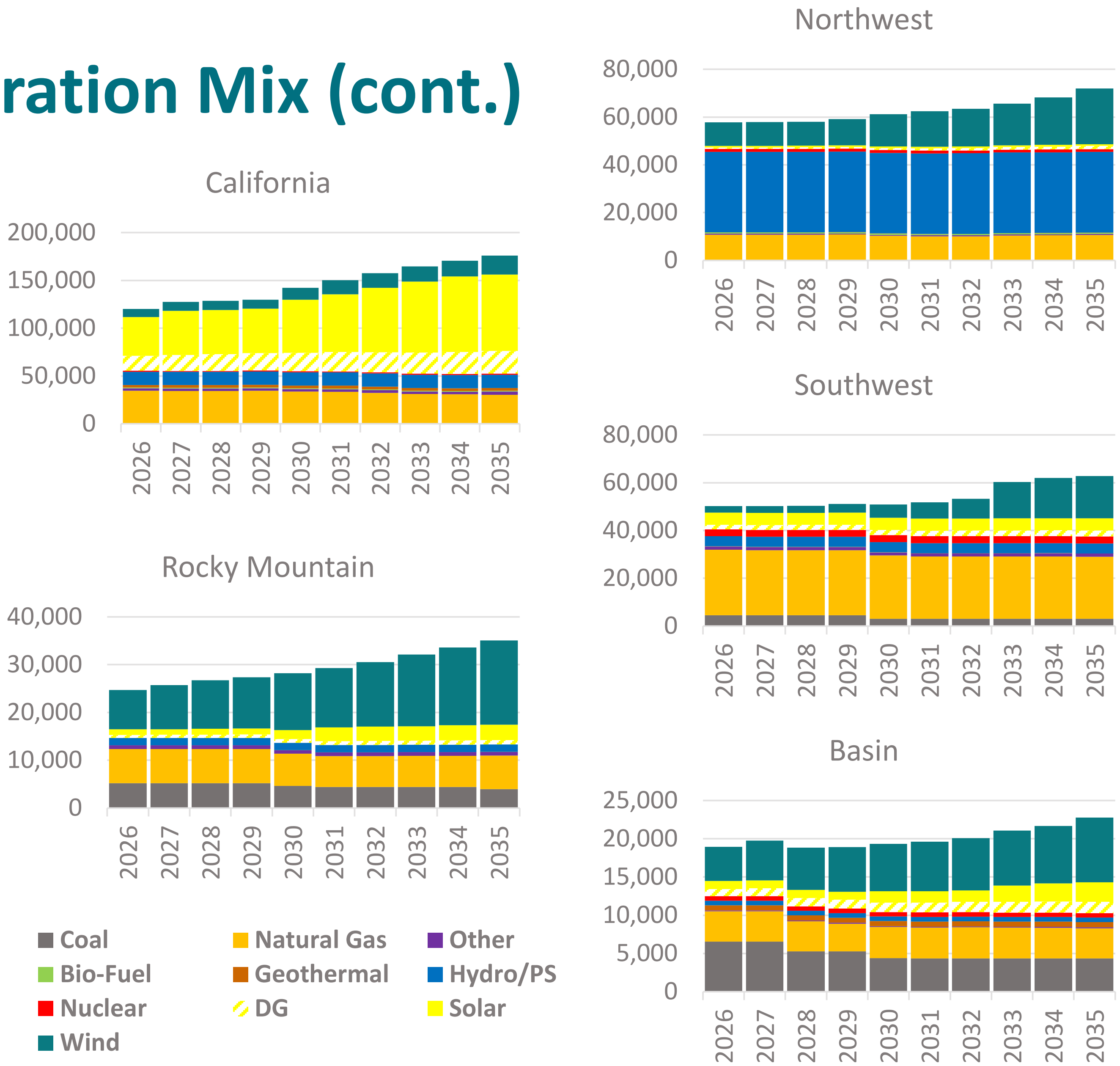




Resource Expansion and Generation Mix (cont.)

- **Significant resource diversity forecasted for all regions by the end of the study period**
- **Resource additions in the Baseline Case do not surpass technical potential limits considered in the study**
- **Policy goals and subsequent resource additions modeled in the Baseline Case cause West-wide carbon emissions to fall to 67% below 1990 levels by 2035**





Resource Adequacy in the Northwest: Details of the Approach

Goal of this study work

Issues of interest to NW sponsors:

- ✓ Investigate the nature of the Northwest capacity challenges as the region moves forward in meeting policy objectives;
- ✓ Consider what amount of new gas-fired generation might be necessary assuming the region adds resources for policy purposes;
- ✓ Evaluate the effectiveness of energy storage and demand-side options to defer or avoid the need to construct thermal resources in the Northwest.

Capacity analysis also important to evaluate when studying system flexibility as to not overstate flexibility needs.

Modeling Approach

- Study performed using GENESYS – same model used by BPA and NWPCC
- Reflects nuances and limited nature of NW hydro system
- Stochastic representation of wind, solar, load, and hydro
- Adequacy target based on NWPCC 5% LOLP threshold

Key Assumptions

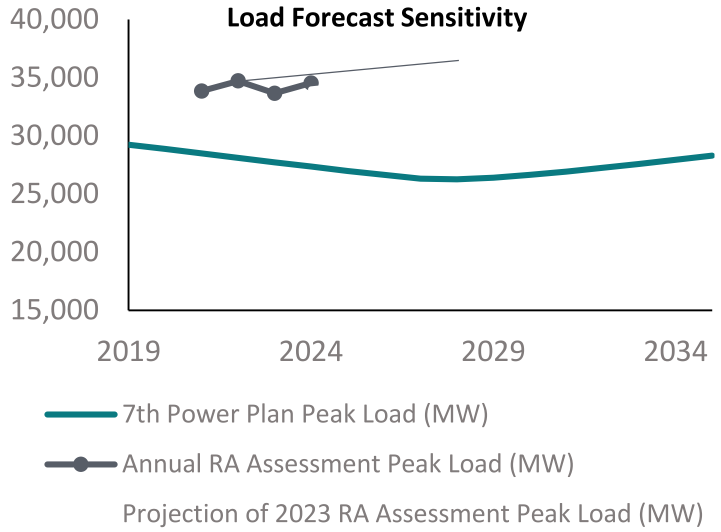
- Footprint identical to NWPCC study area
- Assumed load growth consistent with the NWPCC 7th Power Plan (0.58% CAGR)
- Reflects 4.4 GW of announced or anticipated coal retirements by 2027
- Generation mix in Northwest region established through Baseline Case capacity expansion studies to ensure compliance with assumed policies
- Varied incremental generation additions and loads

