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Pacific Northwest Low Carbon Scenario Analysis

Achieving Least-Cost Carbon Emissions Reductions in the Electricity Sector

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Outline

- Study Background & Context
- Methodology & Scenarios
- Key Inputs & Assumptions
- Results
- Conclusions

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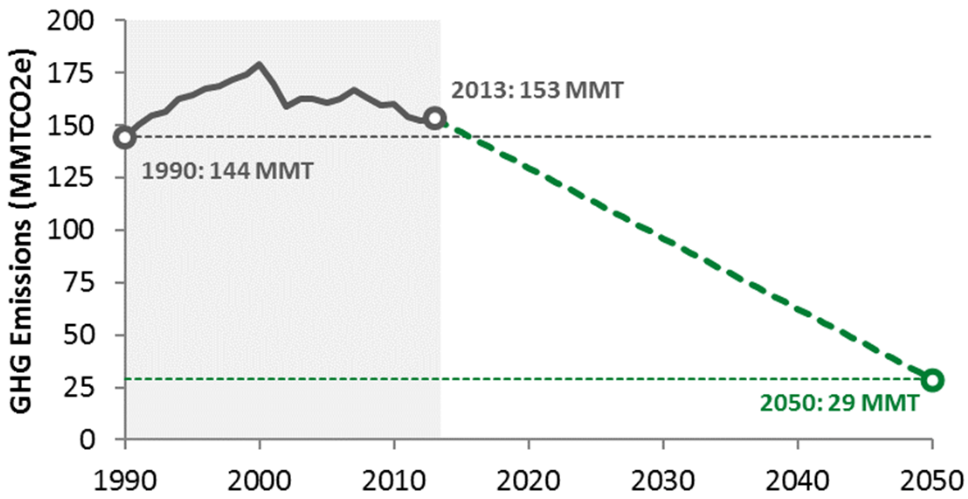
STUDY BACKGROUND & CONTEXT

About This Study

- **Oregon and Washington are currently exploring potential commitments to deep decarbonization in line with international goals:**
  - Oregon: 91% below 1990 levels by 2050 (proposed)
  - Washington: 80% below 1990 levels by 2050 (proposed)
- **This study was conceived to inform policymakers on the effectiveness of various potential policies to reduce GHG emissions in the Northwest:**
  - What are the most cost-effective ways to reduce electricity sector emissions in the Northwest?
  - What is the value of existing carbon-free resources?
- **Study considers the unique characteristics of the Pacific Northwest**
  - Reliance on existing hydropower
  - Historical emphasis on conservation

Oregon and Washington Greenhouse Gas Emissions Trends



Four "Pillars" of Decarbonization to Meet Long-Term Goals

Energy efficiency & conservation	Electrification	Low carbon electricity	Low carbon fuels

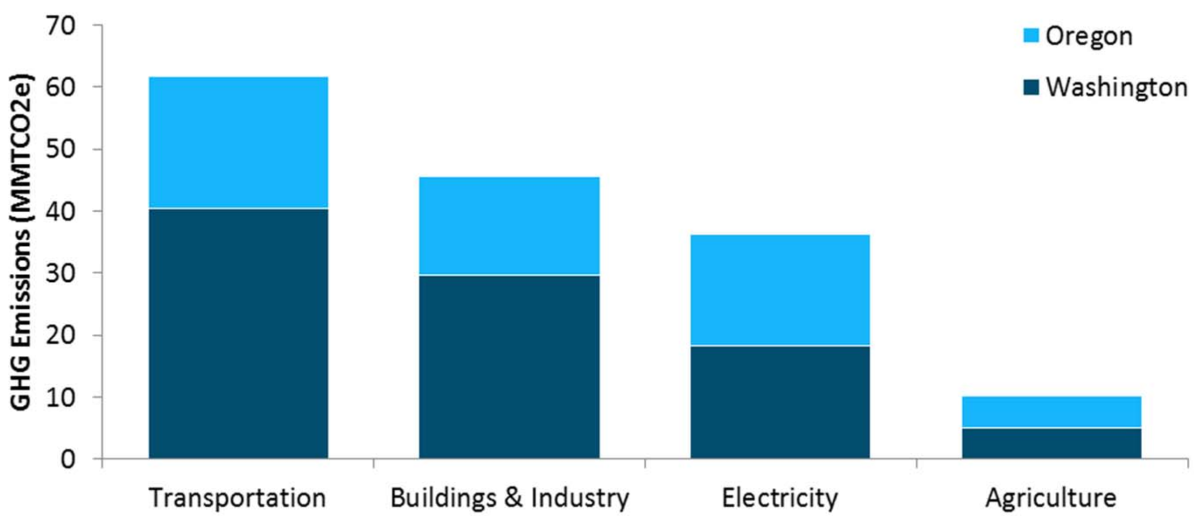
- **Four foundational elements are consistently identified in studies of strategies to meet deep decarbonization goals**
- **Across most decarbonization studies, electric sector plays a central role in meeting goals**
  - Through direct carbon reductions
  - Through electrification of loads to reduce emissions in other sectors

Meeting Long-Term GHG Goals Requires Reductions from All Sectors

+ Largest sources of GHG emissions in the region guide prioritization of emission reduction strategies:

1. Transportation
2. Buildings and industry
3. Electricity

Oregon and Washington Greenhouse Gas Emissions by Sector (2013)



Sources: Report to the Legislature on Washington Greenhouse Gas Emissions Inventory: 2010 – 2013 (*link*); Oregon Greenhouse Gas In-boundary Inventory (*link*)

Carbon Intensity of the Northwest's Electricity Sector is Relatively Low

- **Due to large fleet of existing zero-carbon resources, electric emissions intensity in the Pacific Northwest is already below other regions in the United States**

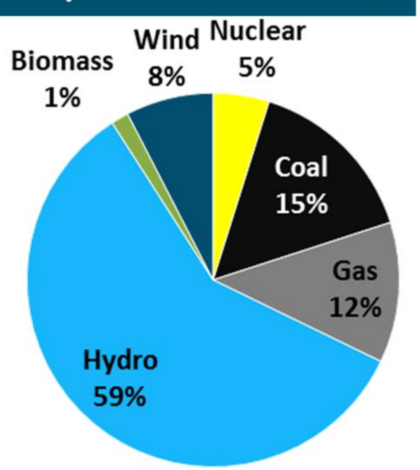
2013 Regional GHG Intensity of Electricity Supply (tons/MWh)

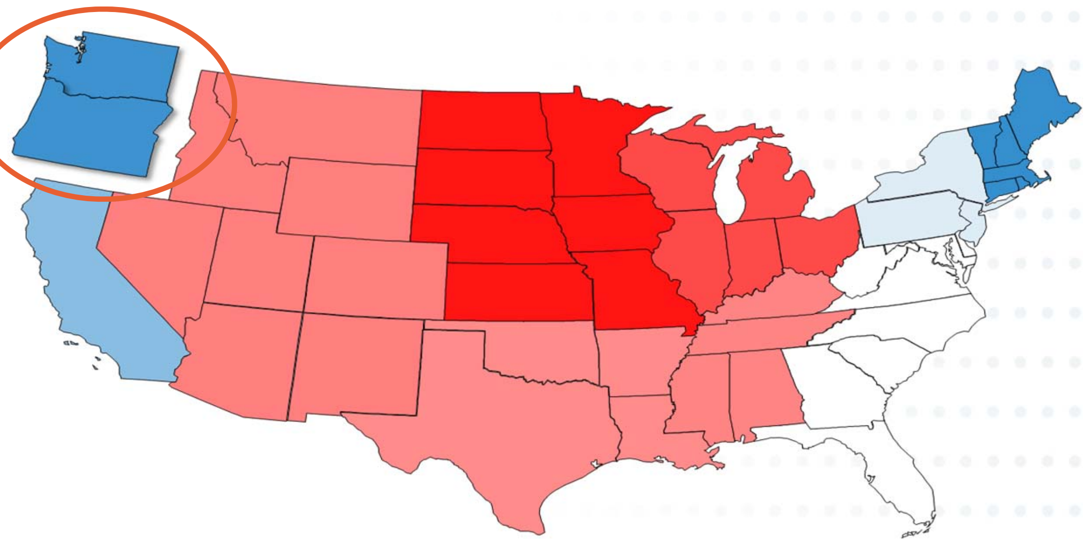
2013 emissions intensity:

0.26 tons/MWh

(includes out-of-state coal resources)

WA/OR Generation Mix



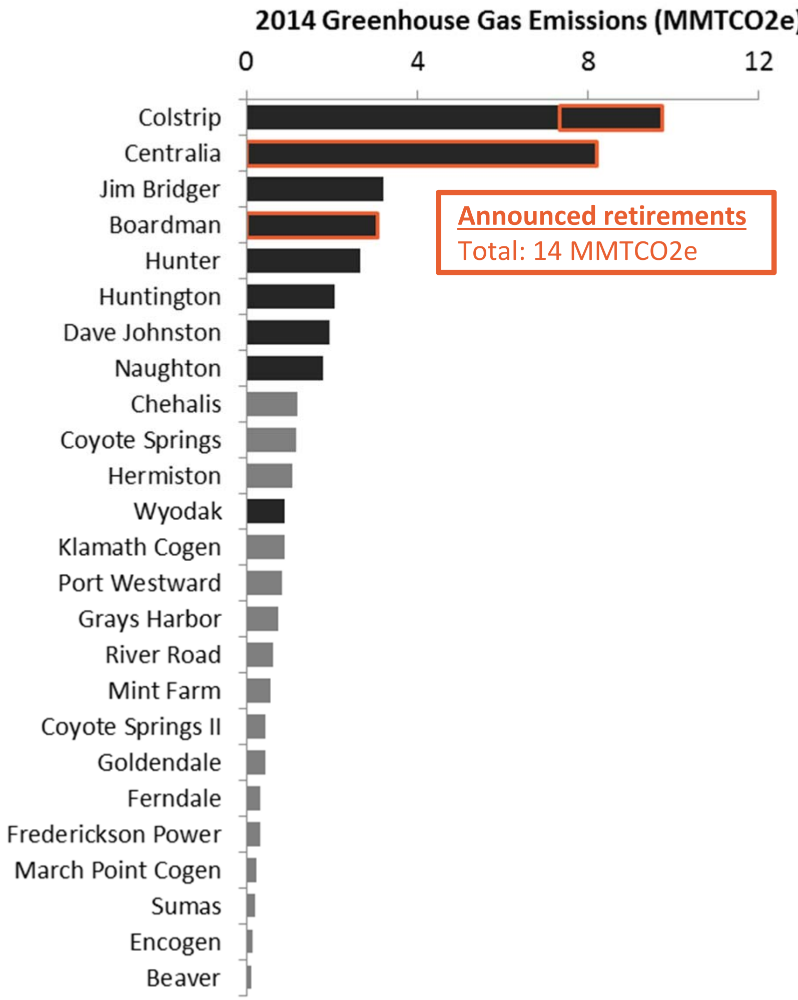


2013 Emissions Intensity (tons/MWh)

0.20	0.25	0.30	0.35	0.40	0.45	0.50	0.55	0.60	0.65	0.70	0.75	0.80

Figure developed using data gathered from state 2013 GHG inventories for Washington, Oregon, and California; supplemented with data from EIA Annual Energy Outlook 2016

A Handful of Plants are Responsible for Most of the Electric Sector GHG Emissions in the Northwest



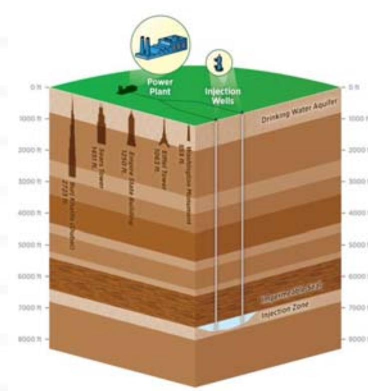
- **Existing coal plants (9 units) are responsible for 33 million metric tons of emissions—roughly 80% of all emissions attributed to Washington & Oregon**
  - Includes contracted generation in Montana, Wyoming
- **Existing gas generation accounts for roughly 9 million metric tons**

Low-Carbon Electricity Generation Becomes the Predominant Source of Primary Energy for the Entire Economy

1. **Renewable**
   - Hydroelectric: *flexible low-carbon resource in the Northwest that can help to balance wind and solar power*
   - Wind: *high quality resources in West, particularly East of the Rockies, intermittent availability*
   - Solar: *high quality resources across the West, intermittent availability*
   - Geothermal: *resource limited*
   - Biomass: *resource limited*

2. **Nuclear**
   - Conventional: *baseload low-carbon resource*
   - Small modular reactors: *potentially flexible low-carbon resource (not considered)*

3. **Fossil generation with carbon capture and storage (CCS)**



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METHODOLOGY & SCENARIOS

Overview of the Analysis

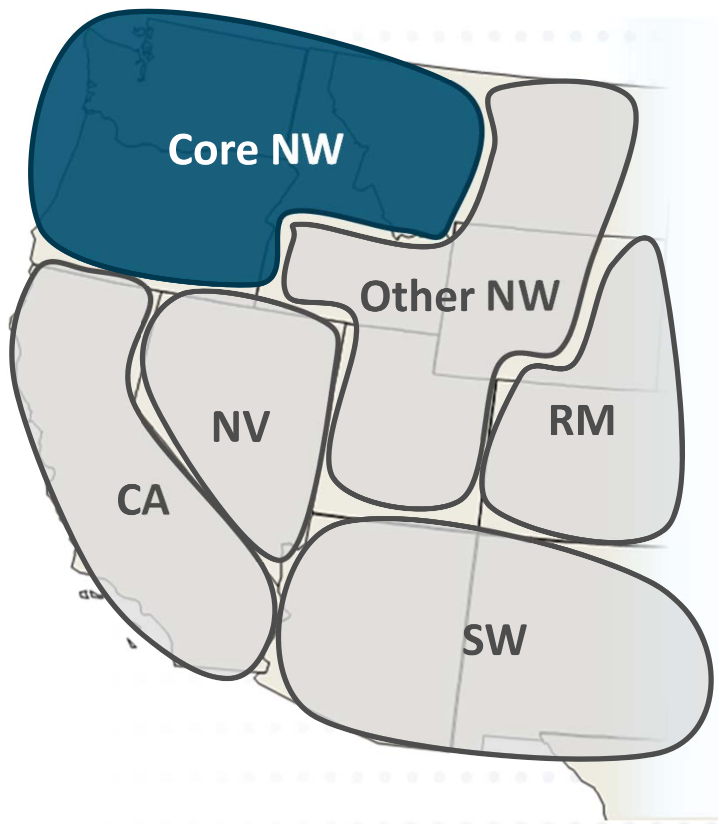
- **This study uses E3's Renewable Energy Solutions (RESOLVE) Model to select optimal portfolio of renewable and conventional resources for each scenario**
  - RESOLVE was designed for modeling operations and investments for high-renewable power systems
  - Utilized in several jurisdictions including California, Hawaii and New York
- **RESOLVE minimizes the sum of investment and operating costs over a defined time period**
  - Investment decisions are made every 10 years between 2020 and 2050
  - Performs optimal dispatch over a representative set of operating days in each year
- **Selects least-cost combination of resources over time**
  - Meets energy, capacity and balancing needs
  - Complies with RPS or GHG target ("overbuilding" portfolio if necessary)

Key Metrics Calculated by RESOLVE

Metric Description	Units
Resource additions for each investment period	MW and aMW
Total resource cost for combined electricity system during each model year	$/year
Annual generation by resource type	GWh or aMW
CO_2 emissions	Metric tons/year
Renewable curtailment	GWh and % of available energy
Electricity market prices	Hourly $/MWh
Average and marginal CO_2 abatement cost	$/metric ton

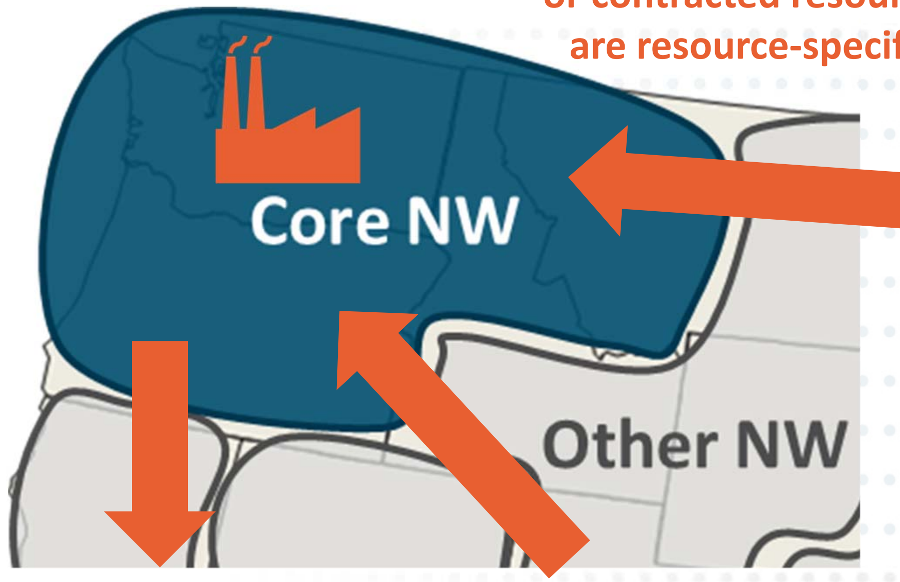
Study Footprint

- **RESOLVE is used to optimize a portfolio for "Core NW" loads in Washington, Oregon, northern Idaho and western Montana**
- **Remaining BAs of the WECC are grouped into five zones**
  - RESOLVE optimizes operations—but not investments—in external zones to reflect market opportunities for energy trading between regions in investment decisions
- **British Columbia and Alberta are not modeled**



Greenhouse Gas Accounting Conventions for Study Footprint

+ **Study focuses on quantifying greenhouse gases associated with Core NW resource mix**
+ **Accounting conventions mirror current cap & trade rules in California**
+ **Emissions attributed to Core NW include:**
  - All fossil generation physically located in the Core NW
  - Ownership shares of remotely-owned coal plants
  - Economic imports, at an assumed rate of 960 lb/MWh
  - No GHG credit for exported generation

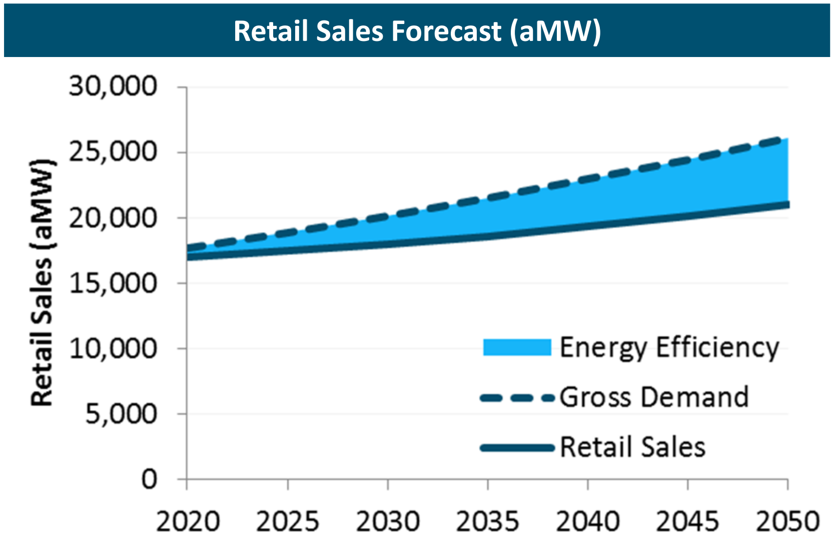


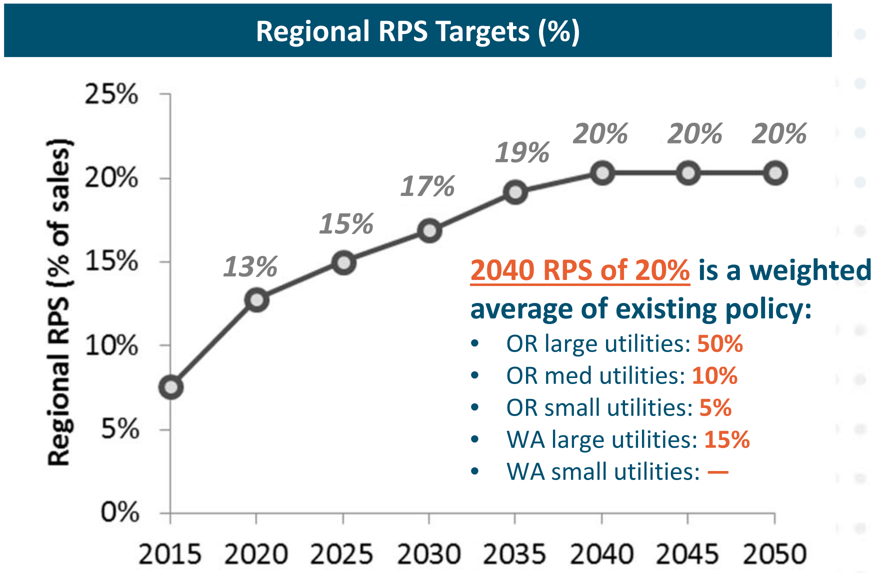
Overview of Core Policy Scenarios

1. **Reference Case:** reflects current state policy and industry trends
2. **Carbon Cap Cases:** meet electric sector reduction goal through implementation of a carbon cap on the electric sector
   - **40%, 60%,** and **80%** GHG reduction by 2050
3. **Carbon Tax Cases:** impose an escalating carbon tax on the electric sector
   - **WA Leg. tax proposal** ($15/ton in 2020 escalating at 5.5%/yr. + inflation)
   - **WA Gov. tax proposal** ($25/ton in 2020 escalating at 3.0%/yr. + inflation)
4. **High RPS Cases:** impose increased RPS targets upon WA & OR utilities by 2050 as a policy mechanism to decarbonize the electric sector
   - **30%, 40%,** and **50%** RPS achieved regionally by 2050
5. **'No New Gas' Case:** prohibits construction of new gas generation

Reference Case

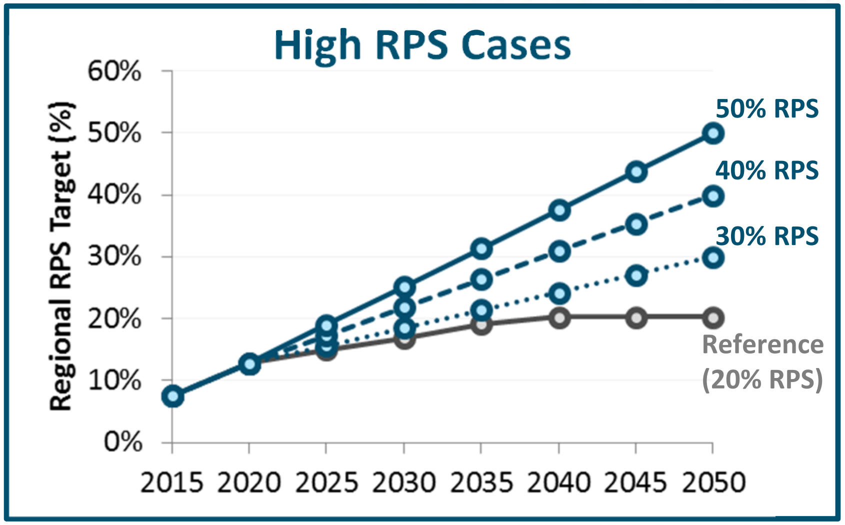
+ **Reference Case captures current policies and trends:**
  - **Achievement of cost-effective energy efficiency** as identified in NWPCC 7th Power Plan
  - **Announced coal plant retirements:** Boardman (2020), Colstrip 1 & 2 (2022), Centralia (2020/'24)
  - **State- and utility-specific RPS goals:** achieves regionwide weighted average of 20% RPS by 2040

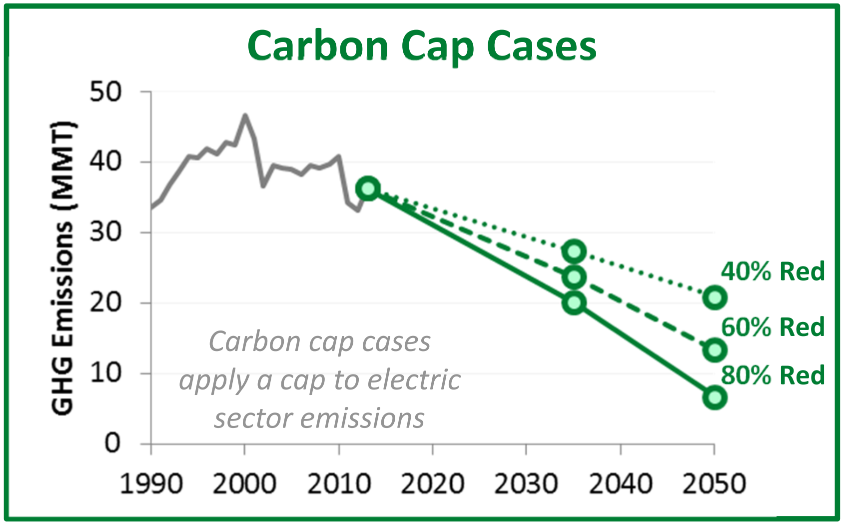


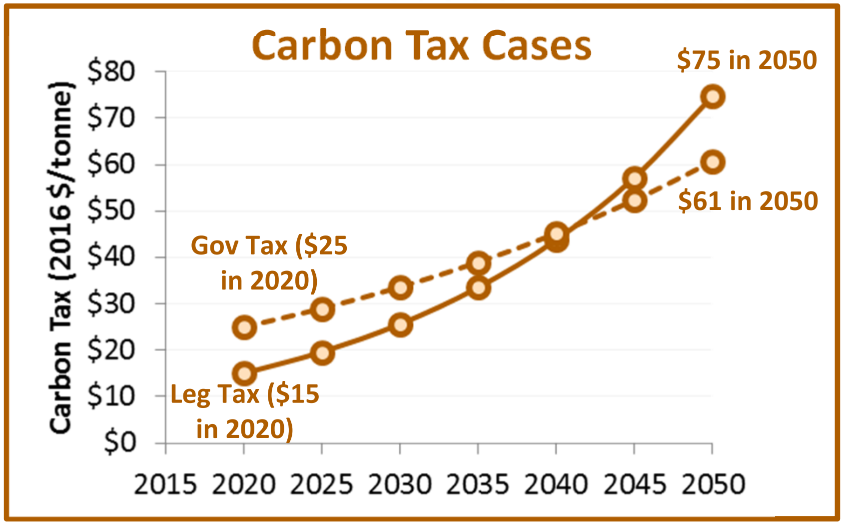


Core Policy Scenario Trajectories

- Each scenario is defined by a set of goals, constraints, or cost assumptions through 2050
- 'No New Gas' case prohibits construction of new gas generation across the entire horizon







Sensitivity Analysis Used to Explore Additional Questions

Sensitivity	Purpose
A. No Revenue Recycling	Examine impact to ratepayers if revenue collected under carbon pricing mechanism is not returned to the electricity sector
B. Loss of Existing Carbon-Free Resources	Examine the cost and GHG implications of decommissioning existing hydro and nuclear generation
C. High Energy Efficiency	Examine the potential role of higher-cost energy efficiency measures in a GHG-constrained future
D. High Electric Vehicles	Explore the role of vehicle as a potential strategy for reducing GHG emissions in the transportation sector
E. High & Low Gas Prices	Examine sensitivity of key learnings to assumptions on future natural gas prices
F. Low Technology Costs	Explore changes in cost and portfolio composition under assumptions of lower costs for solar, wind and energy storage
G. California 100% RPS	Explore implications of California clean energy policy on decarbonization in the Northwest

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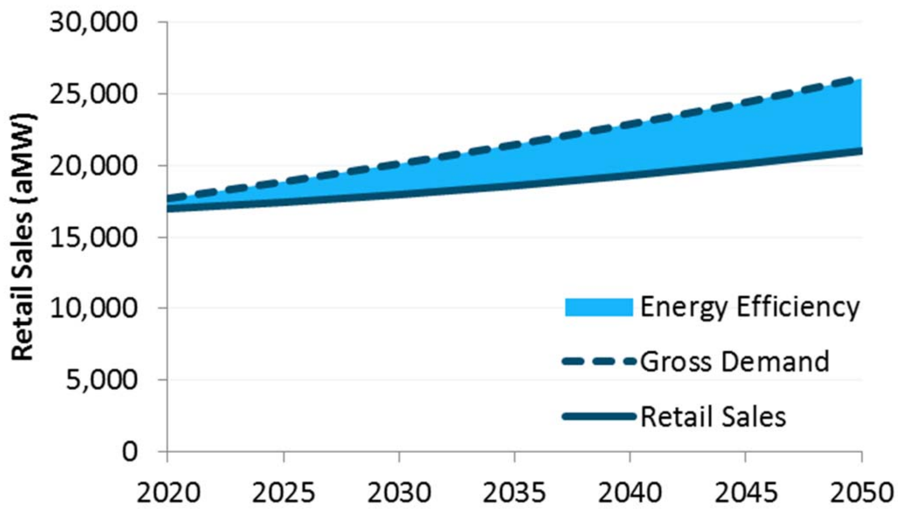
KEY INPUTS & ASSUMPTIONS