Resource Adequacy in the Northwest: Findings

- **If <u>no generation</u> is added, capacity need of 1,100 MW occurs no later than 2030**
- **Results indicate that Baseline Case includes sufficient capacity to maintain Northwest reliability through 2035**
  - Assumes that 16 GW of renewables, 3.2 GW of gas, and 5.9 GW of thermal retirements occur (by 2035)
- **If no gas is added in Baseline, 500 MW capacity need arises by no later than 2030 (8% LOLP), increasing to a 1,500 MW need in 2035 (23% LOLP)**
  - Even if public policy needs in the region are met, a minimum of 1.5 GW of firm capacity is still needed to ensure reliability

When load loss events do occur in these study cases, they are for extended periods:
Up to 36 GW and 24 hour durations

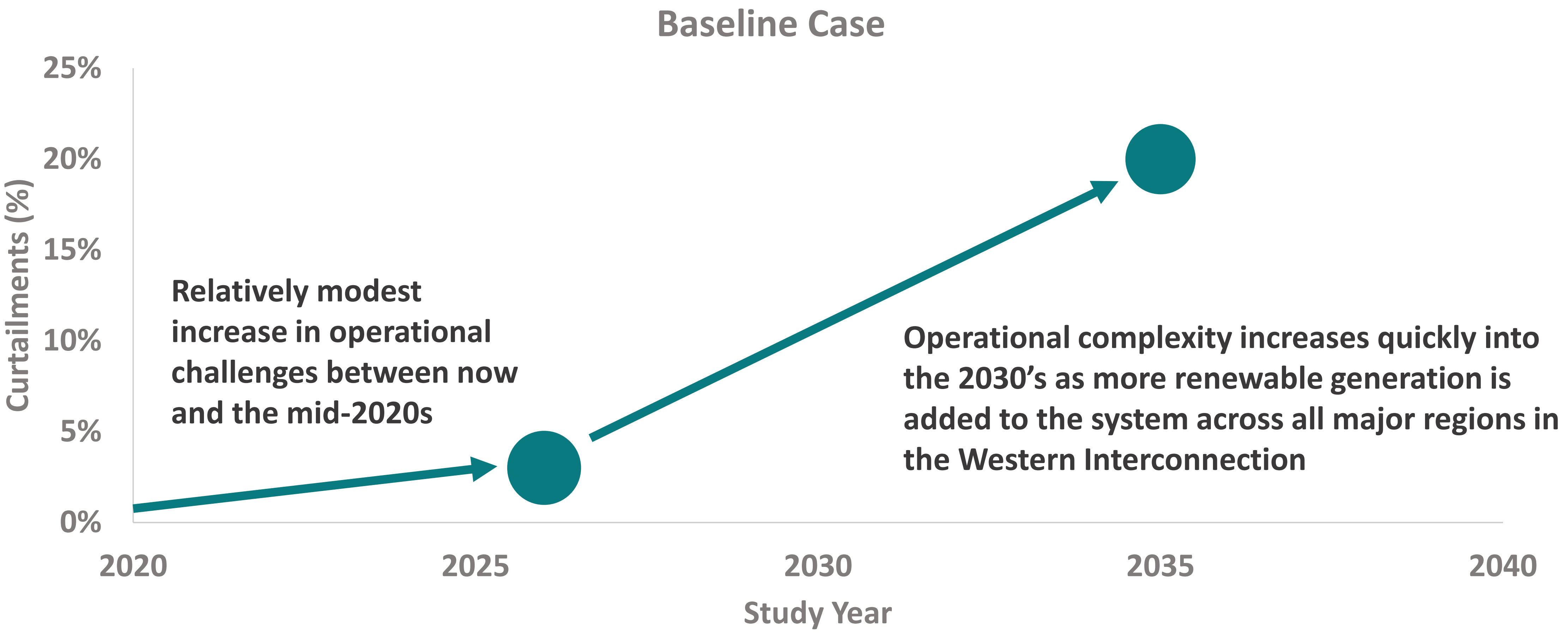
- **Long-term capacity needs for the Northwest system, after accounting for capacity supplied by policy-driven resources, can be met with: gas, long-duration storage, or increased access to market purchases**
- **The results of this study were <u>very</u> sensitive to the load forecast assumption**
  - The timing and magnitude of Northwest adequacy shortages are highly dependent on load forecast assumptions
  - The firm capacity need of the region may be as large as **2.8 GW and could occur no later than 2027**
  - Conversations about region's resource adequacy needs must consider the most appropriate load forecast