Demand Forecast Assumptions

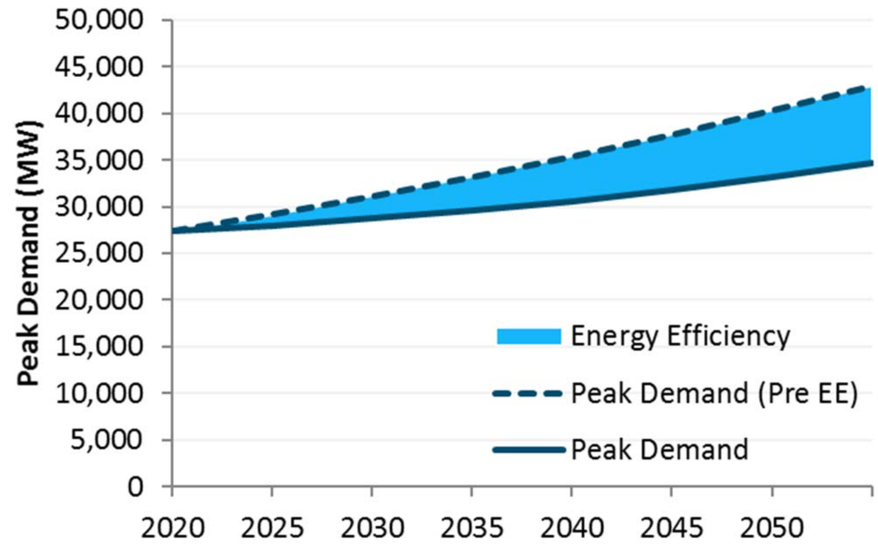
+ **Demand forecast benchmarked against multiple long-term projections**
  - Assumes 7th Power Plan EE is included in load
  - Average growth rate after efficiency: **0.7% / yr**

Source	Pre EE	Post EE
PNUCC Load Fcst	1.7%	0.9%
BPA White Book	1.1%	—
NWPCC 7th Plan	0.9%	0.0%
TEPPC 2026 CC	—	1.3%
E3 Recommended	**1.3%**	**0.7%**

Retail Sales Forecast (aMW)



Peak Demand Forecast (MW)

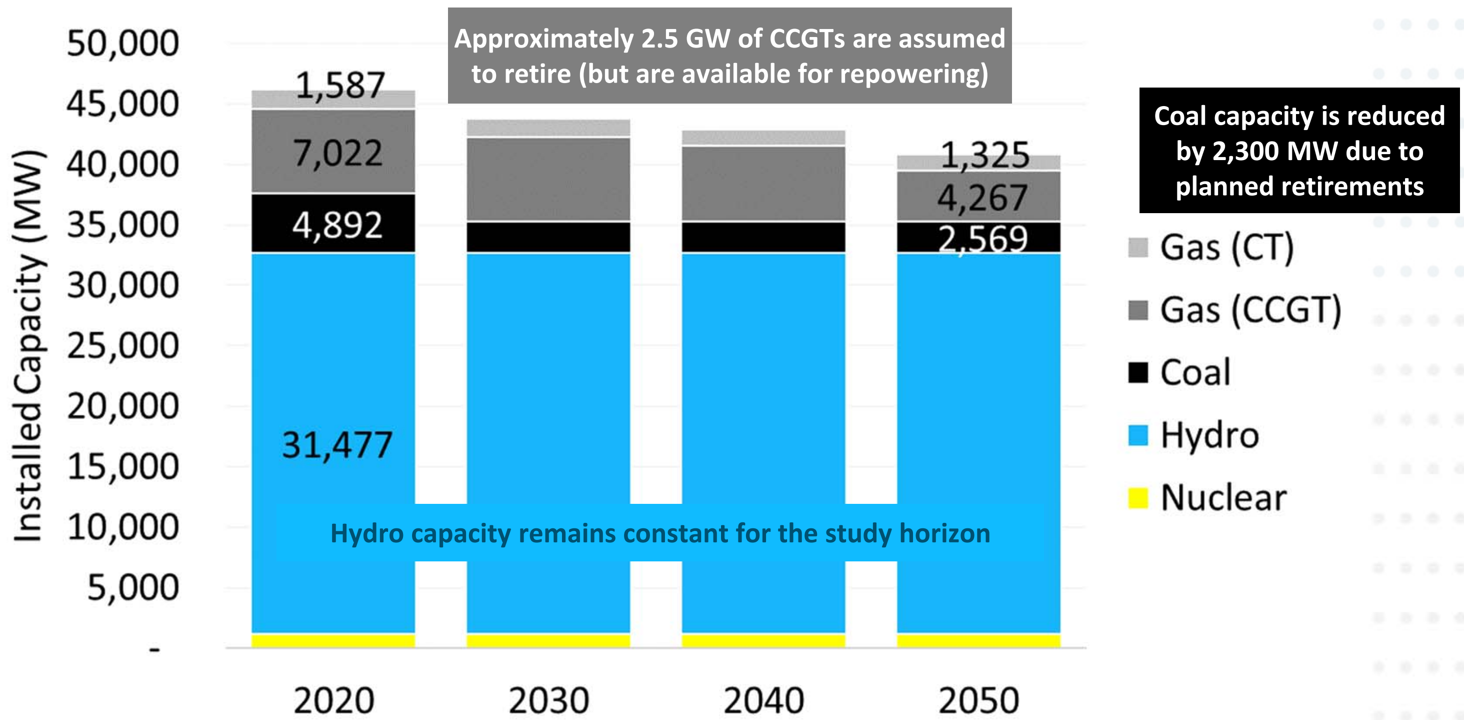


Existing Resource Assumptions
Conventional Generation

- **Conventional fleet data is derived using TEPPC 2026 common case**
- **Announced coal retirements included**
  - Boardman (2020)
  - Centralia 1 & 2 (2020/2024)
  - Colstrip 1 & 2 (2022)

Remaining coal generation reflects OR/WA ownership shares of remote resources

- **Remaining coal & nuclear remains online throughout analysis**



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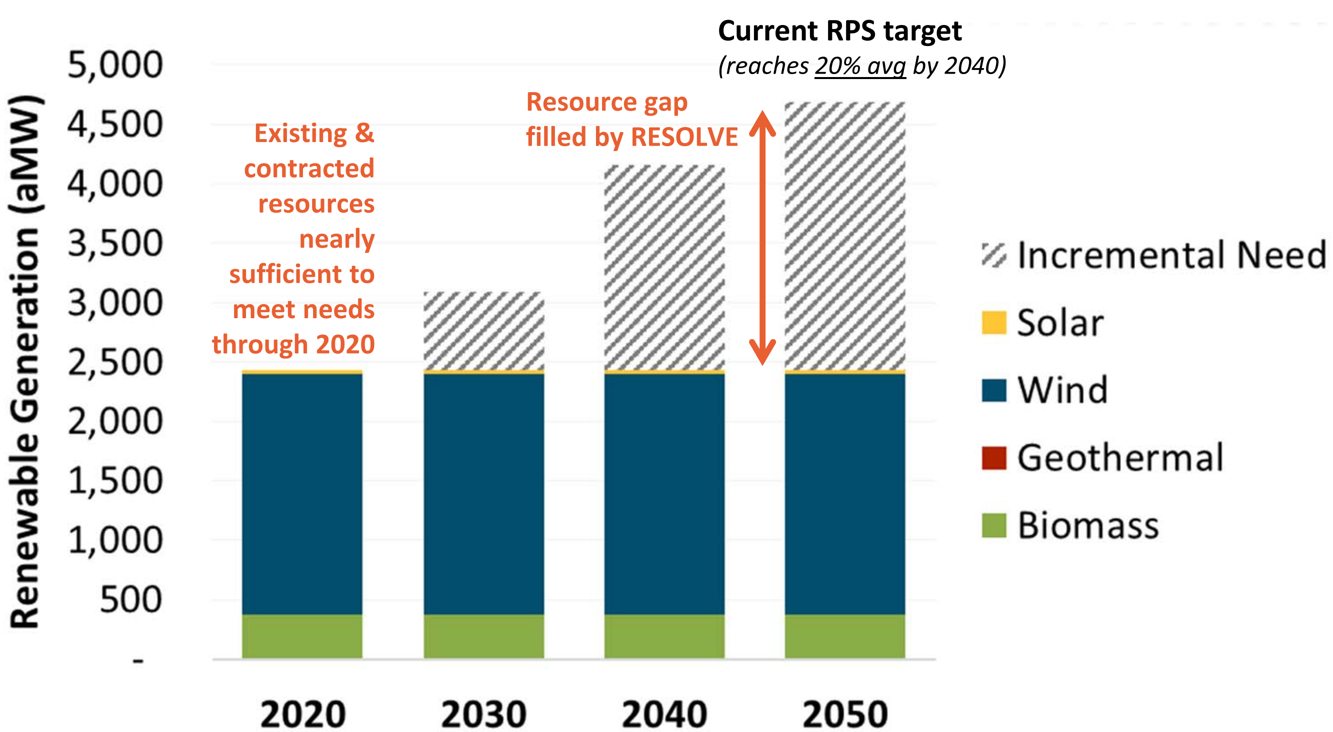
Existing Resource Assumptions
Renewable Generation

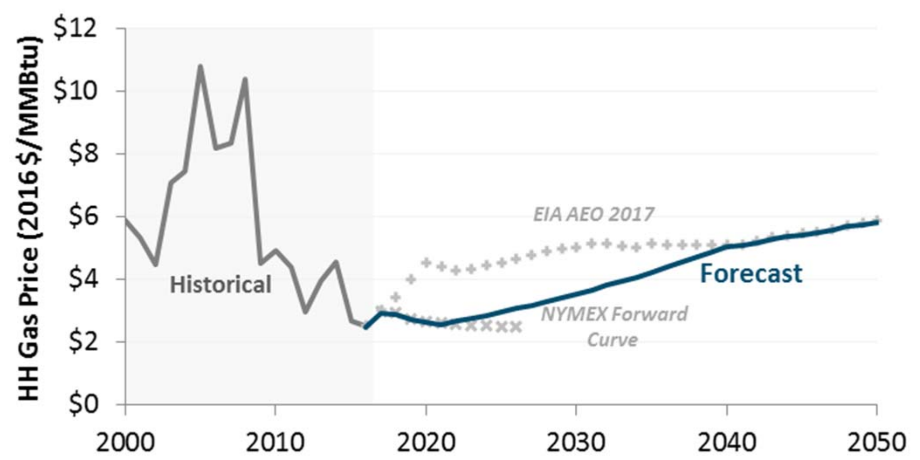
+ **Baseline renewable portfolio includes existing resources and planned near-term additions**
    - All assumed to remain online indefinitely through analysis
    - Based on Western Electric Coordinating Council's 2026 Common Case
    - Excludes renewable resources contracted to California



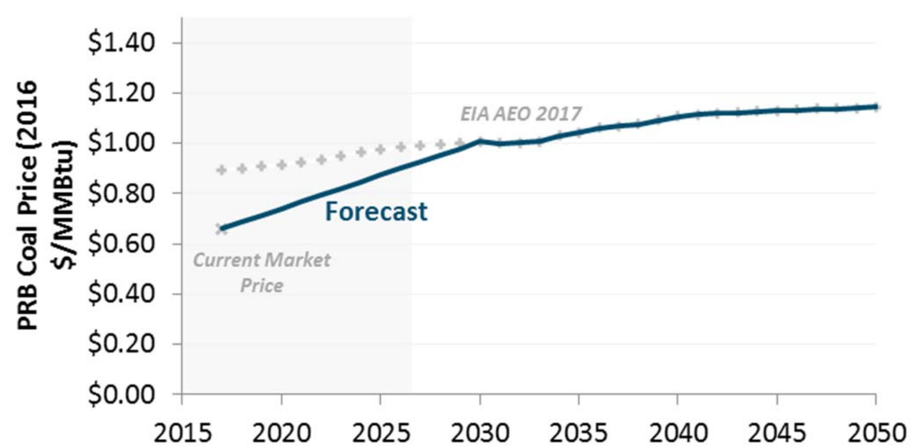
Fuel Price Forecasts

+ **Gas price forecast blends market data and long-term fundamentals**
  - 2017-’21: NYMEX forwards
  - 2022-’40: transition
  - 2040-’50: EIA AEO 2017
+ **Coal price forecast transitions from current market prices to long-term fundamental forecast**
  - 2017: current market data
  - 2030-’50: EIA AEO 2017
+ **Basis differentials and adders for delivery applied**

Henry Hub Gas Price Forecast (2016 $/MMBtu)



Powder River Basin Coal Price ($/MMBtu)

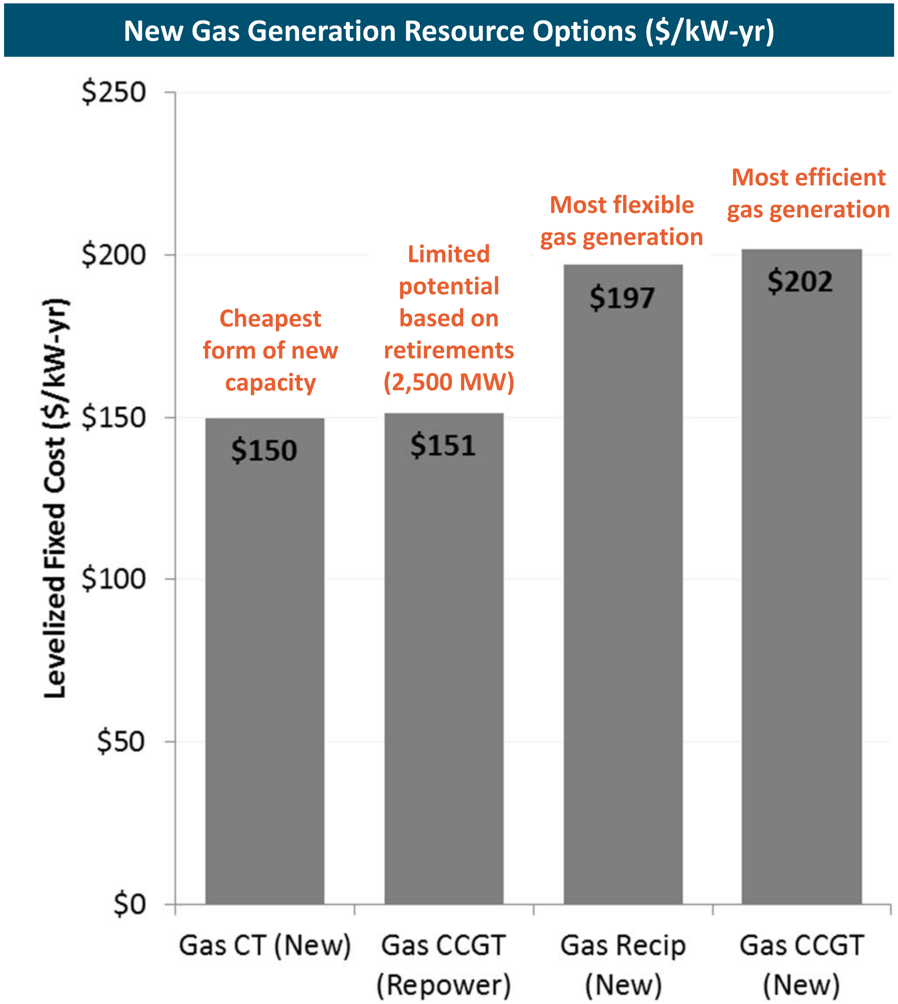


Resource Options in RESOLVE

Resource Option	Examples of Available Options	Functionality
Natural Gas Generation	• Simple cycle gas turbines • Reciprocating engines • Combined cycle gas turbines • Repowered CCGTs	• Dispatches economically based on heat rate, subject to ramping limitations • Contributes to meeting reserve needs and ramping constraints
Renewable Generation	• Geothermal • Hydro upgrades • Solar PV • Wind	• Produces zero-carbon generation that contributes to meeting RPS goals • Curtailable when necessary to help balance load
Energy Storage	• Batteries (>1 hr) • Pumped Storage (>12 hr)	• Stores excess energy for later use • Contributes to meeting reserve needs and ramping constraints
Energy Efficiency	• HVAC & appliances • Lighting	• Reduces load, retail sales, planning reserve margin need
Demand Response	• Interruptible tariff (ag) • DLC: space & water heating (res)	• Contributes to planning reserve margin needs

New Resource Options
Natural Gas Generation

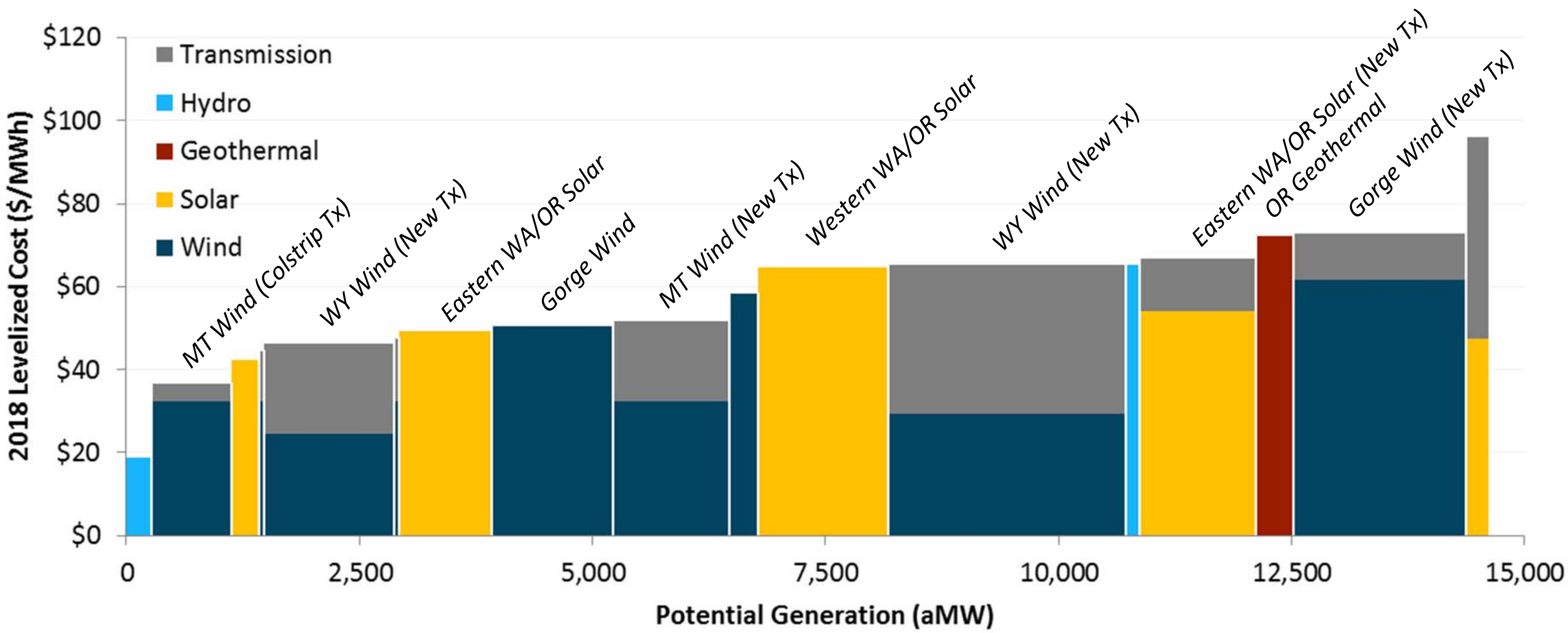
+ **Four options for new gas generation are considered:**
  - Frame combustion turbines
  - Repowering of retiring combined cycle gas turbines (assumed cost of 75% of new CCGT cost)
  - Reciprocating engines
  - New CCGTs
+ **Costs and characteristics of new gas units are based on E3's "Cost and Performance Assessment of Generation Technologies" study prepared for WECC**
  - Capital cost of new gas generation assumed to remain constant in real terms over time



New Resource Options
Renewable Generation

+ **Renewable supply curve captures regional and technological diversity of options for renewable development**
  • Adders for new transmission and wheeling included as necessary
+ **Resources selected based on value and "fit" in addition to cost**

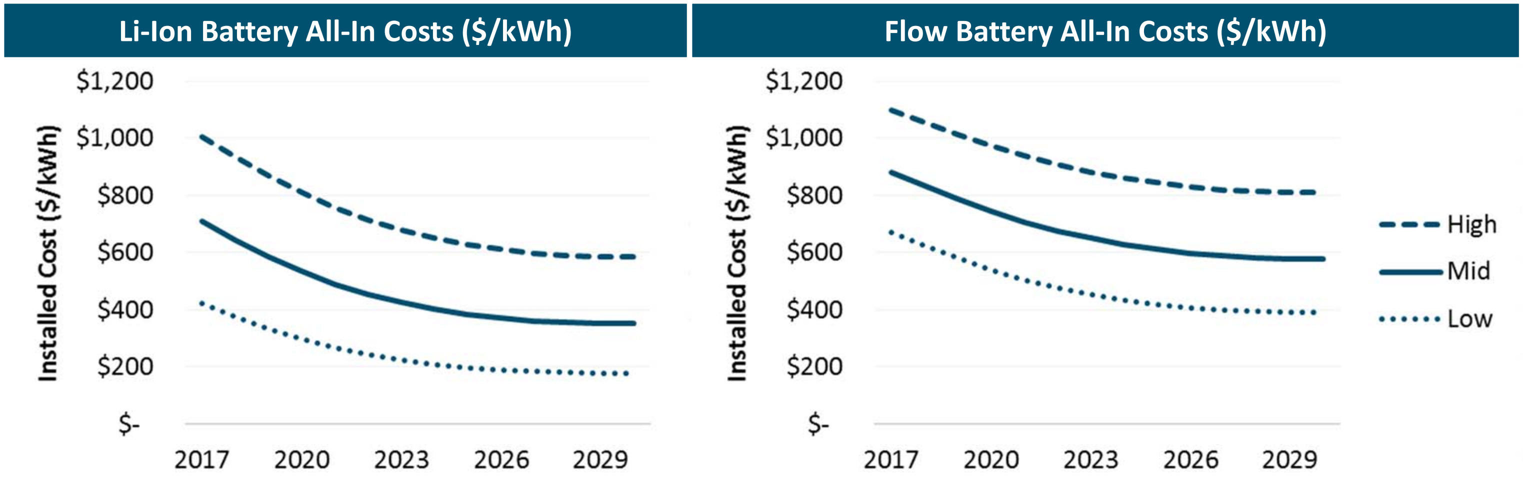
Renewable Resource Supply Curve ($/MWh)



Note: chart shows only resource cost; RESOLVE selects new resources based on both cost and value

New Resource Options
Energy Storage

+ **Assumptions on energy storage cost drive cost-effectiveness of investments in integration solutions**
+ **Battery cost assumptions (current & future) derived from Lazard Levelized Cost of Storage 2.0**



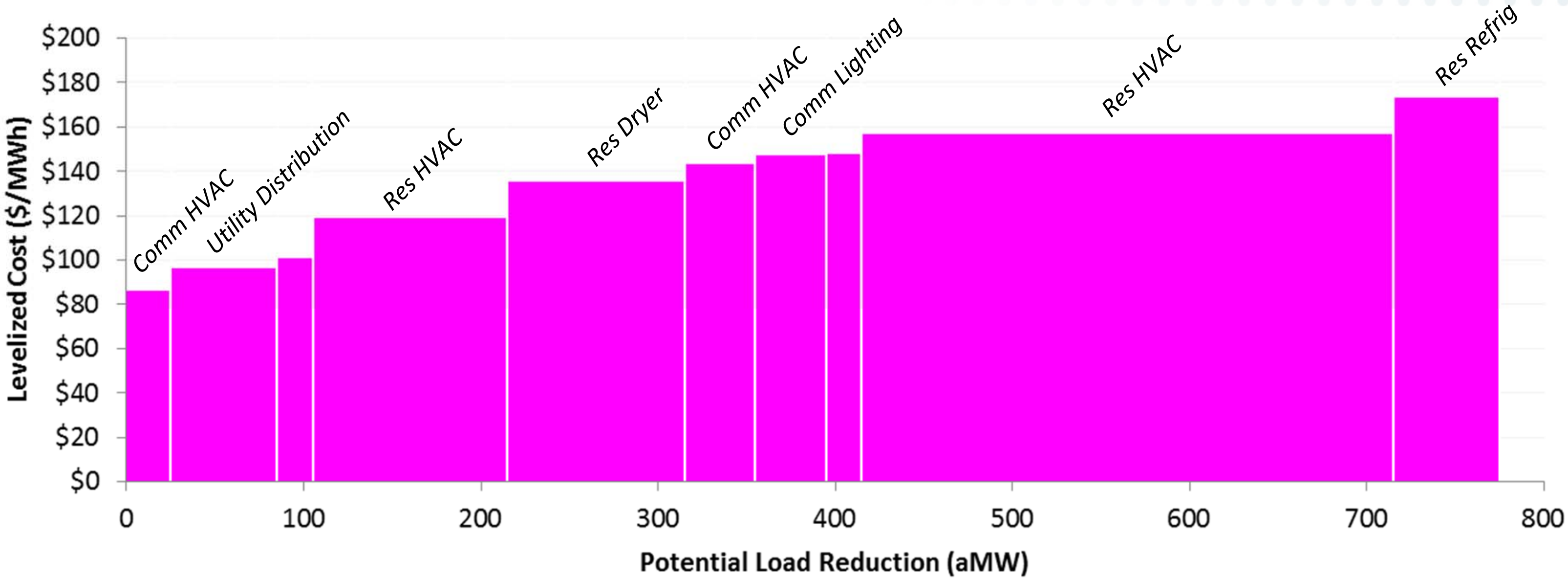
Capital costs shown for 4-hr storage devices; RESOLVE can select optimal duration for energy storage resources

+ **Pumped storage assumed to cost $2,875/kW**
  - Limited to 5,000 MW of potential in Northwest

New Resource Options
Incremental Energy Efficiency

+ **Supply curve of incremental energy efficiency constructed from measures identified in the NWPCC Seventh Power Plan as "not cost effective"**
  - Resources bundled by cost and end use for purpose of selection in RESOLVE

Energy Efficiency Supply Curve ($/MWh)



Note: chart shows only EE measures that are treated as options in RESOLVE; all EE identified by NWPCC as cost-effective is included in the load forecast

New Resource Options
Demand Response

- Demand response cost & potential incorporated from Navigant's *Assessing Demand Response Program Potential for the Seventh Power Plan*
- From this study, two DR resources—representing the majority of winter peak load reduction potential—are included in RESOLVE:
  1. <u>Agricultural interruptible tariff:</u> **657 MW** available by 2050 at a cost of **$19 / kW-yr.**
  2. <u>Residential space & water heating direct load control (DLC):</u> **902 MW** available by 2050 at a cost of **$59 / kW-yr.**

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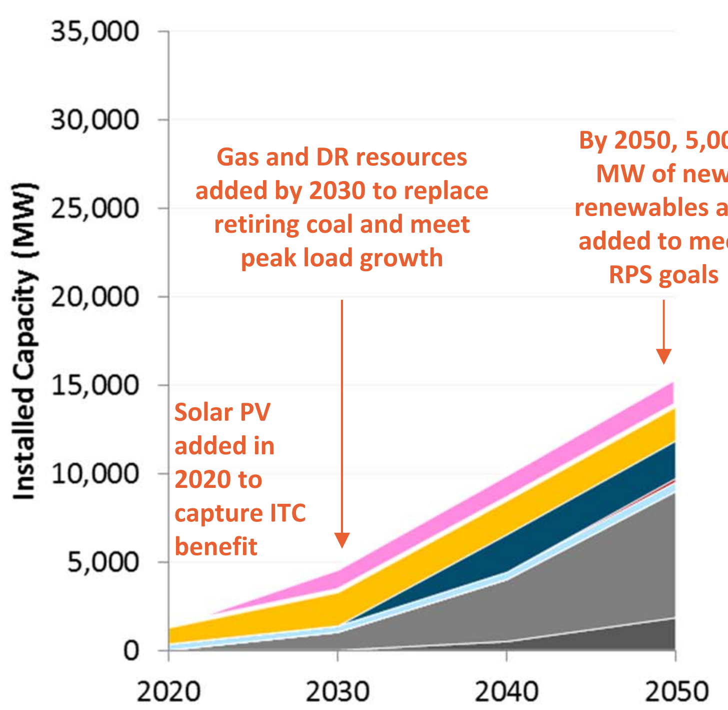
CORE POLICY SCENARIOS: PORTFOLIO SUMMARIES

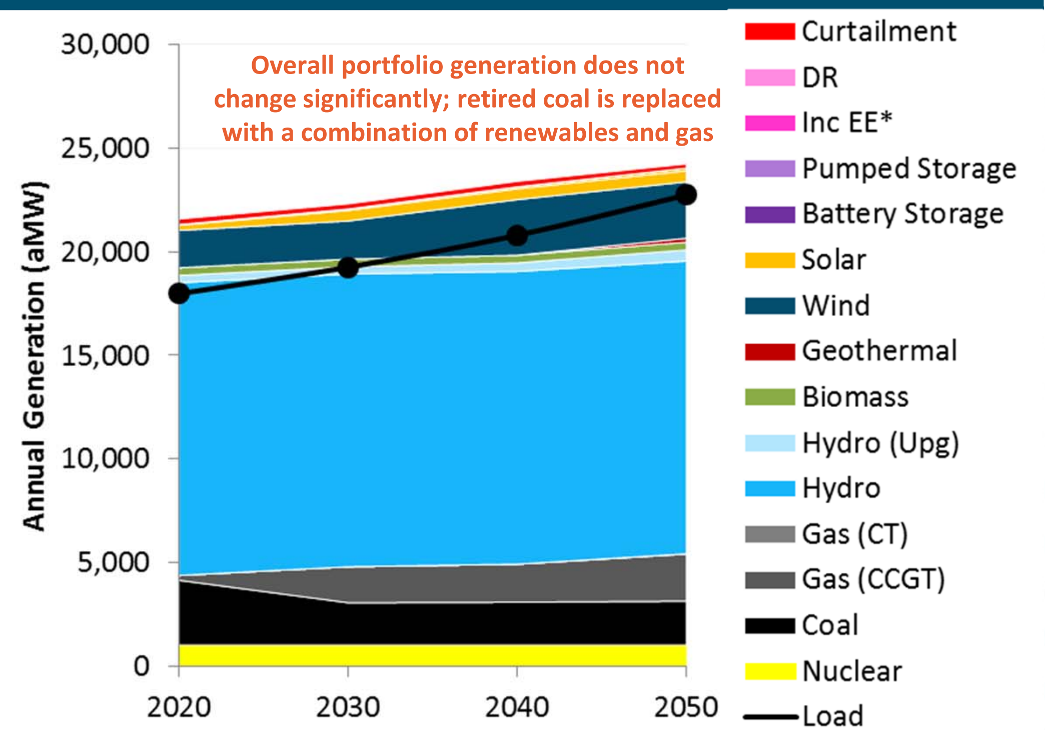
Portfolio Summary
Reference Case

- New gas gen. and DR added after 2020 to meet capacity needs
- Planned coal retirements result in increased reliance on gas generation
- By 2050, 5 GW of renewable resources are needed to meet RPS goals