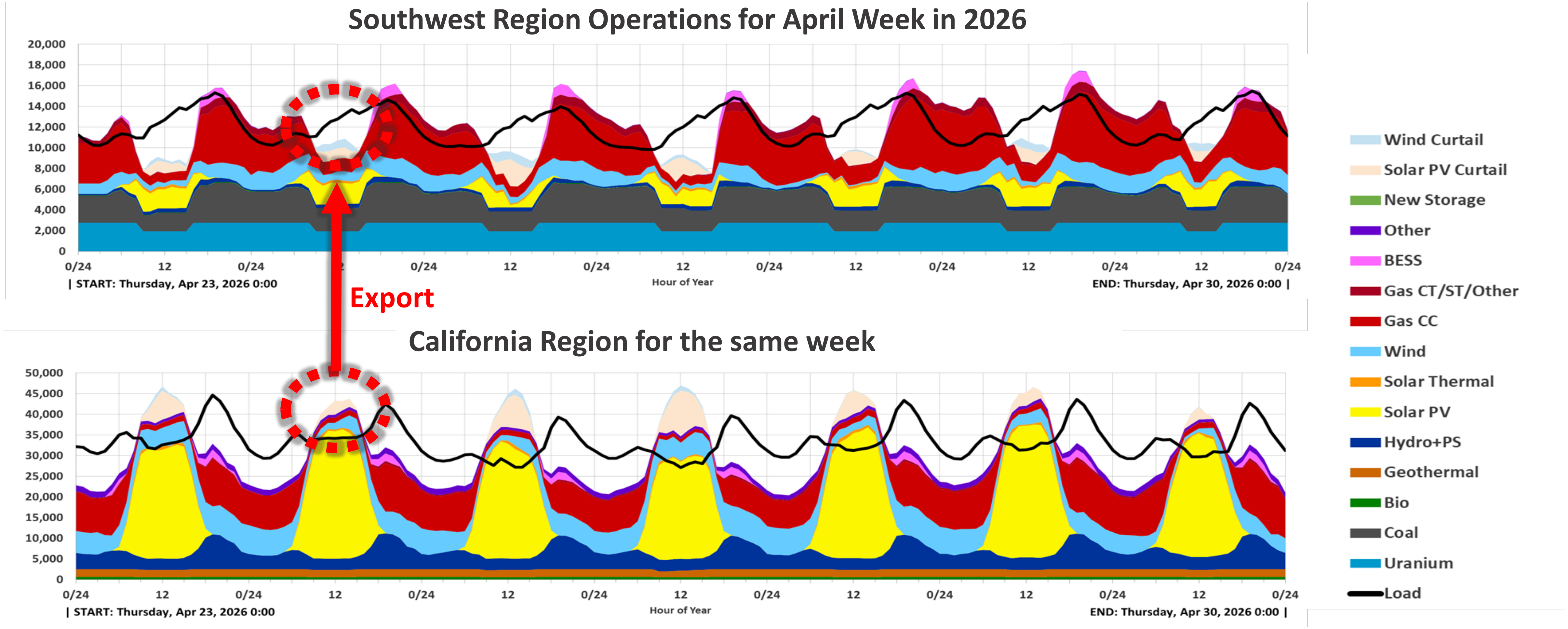
Study Year

Baseline Case	2026	2035
Curtailments (%)	3%	20%
Clean Energy Penetration (%)	✓ Hit 33% target 36%	✖ Missed 64% target 52%
Transmission Congestion	Isolated/Low	High
Production Costs ($B)	$11.1	$10.0
CO_2 Emissions (Million Metric Tons)	161	134

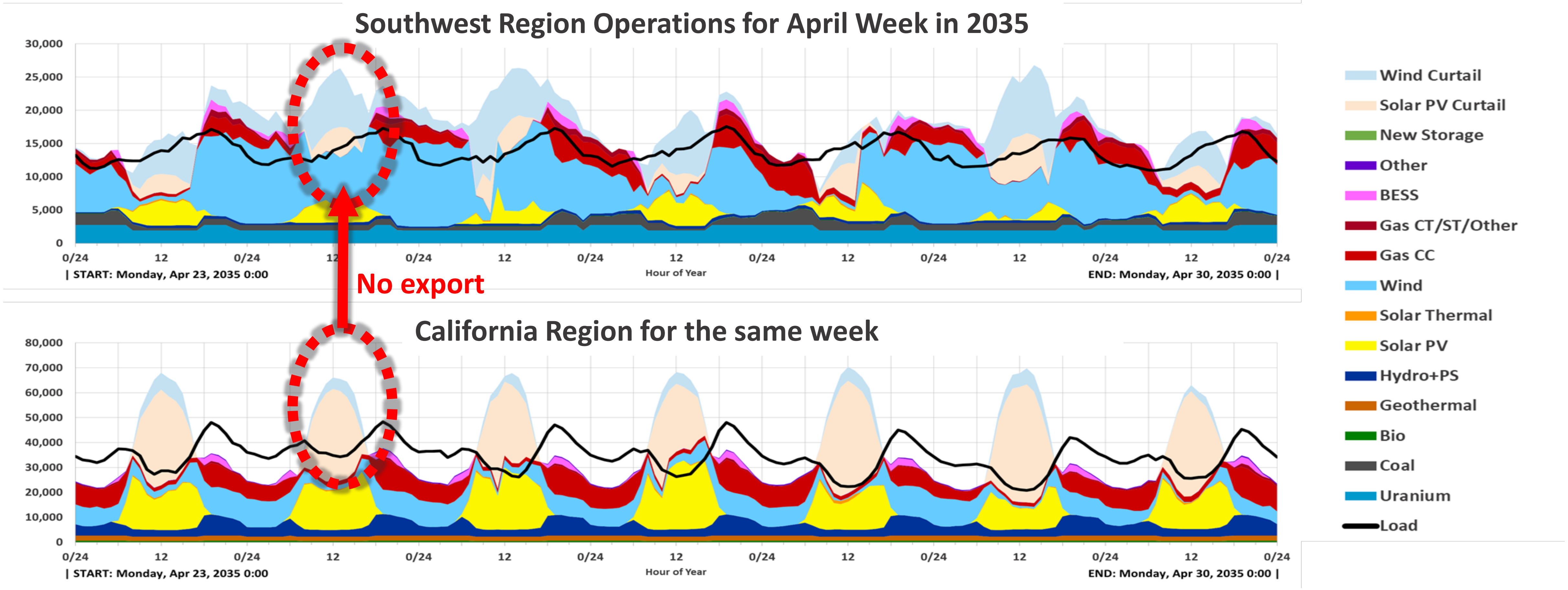
The need to implement flexibility enabling strategies across the West increases over time



In the 2020’s, interregional exchange is viable and a common flexibility strategy, however…