Resources Added (MW)



Energy Balance (aMW)



* EE shown here is incremental to efficiency included in load forecast (based on NWPCC 7th Plan)

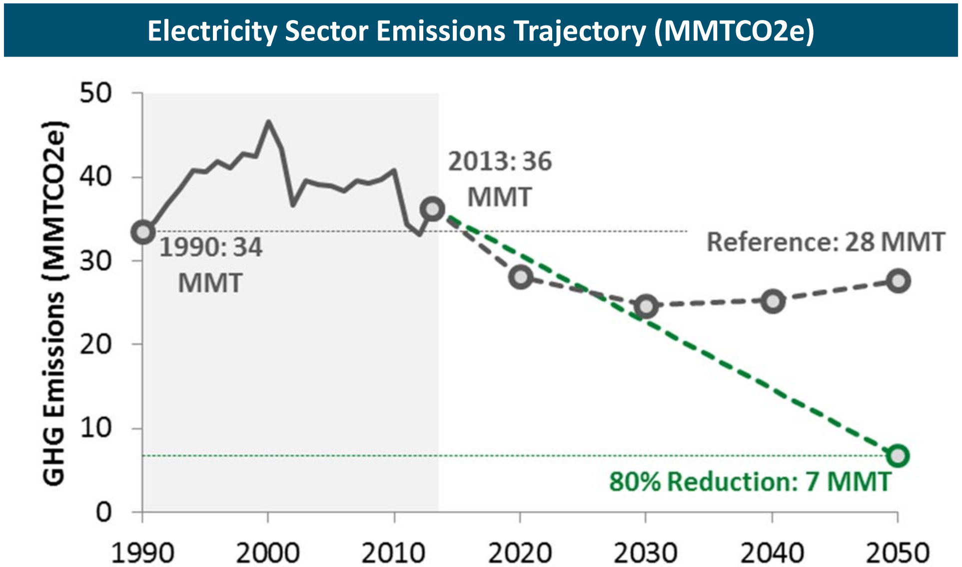
Emissions Trajectory
Reference Case

+ Through 2030, current policies and trends result in emissions reductions that are generally consistent with long-term goals

- Load growth limited by cost-effective energy efficiency
- 2,500 MW of renewable generation added to meet RPS policy goals by 2030
- 2,300 MW of coal capacity retired

+ Additional measures are needed to meet long-term goals beyond 2030

- Coal generation remains the largest source of emissions beyond 2030
- Additional gas generation & imports are needed to meet load growth
- Emissions start to trend back up after 2030 without new policy



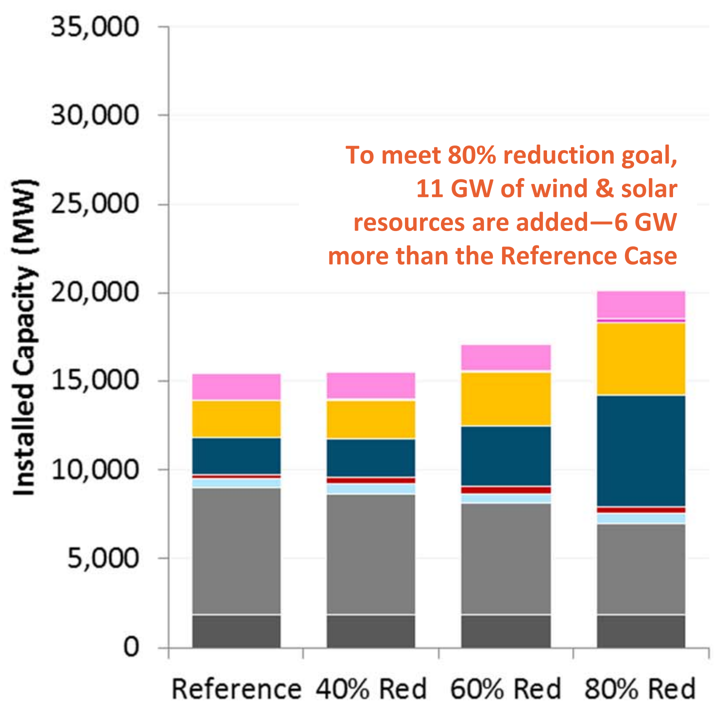
2050 Portfolio Summary
Carbon Cap Scenarios

Highlights

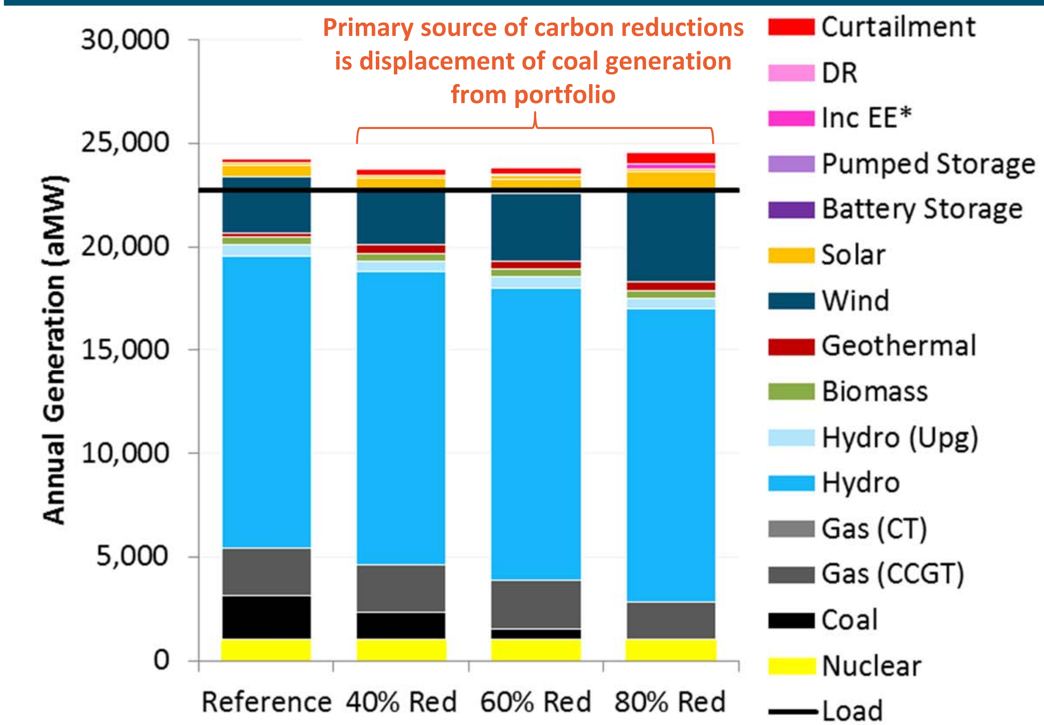
- Coal retired under 80% Case, replaced with renewables & gas
- 11 GW of new renewables by 2050
- 7 GW of new gas capacity added
- Gas capacity factor is 30% in 2050

Scenario	Inc Cost ($MM/yr.)	GHG Reductions (MMT)	Effective RPS %	Zero CO2 %
Reference	—	—	20%	91%
40% Reduction	+$163	7.5	21%	92%
60% Reduction	+$434	14.2	25%	95%
80% Reduction	+$1,046	20.9	31%	102%

Resources Added (MW)



Energy Balance (aMW)



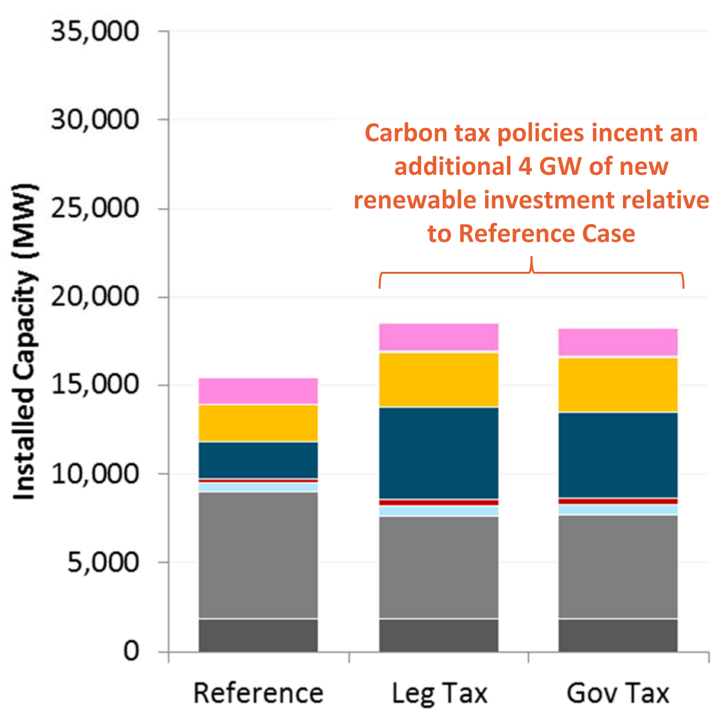
* EE shown here is incremental to efficiency included in load forecast (based on NWPCC 7th Plan)

2050 Portfolio Summary
Carbon Tax Scenarios

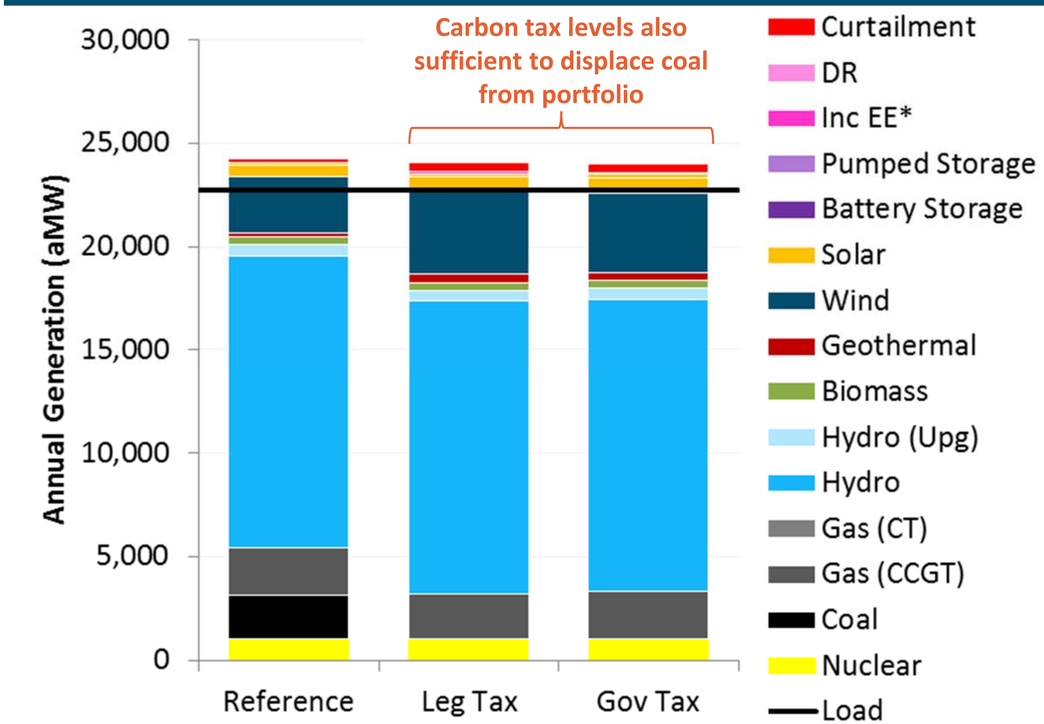
Highlights
- Coal retired under both cases and replaced with renewables & gas
- 9 GW of new renewables needed
- Carbon tax and cap lead to similar outcomes with these resource costs

Scenario	Inc Cost ($MM/yr.)	GHG Reductions (MMT)	Effective RPS %	Zero CO2 %
Reference	—	—	20%	91%
Leg Tax ($15-75)	+$804	19.1	28%	99%
Gov Tax ($25-61)	+$775	18.7	28%	99%

Resources Added (MW)



Energy Balance (aMW)



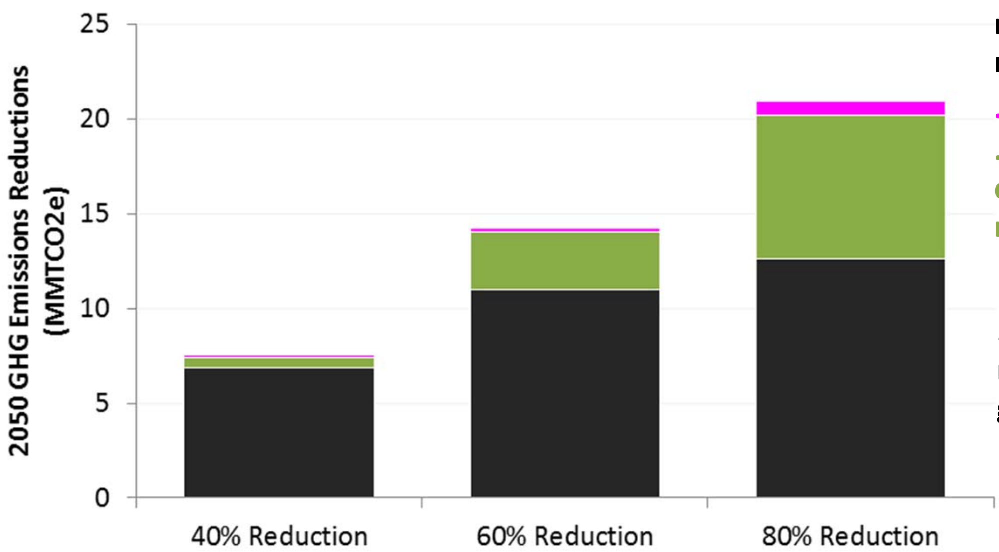
* EE shown here is incremental to efficiency included in load forecast (based on NWPCC 7th Plan)

Sources of Carbon Reductions in GHG Constrained Cases

+ **Three key strategies needed to meet 80% reduction goals:**

  1. **Coal displacement:** reduced utilization and/or retirement of existing coal resources & replacement with natural gas
  2. **Renewables:** displacement of gas & coal generation with additional investment in renewable generation
  3. **Energy efficiency:** reductions in load due to additional energy efficiency

Emissions Reductions Relative to Reference Case (MMTCO2e)



Of the 21 MMT of emissions reductions needed to meet the 80% reduction goal…

…1 MMT is due to incremental EE

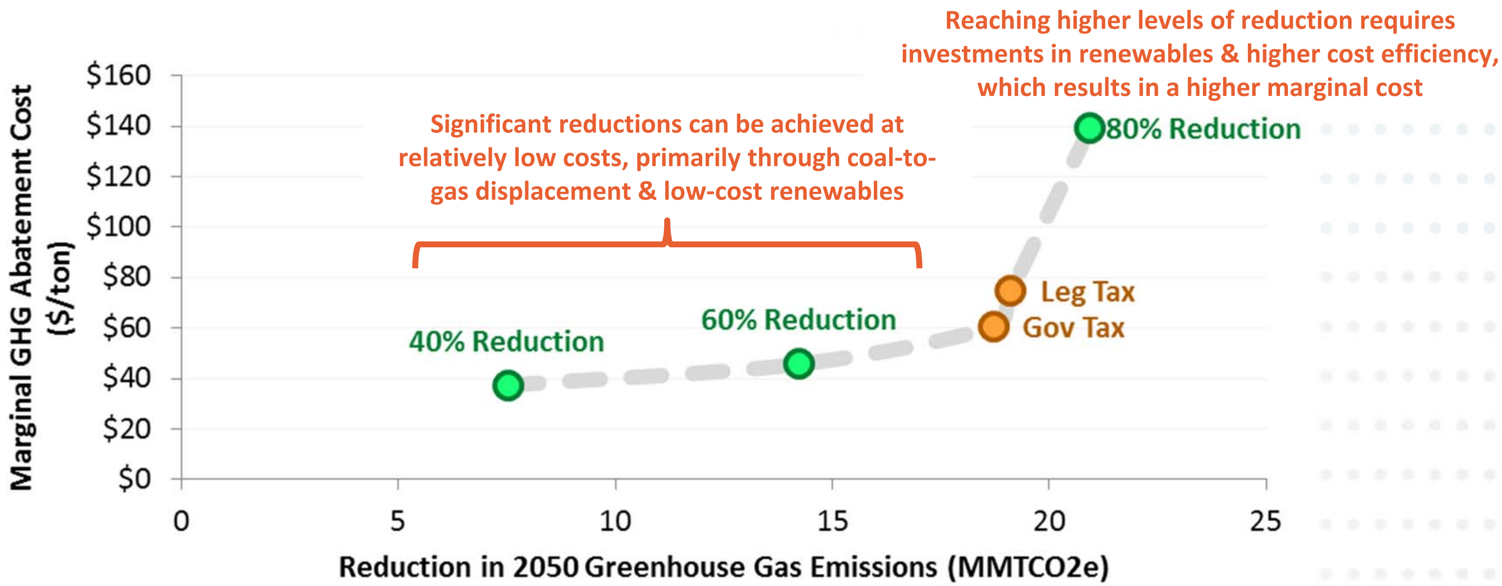
…7 MMT result from displacement of natural gas with renewables

…13 MMT are a result of the retirement of existing coal generation

Marginal Greenhouse Gas Abatement Costs

- Shape of GHG marginal cost curve highlights (1) low-hanging fruit; and (2) high cost of final mitigation measures needed to meet 2050 targets
- GHG abatement results of carbon tax scenarios are consistent with scenarios based on targets

Marginal Greenhouse Gas Abatement Cost Curve ($/metric ton)



Note: marginal GHG abatement cost based on shadow price of GHG constraint for GHG policy scenarios; based on assumed 2050 carbon tax for tax scenarios

Carbon Tax vs. Cap-and-Trade: Qualitative Factors

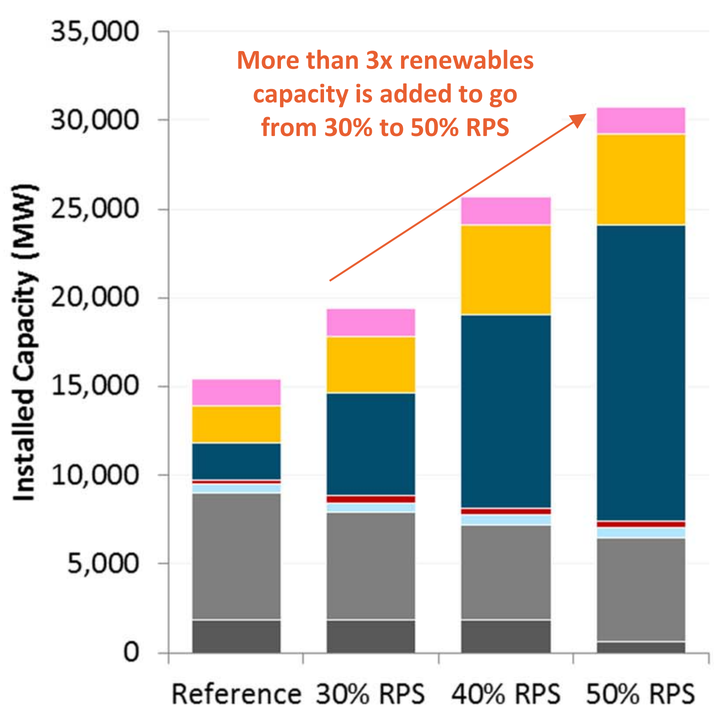
Resource Option	Carbon Tax	Carbon Cap-and-Trade
Compliance mechanism	Pay tax on each ton of CO2 emissions	Surrender carbon allowance for each ton of CO2 emissions
Disposition of funds collected	Tax revenue appropriated through legislative process	Allowances can be auctioned or allocated to affected companies; auction revenues administered by state agency (e.g., DEQ)
Breadth of carbon abatement options	In-state abatement options only	Ability to link with regional carbon markets to expand liquidity
Effect on electric markets	Potential for multiple prices on carbon within Western Interconnection creates challenges for market liquidity and interconnected operations	Single regional price on carbon would preserve wholesale power market liquidity and avoid operational wrinkles
Emissions reductions	Carbon price is fixed but actual emissions levels would vary	Emissions levels are specified, but carbon price would vary over time as abatement costs change

2050 Portfolio Summary
High RPS Scenarios

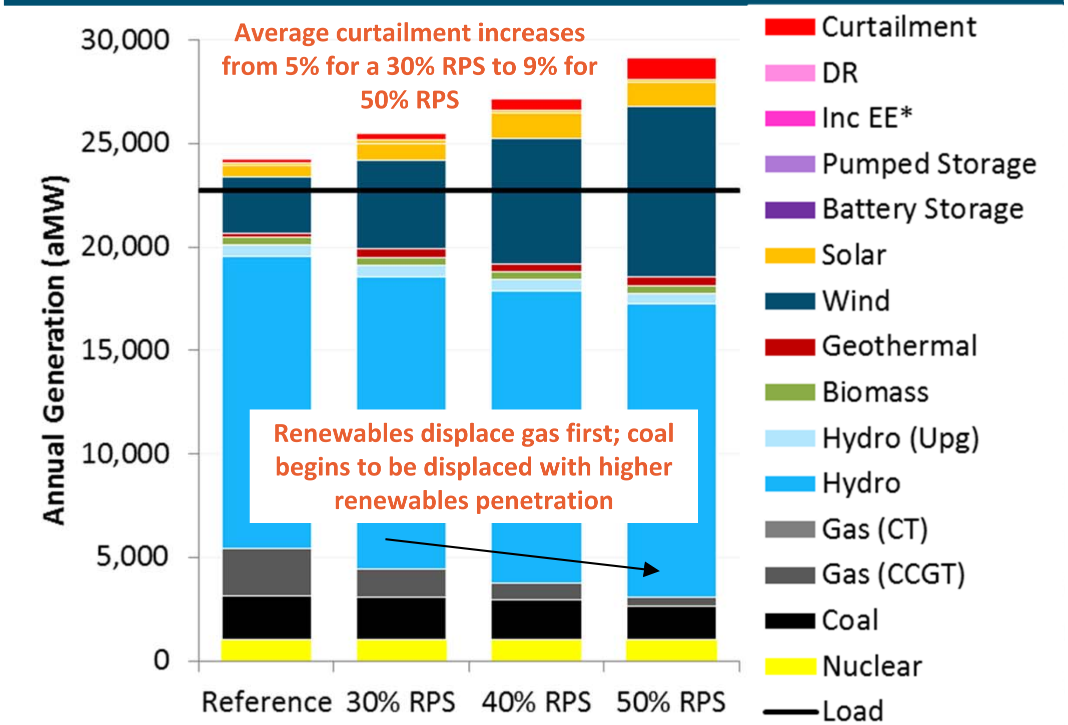
Highlights
- 23 GW of new renewables needed to meet a 50% RPS by 2050
- Curtailment increases to 9% of available renewable energy
- Coal provides most thermal energy

Scenario	Inc Cost ($MM/yr.)	GHG Reductions (MMT)	Effective RPS %	Zero CO2 %
Reference	—	—	20%	91%
30% RPS	+$330	4.3	30%	101%
40% RPS	+$1,077	7.5	40%	111%
50% RPS	+$2,146	11.5	50%	121%

Resources Added (MW)



Energy Balance (aMW)

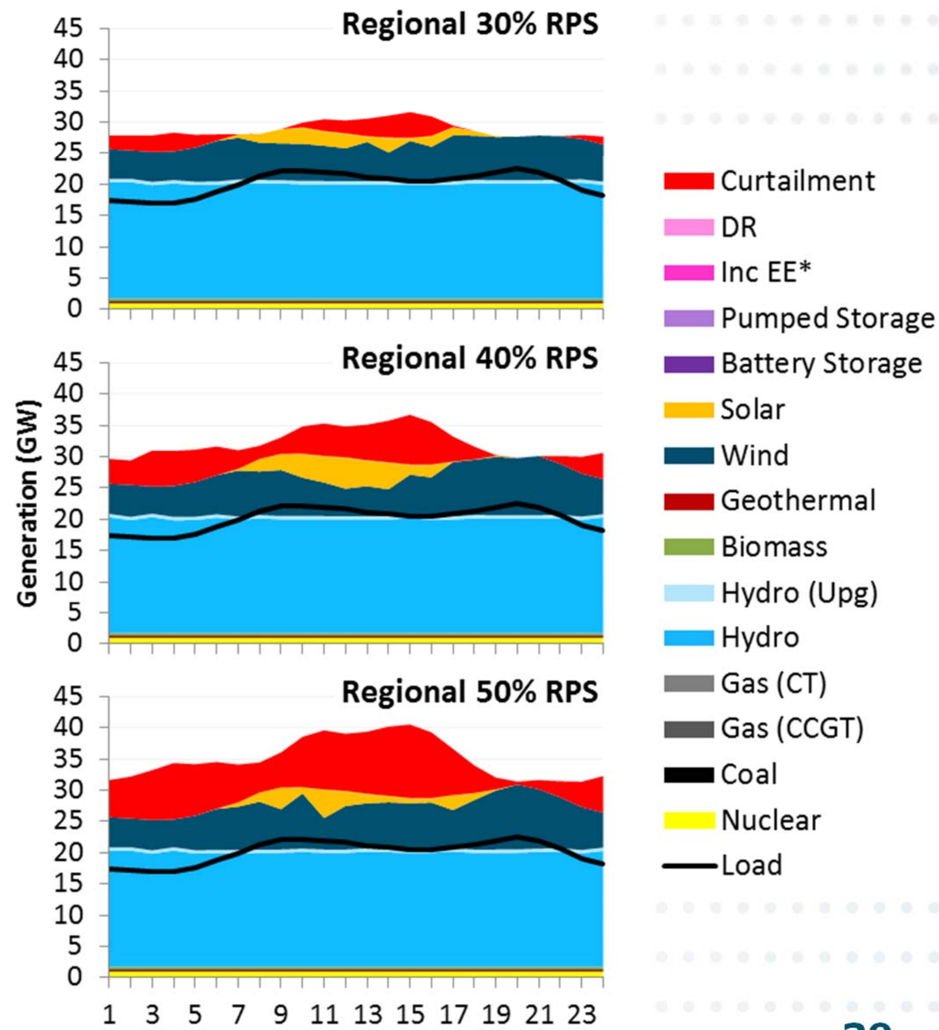


* EE shown here is incremental to efficiency included in load forecast (based on NWPCC 7th Plan)

Renewable Curtailment Becomes the Primary Integration Challenge

- Higher renewable generation results in increased frequency and magnitude of renewable curtailment
- A significant proportion of incremental renewable generation above 30% RPS is either exported or curtailed
- Predominance of hydropower contributes to renewable curtailment but already serves as a zero-carbon baseload power source in the region

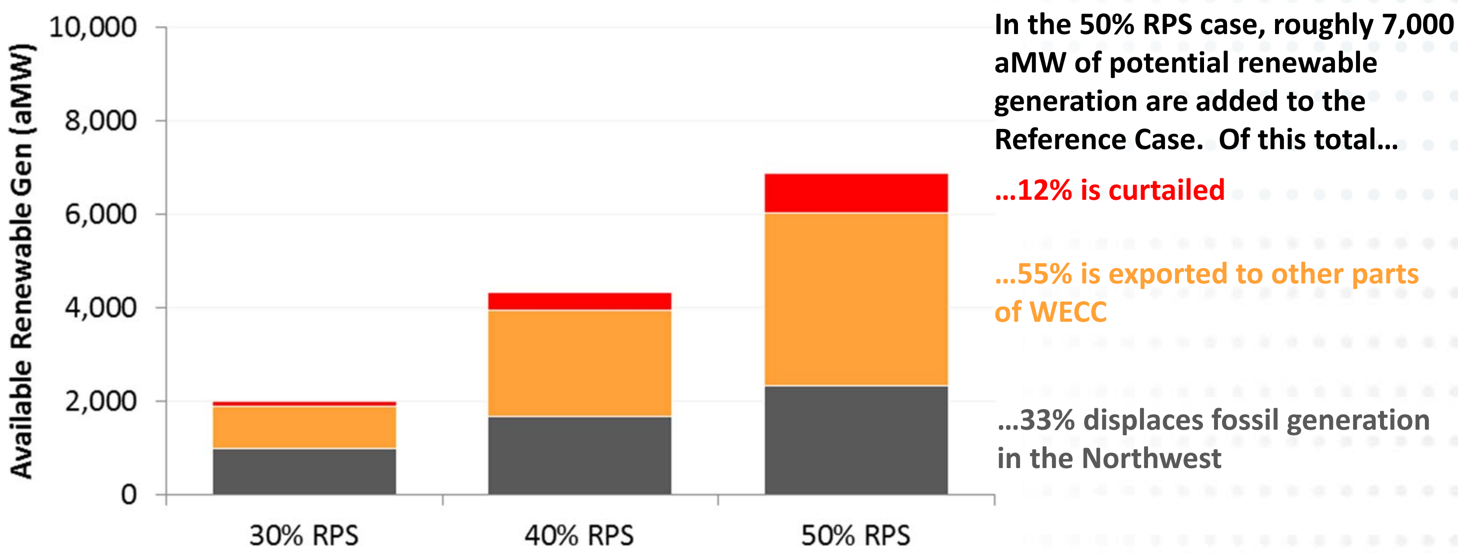
Snapshot of Daily Operations on a High Hydro Day (2050)