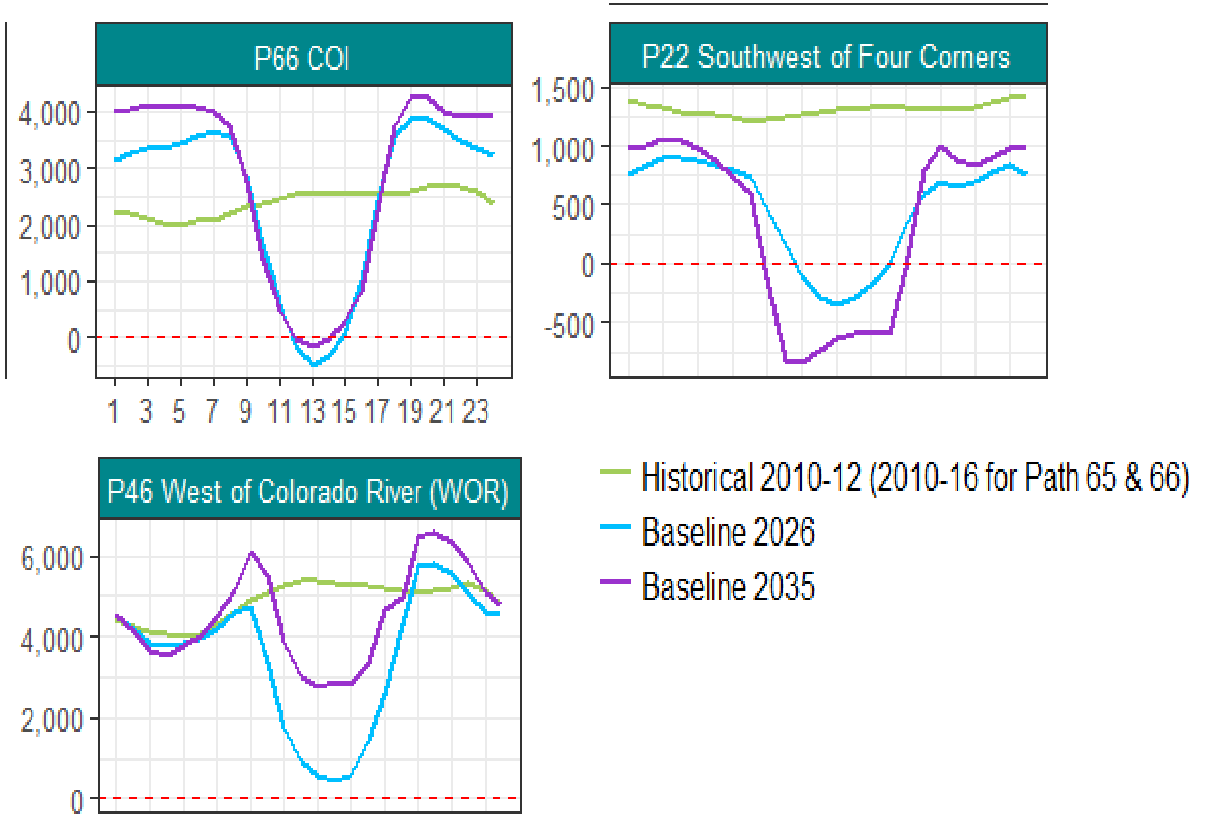


…a lack of buyers for excess renewable power is partially to blame for the flexibility challenges apparent in the 2030s

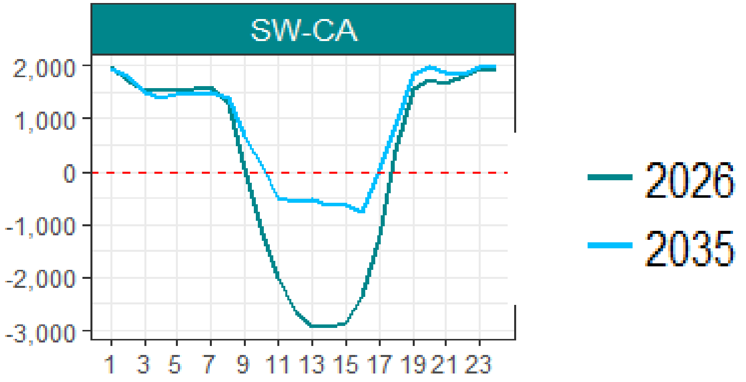


Interregional power flows increase and support system flexibility

Average hourly flows on WECC paths show divergence from history and diurnal flow patters



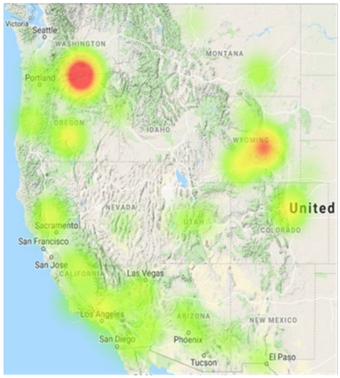
- **Results indicate that interregional power flows may change significantly from historical levels – more dynamic use of system indicates "unplanned" value in system**
- **Diurnal changes in flow patterns become the new norm**
- **In certain instances, interregional power flows can decrease under high penetrations of renewables**



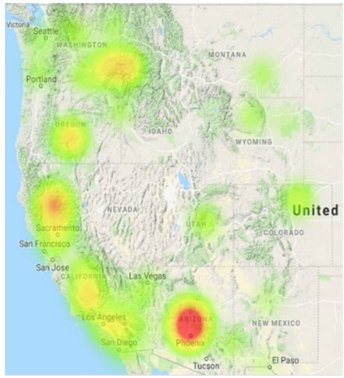
The transmission system is robust and versatile, but it does have limitations

- The near-term transmission system, as represented this study, proved to be robust from a reliability standpoint
- With few exceptions, there is very little system congestion in 2026 (with the assumed regional coordination in place), but transmission limitations represent a material barrier to achieving the assumed policy targets in 2035
- Depending on where resources are sited, there is a potential need for significant transmission expansion to meet long-run policy goals,

Few reliability "hot spots" identified in 2026



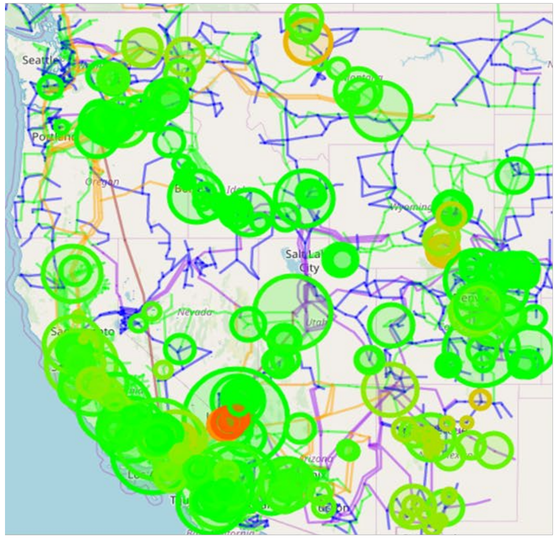
2026 Peak Renewables

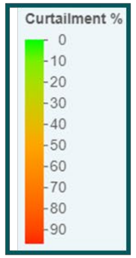


2026 Peak Demand

Isolated congestion in 2026, but more widespread transmission constraints by 2035

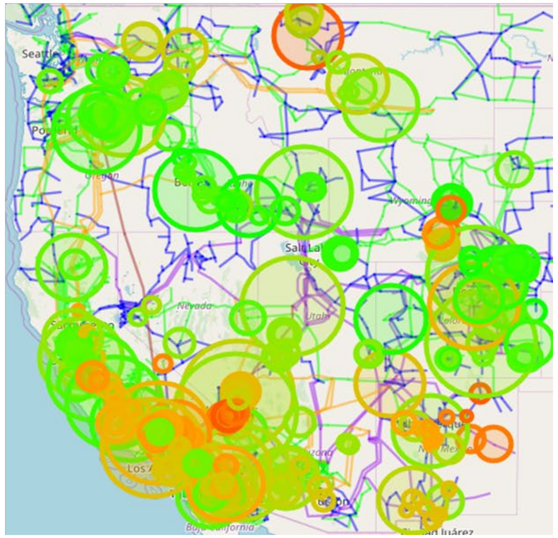
2026 Baseline





Circle size based on interconnected capacity

2035 Baseline



ENERGY STRATEGIES

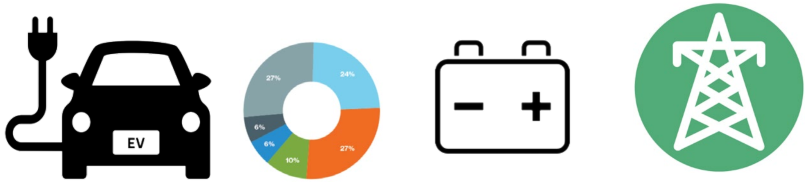
Scenarios consider flexibility levels higher and lower than the Baseline Case

Default level of system flexibility

Baseline

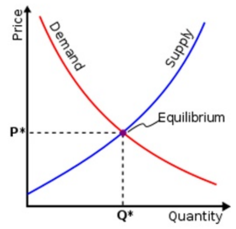
Integration Strategies — Increases system flexibility

Added:



Limited Regional Coordination — Decreases system flexibility

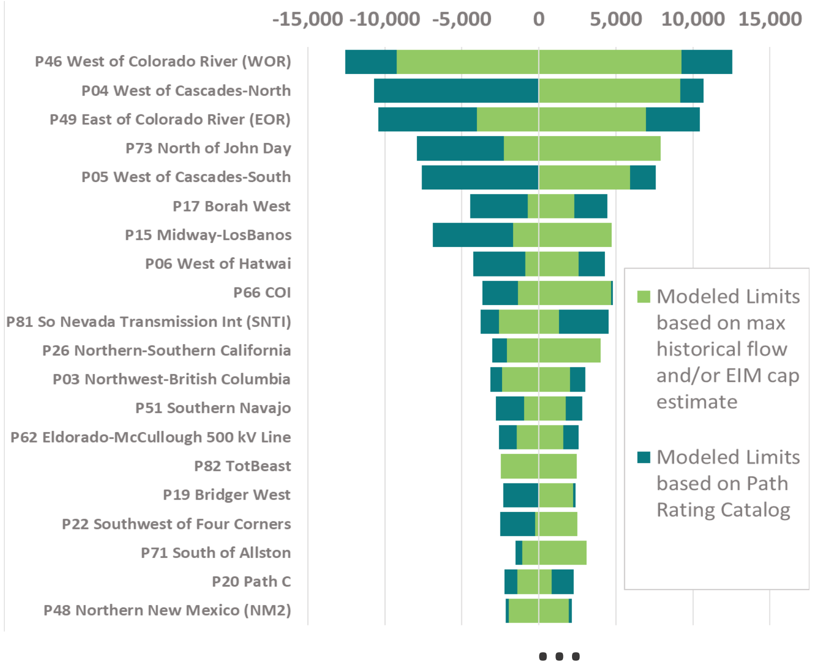
Removed:



Limited Coordination Scenario

- ***Removes institutional flexibility*** **built into Baseline Case in the form of wholesale market coordination**
  - ❖ "What if increased coordination of Western wholesale power markets **does not occur**"?
- **Key assumptions:**
  - ❖ Western EIM continues, but a West-wide day-ahead wholesale market does not materialize
  - ❖ Flows on key paths are limited to historical maximums
  - ❖ Ramping of flows on key paths are limited to historical maximums

Path limits based on historical values



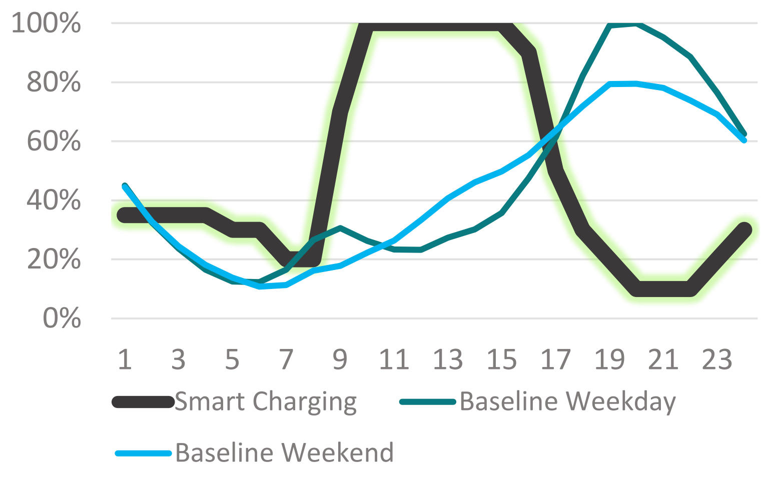
On-Peak & off-peak non-firm wheeling charges assumed for all day-ahead transactions