Impact of Incremental Renewables on Carbon is Limited

- Under High RPS policies, renewables become less effective at reducing carbon in the Northwest, as large shares of generation are either exported or curtailed
- Frequency and magnitude of renewable curtailment events grows considerably, driving up cost of meeting RPS targets

Impact of Incremental Renewable Resources Added (aMW)



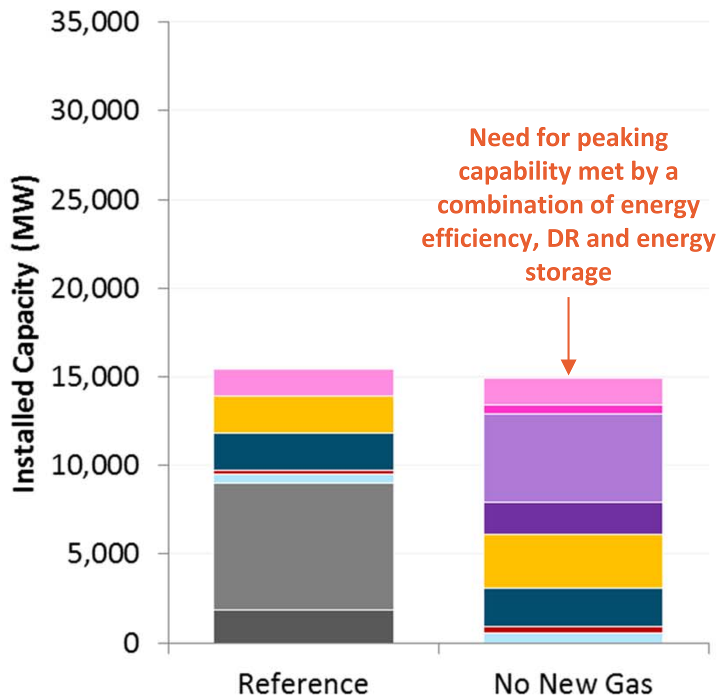
2050 Portfolio Summary
No New Gas Scenario

Highlights

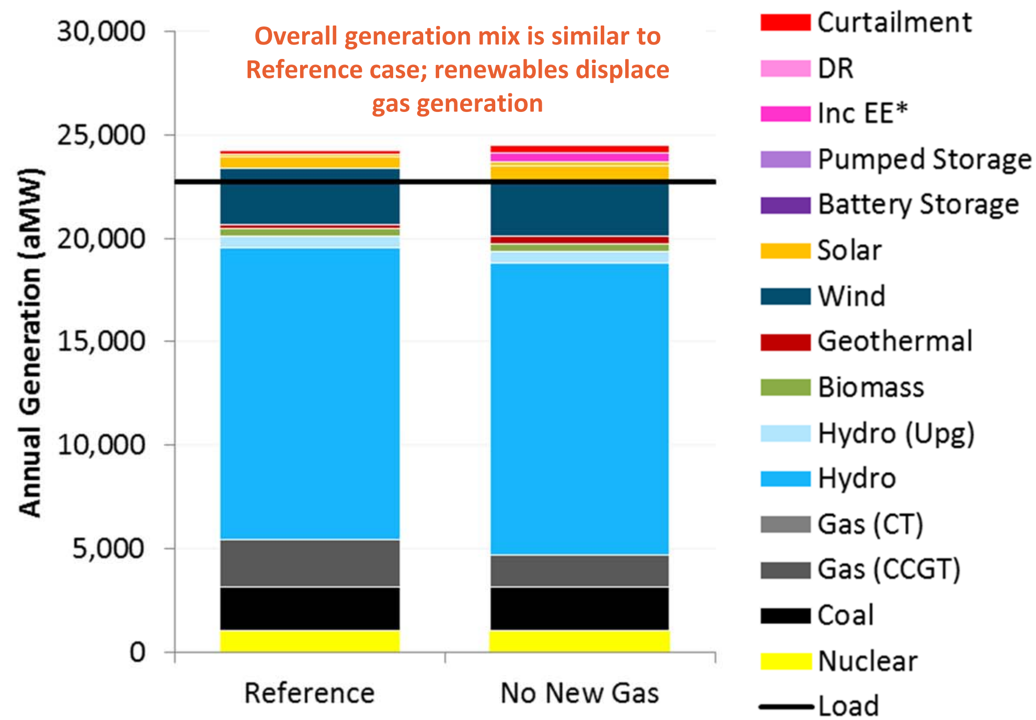
- 7 GW of new energy storage added to meet capacity needs
- Very little change in coal & gas generation or GHG emissions

Scenario	Inc Cost ($MM/yr.)	GHG Reductions (MMT)	Effective RPS %	Zero CO2 %
Reference	—	—	20%	91%
No New Gas	+$1,202	2.0	22%	93%

Resources Added (MW)



Energy Balance (aMW)



* EE shown here is incremental to efficiency included in load forecast (based on NWPCC 7th Plan)

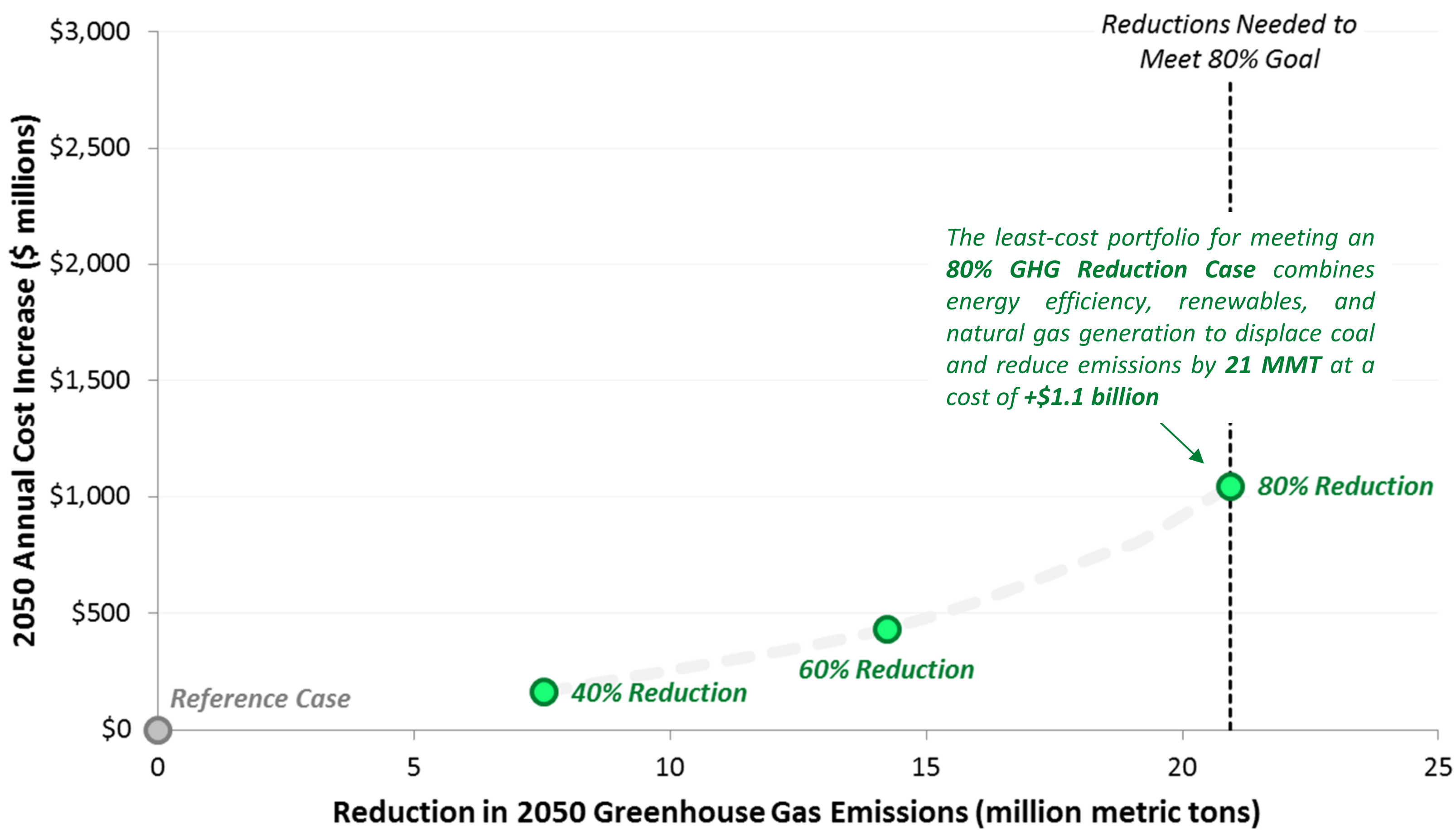
No New Gas Scenario Might Not Be Resource Adequate After 2025

+ **New resources are needed in 2025-2030 time frame to ensure resource adequacy due to coal plant retirements and load growth**
    - Primary source of capacity added under No New Gas Case is energy storage (pumped hydro & batteries)
+ **Storage provides capacity to help meet peak demands but does not generate energy that is needed during low hydro years or multi-day low generation events**
+ **More study is needed to analyze whether the system as modeled meets reliability expectations**
    - The ‘No New Gas’ portfolio meets the current reserve margin requirement with the addition of new energy storage
    - However, it is unclear how much energy storage can contribute to Resource Adequacy in the Pacific Northwest

Energy+Environmental Economics

CORE POLICY SCENARIOS: SUMMARY OF COST & EMISSIONS IMPACTS

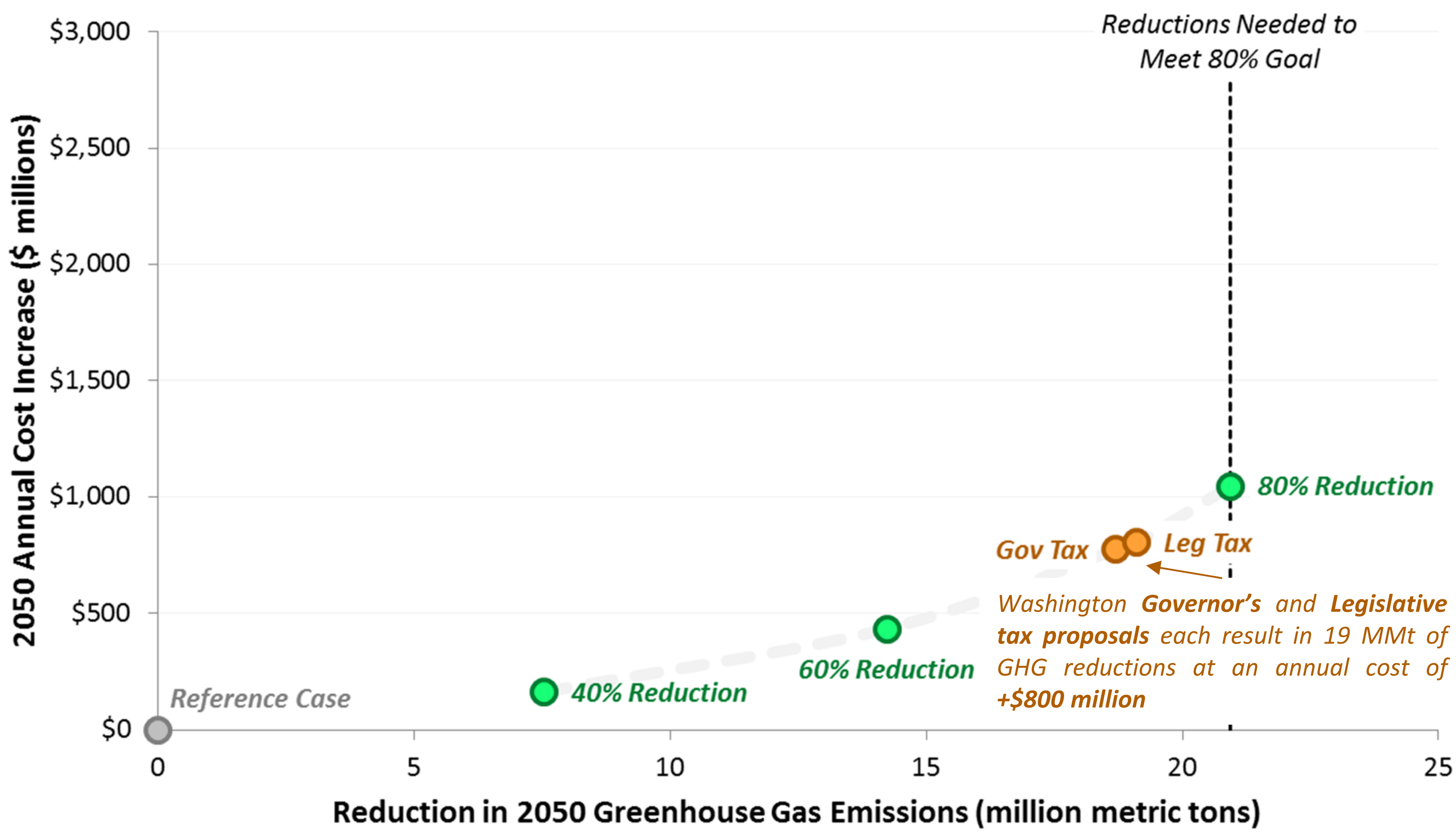
Cost & Emissions Impacts
Carbon Cap Cases



Note: Reference Case reflects current industry trends and state policies, including Oregon's 50% RPS goal for IOUs and Washington's 15% RPS for large utilities