Business-as-usual transmission operations and efficiency

Integration Strategies Scenario

- ***Increases flexibility*** **not already built into Baseline Case**
  - ❖ "How effective are investments or decisions that increase system flexibility?"
- **Key assumptions:**
  - ❖ New **transmission upgrades** to help deliver renewable power to loads
  - ❖ Major build-out of long-duration **storage** (10 GW) and 4-hour battery storage co-located at new renewable energy facilities (32 GW)
  - ❖ **Managed charging** of EV-loads
  - ❖ Additional **resource diversity** and enhanced generator siting

Assumed EV Charging Shape (avg. day)



Assumed Incremental Storage (GW)

Technology	2026	2035
4-hr Battery	2.1	32.5
12-hr Pumped Storage	0.60	10.2

Integration Strategies Scenario

Compared to Baseline

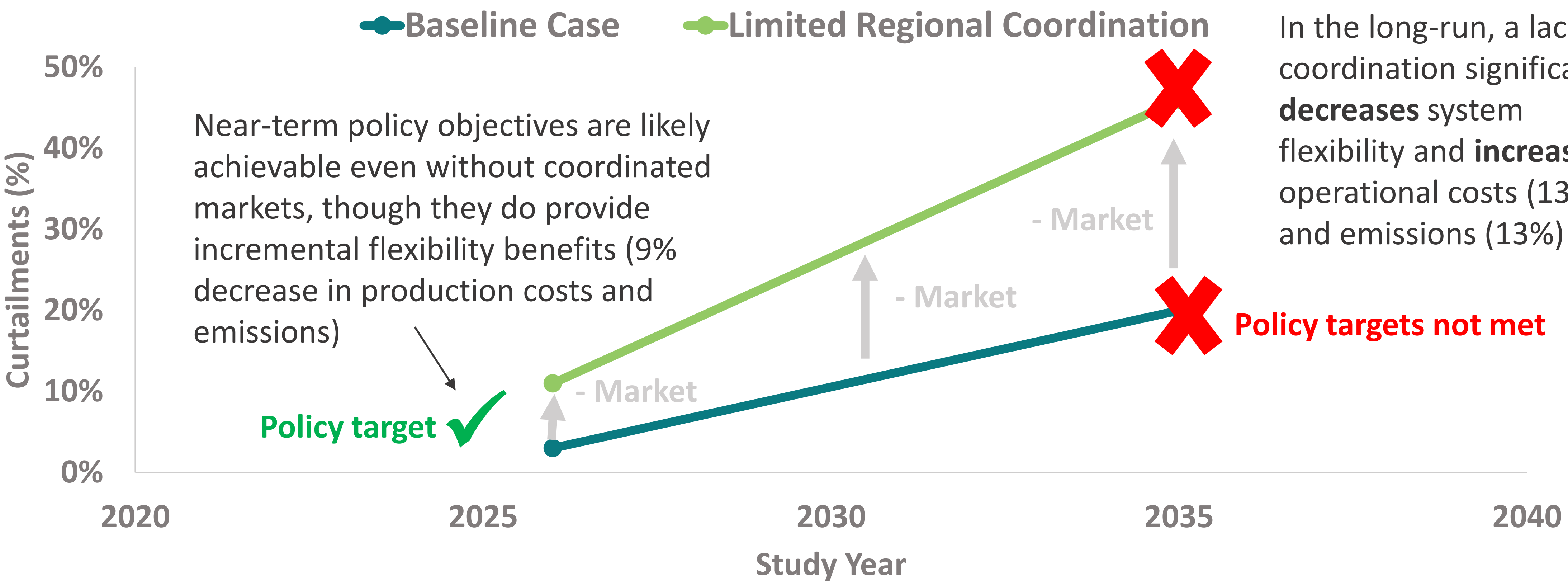
	Study Year	
	2026	**2035**
Curtailments (%)	0% ↓	9% ↓
Clean Energy Penetration (%)	✓ Hit target 37% ↑	✓ Hit target 69% ↑
Transmission Congestion	Very Low ↓	Low ↓
Production Costs ($B)	$10.7 ↓ 4%	$7.8 ↓ 22%
CO_2 Emissions (Million Metric Tons)	159 ↓ 1%	108 ↓ 19%

Limited Coordination Scenario

Compared to Baseline

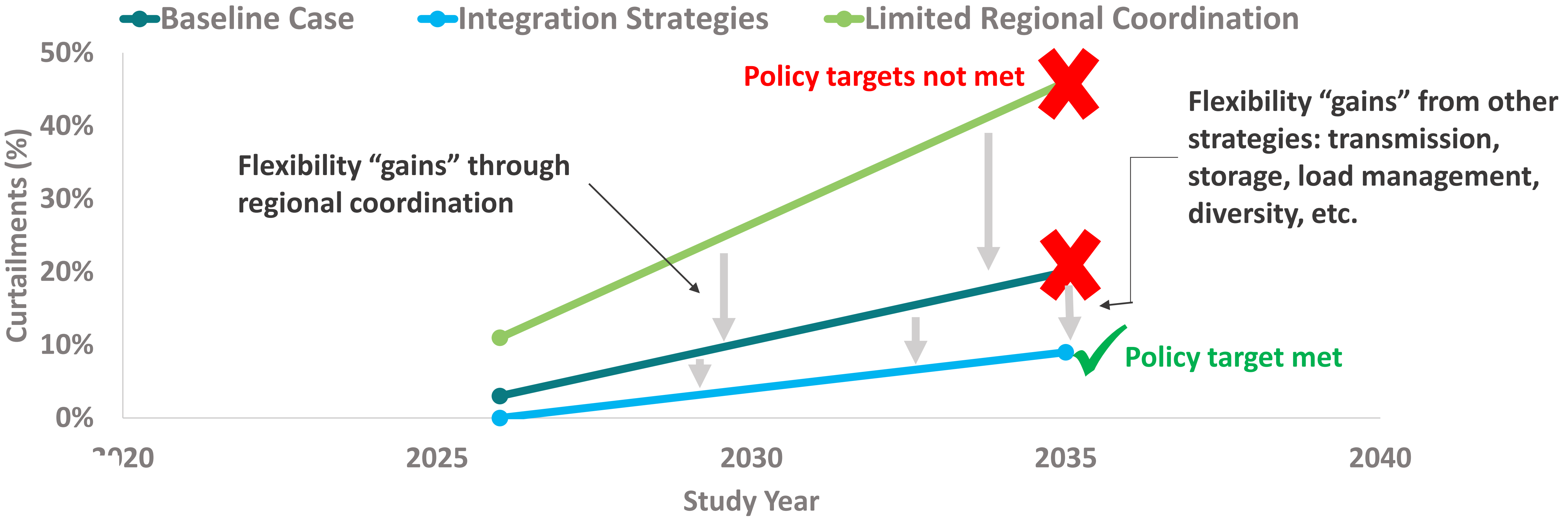
	Study Year: 2026	Study Year: 2035
Curtailments (%)	11% ↑	46% ↑
Clean Energy Penetration (%)	✓ Hit target 34% ↓	✗ Missed target 49% ↓
Transmission Congestion	Low ↑	Very High ↑
Production Costs ($B)	$12.1 ↑ 9%	$11.3 ↑ 13%
CO_2 Emissions (Million Metric Tons)	165 ↑ 9%	151 ↑ 13%

Coordinated wholesale markets increase system flexibility across the West

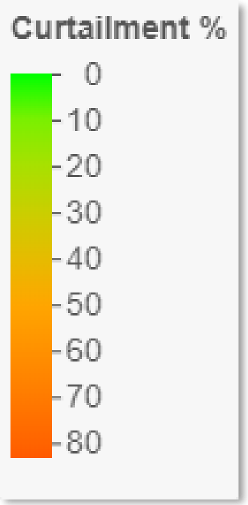


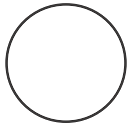
In the long-run, a lack of coordination significantly **decreases** system flexibility and **increases** operational costs (13%) and emissions (13%)

A balanced set of solutions are likely needed to increase system flexibility to levels necessary for assumed policy goals

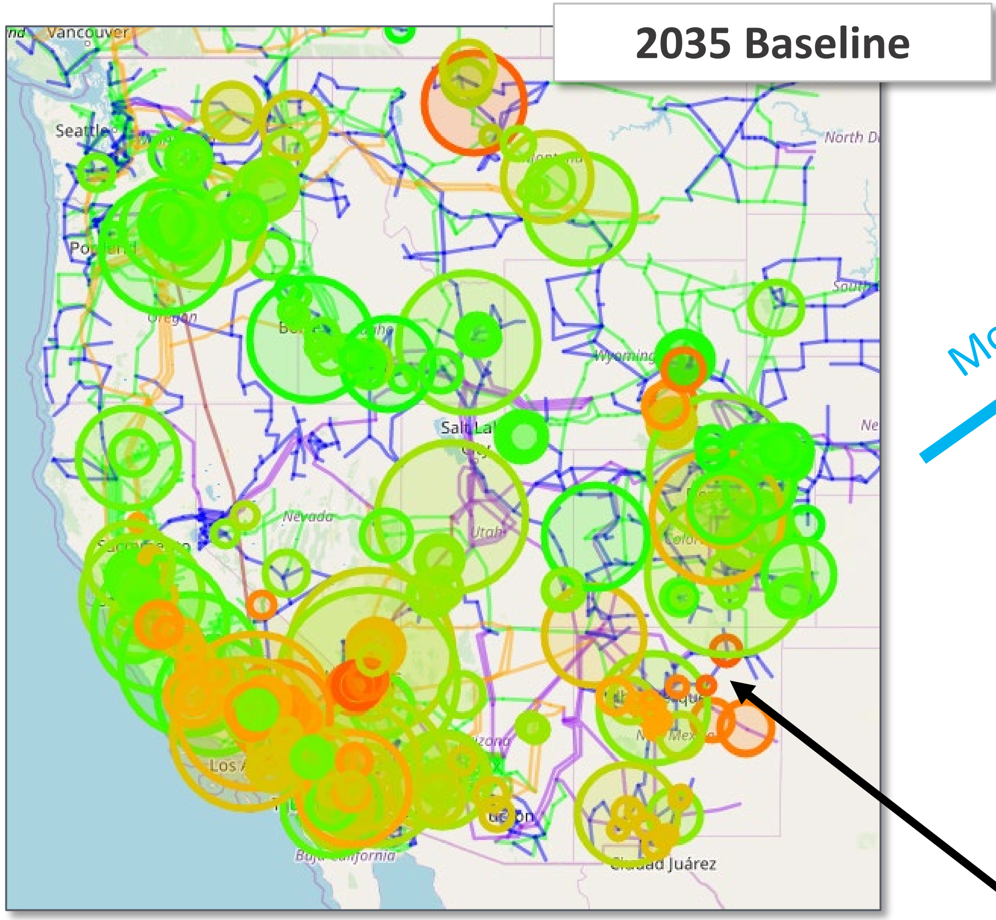


Transmission "shortages" increase into the 2030s and significant build-outs may be required

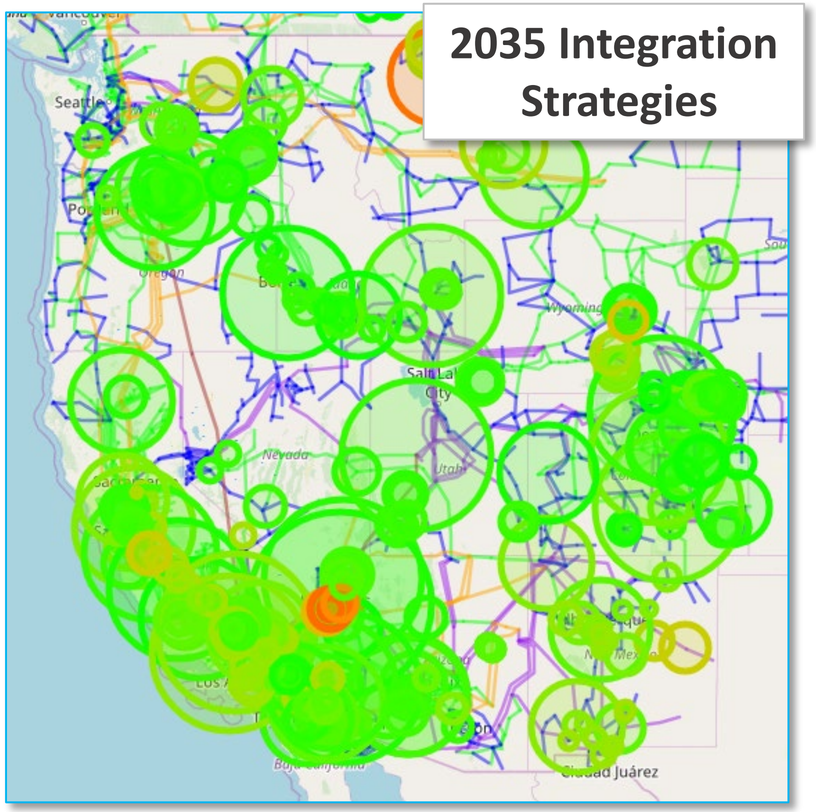




Circle size indicates interconnected renewable capacity



More transmission



Integration Strategies scenario included substantive transmission builds in California, Colorado, New Mexico, Wyoming/Utah, and Montana, with minor upgrades in the rest of the NW region

Localized curtailments are caused by a lack of transmission

ENERGY STRATEGIES

Summary

- ✓ **The West can achieve near-term policy targets with modest curtailments and without major changes to system flexibility. However, over time policy targets become more difficult to achieve.**
  - ❖ By aggregating individual state goals, this study estimates 2026 and 2035 Western clean energy penetration targets of 33% and 64%, respectively.
- ✓ **A balanced set of flexibility solutions are likely needed. Market coordination, flexibility investments, customer programs and new operational practices are all going to help and are all likely to be required.**
  - ❖ A scenario that includes these solutions, together, achieved a 2035 clean energy penetration of 69%, exceeding the estimated West-wide policy target.
- ✓ **The need to implement flexibility enabling strategies across the West increases over time.**
  - ❖ In the near-term, flexibility challenges exist and the system will benefit, operationally, from certain investments and enhanced market coordination.
  - ❖ However, for this near-term timeframe the West is reasonably primed – in terms of system flexibility – to achieve near-term policy targets.
- ✓ **In the long-term, results indicate that material flexibility challenges exist in the West and, absent implementation of some or all of the flexibility solutions listed above (or solutions providing similar flexibility effects), the West may lack sufficient grid flexibility to achieve state energy goals.**

Summary

- ✓ **Interregional power transfers are likely to increase in the coming years and such economic transfers are one of the most effective tools to for increasing system flexibility.**
  - ❖ In the near-term, modeling indicates that regions will rely heavily on the ability to export excess generation to their neighbors. Coordinated power markets help make these transactions more efficient
- ✓ **In the long-term, the same neighbors often find themselves with excess energy of their own (because of increasing renewable deployments), which tends to exacerbate flexibility challenges across the system as there are fewer willing buyers for excess power.**
  - ❖ Exporting power, on its own, is not a viable flexibility solution in the long run.
- ✓ **While the study did not consider the effectiveness of all potential flexibility solutions, it does indicate that no technological breakthroughs are needed in order to achieve regional flexibility levels appropriate for resource mixes commensurate with state policy goals.**
  - ❖ New or maturing technologies will only add to the supply of flexibility solutions
- ✓ **Coordinated wholesale markets are effective at increasing system flexibility across the West.**
  - ❖ Near-term policy targets are achievable even if coordinated wholesale markets in the West do not materialize.
  - ❖ In the long-term, results indicate that it will be very difficult, or at least extremely costly, to achieve Western policy targets without broad coordination of wholesale markets.

Summary

- ✓ **The study estimates that the West must add roughly 9 GW of renewable energy, per year, starting in 2026, in order to provide energy sufficient to meet state policy goals through 2035.**
  - ❖ Investments in renewable energy represent only a subset of the potential infrastructure needs
  - ❖ Suggest that significant work must be undertaken across the Western region in order to realize a resource mix, transmission grid, and market paradigm that suits state policy targets.
- ✓ **Results indicate relatively few major transmission constraints on the system exist in the mid-2020s. As the resource portfolio evolves into the 2030s, the need for transmission becomes more obvious and resources face constraints.**
  - ❖ The Western transmission system is robust and dynamic, providing value in unanticipated ways.
- ✓ **The portfolios considered in this study were constructed to achieve regional adequacy targets, and in the case of the Northwest region, additional detailed analysis was performed to ensure the selected portfolio contained sufficient capacity.**
  - ❖ That modeling indicates that the Northwest region has a near-term capacity challenge, but that the deficit is one that can be addressed with existing technologies and resource options.
  - ❖ The nature of the capacity challenge in the Northwest varies widely depending on assumptions regarding load forecasts and assumed resource build-outs.

Other Study Observations

- Allowing the full use of the transmission system, with efficient price signals and congestion management, can help increase system flexibility.
- Severe data limitations in evaluating historical performance of grid.
- Economic curtailment of renewables will be a tool that system operators use often in the coming decades.
- Targeted transmission upgrades were an important source of flexibility in this study.
- Sources of system flexibility that proved effective in this study are proxies for similar flexibility solutions not studied.
- Exporting surplus power to neighboring states is, at times, a viable flexibility strategy for states seeking to increase their renewable penetration. However, as neighboring areas join in and begin to increase their renewable penetration to significant levels, the ability to export excess power diminishes for both states since they both have more frequent periods of excess power.

ENERGY STRATEGIES

THANK YOU

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