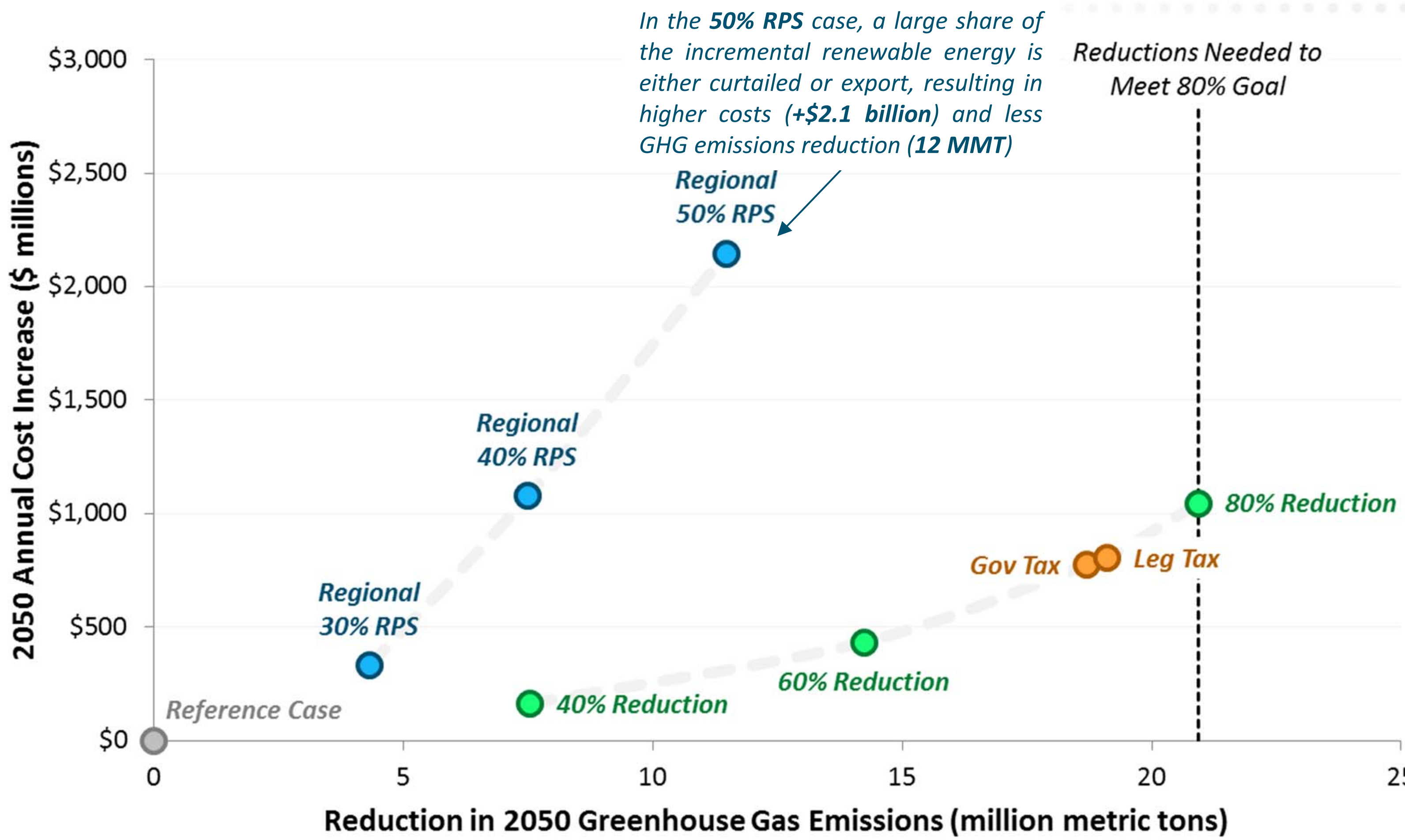
Cost & Emissions Impacts

Carbon Tax Cases



Note: Reference Case reflects current industry trends and state policies, including Oregon's 50% RPS goal for IOUs and Washington's 15% RPS for large utilities

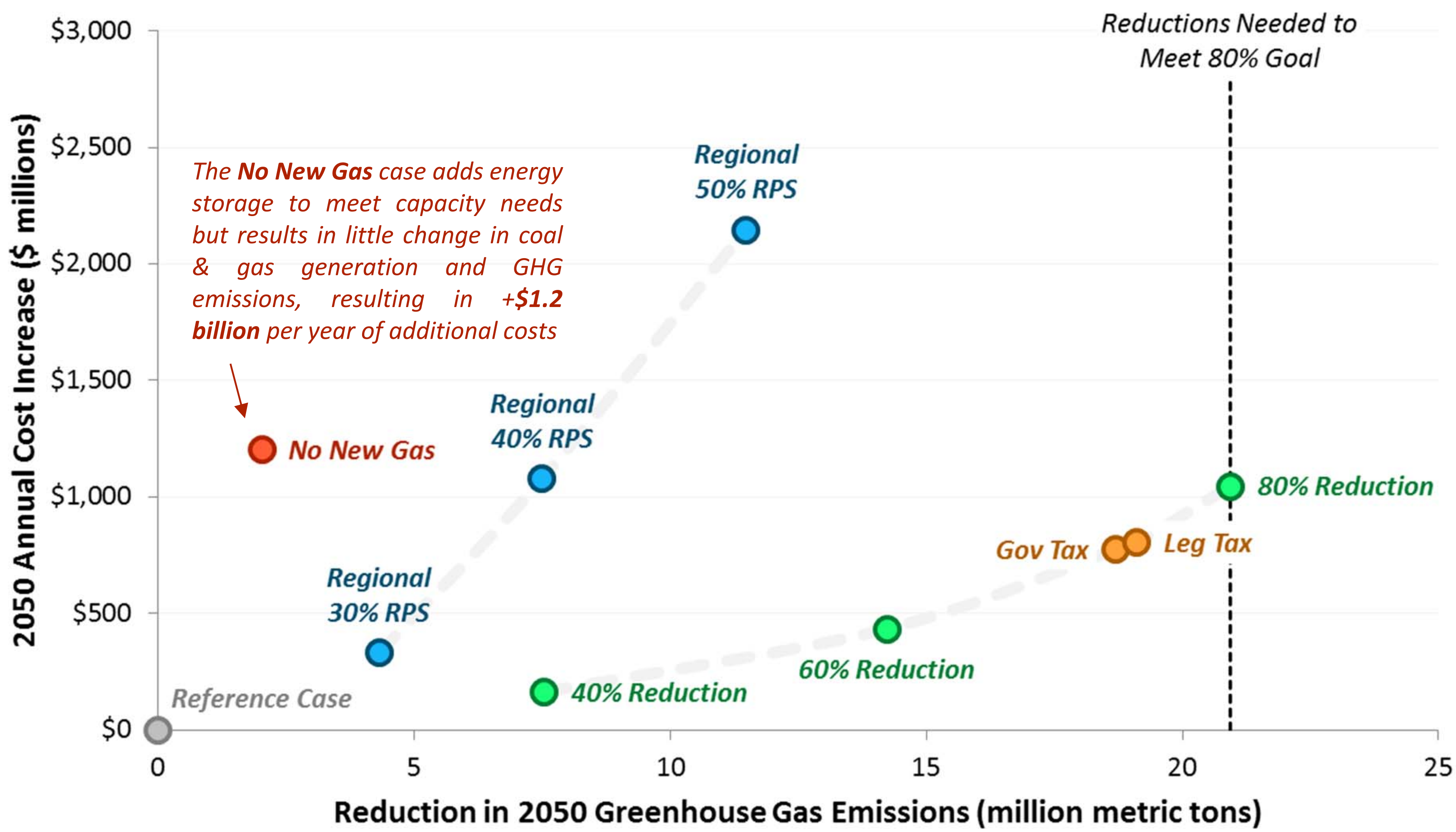
Cost & Emissions Impacts
High RPS Cases



Note: Reference Case reflects current industry trends and state policies, including Oregon's 50% RPS goal for IOUs and Washington's 15% RPS for large utilities

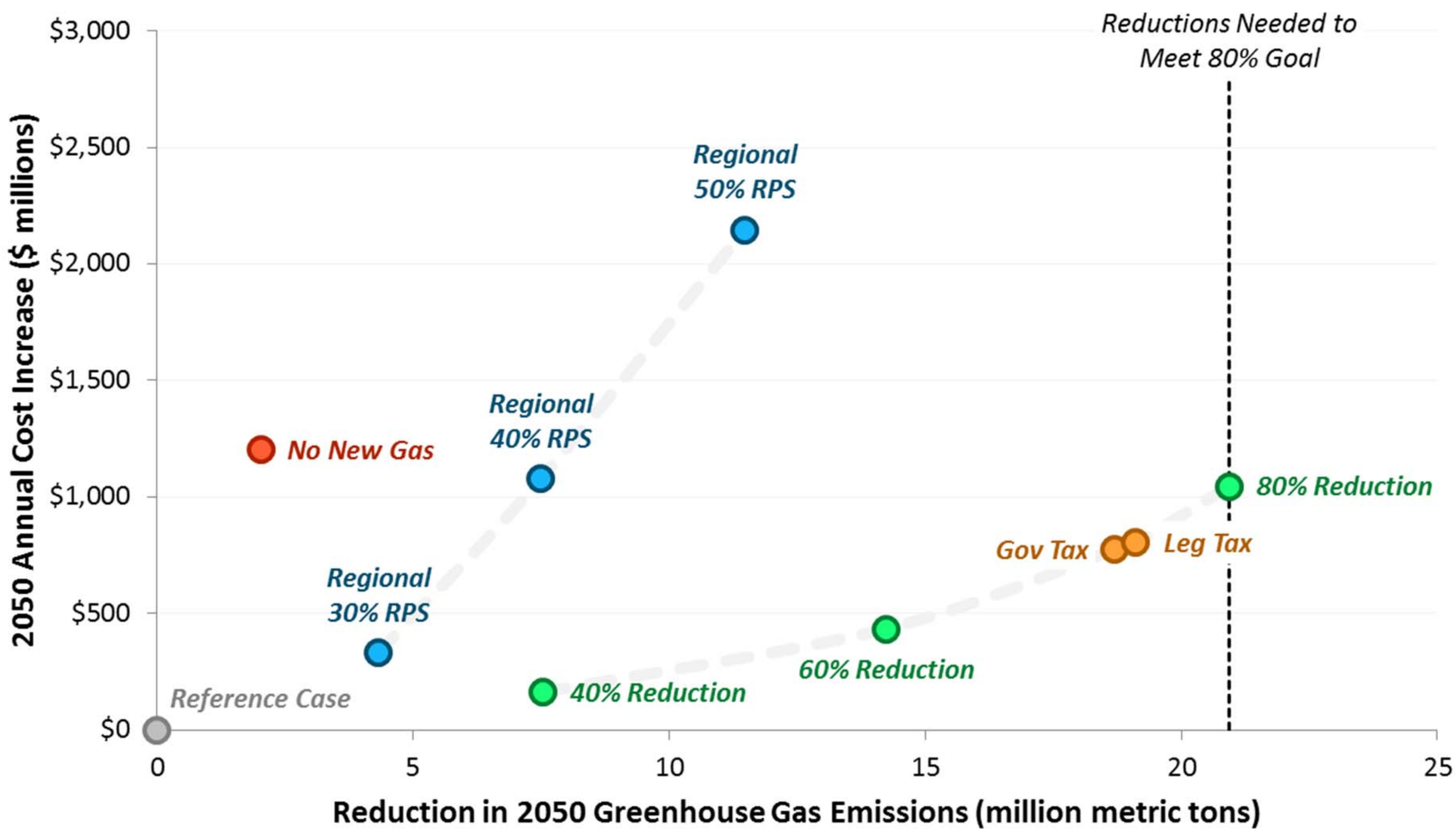
Cost & Emissions Impacts

No New Gas Case



Note: Reference Case reflects current industry trends and state policies, including Oregon's 50% RPS goal for IOUs and Washington's 15% RPS for large utilities

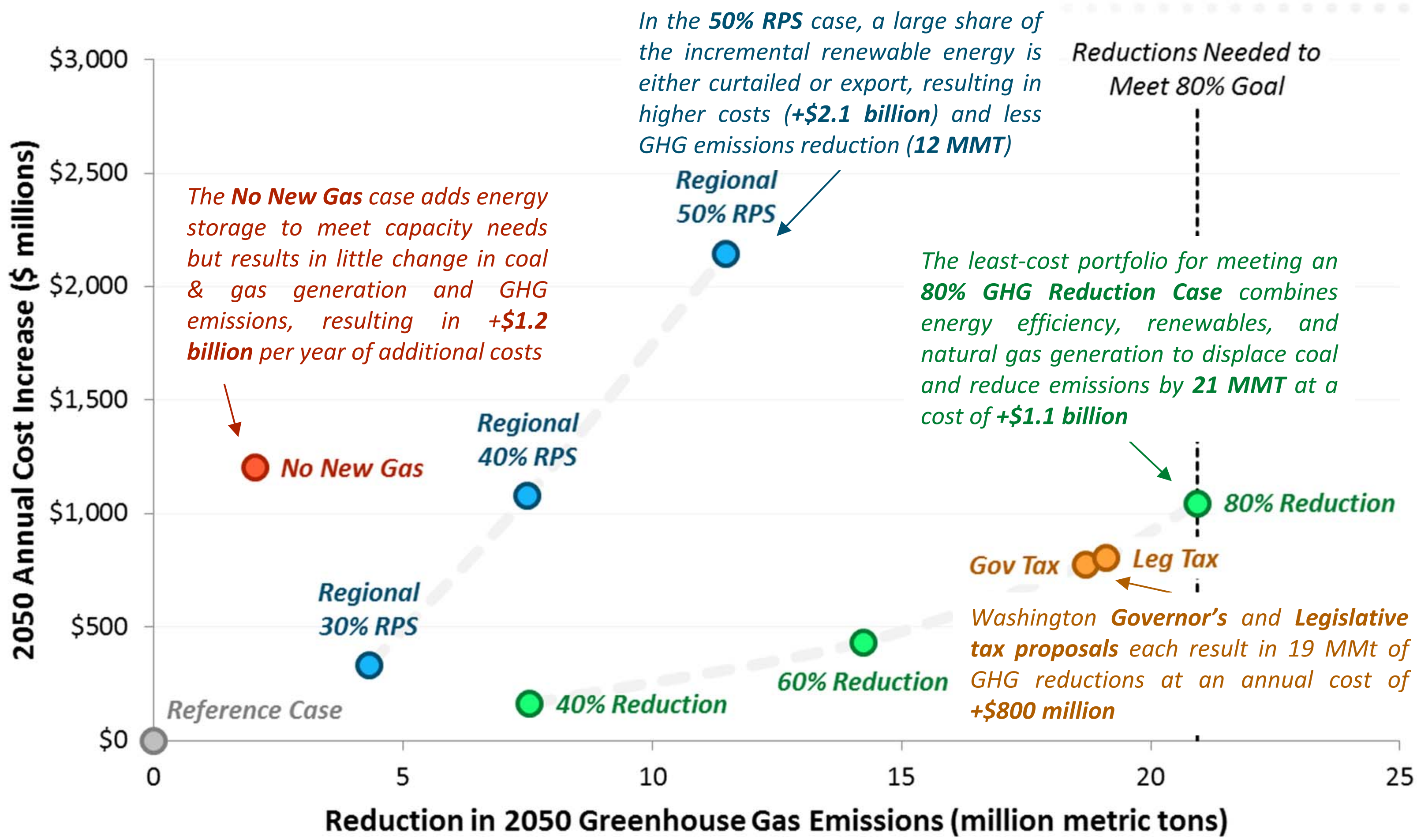
Cost & Emissions Impacts
All Cases



Note: Reference Case reflects current industry trends and state policies, including Oregon's 50% RPS goal for IOUs and Washington's 15% RPS for large utilities

Cost & Emissions Impacts

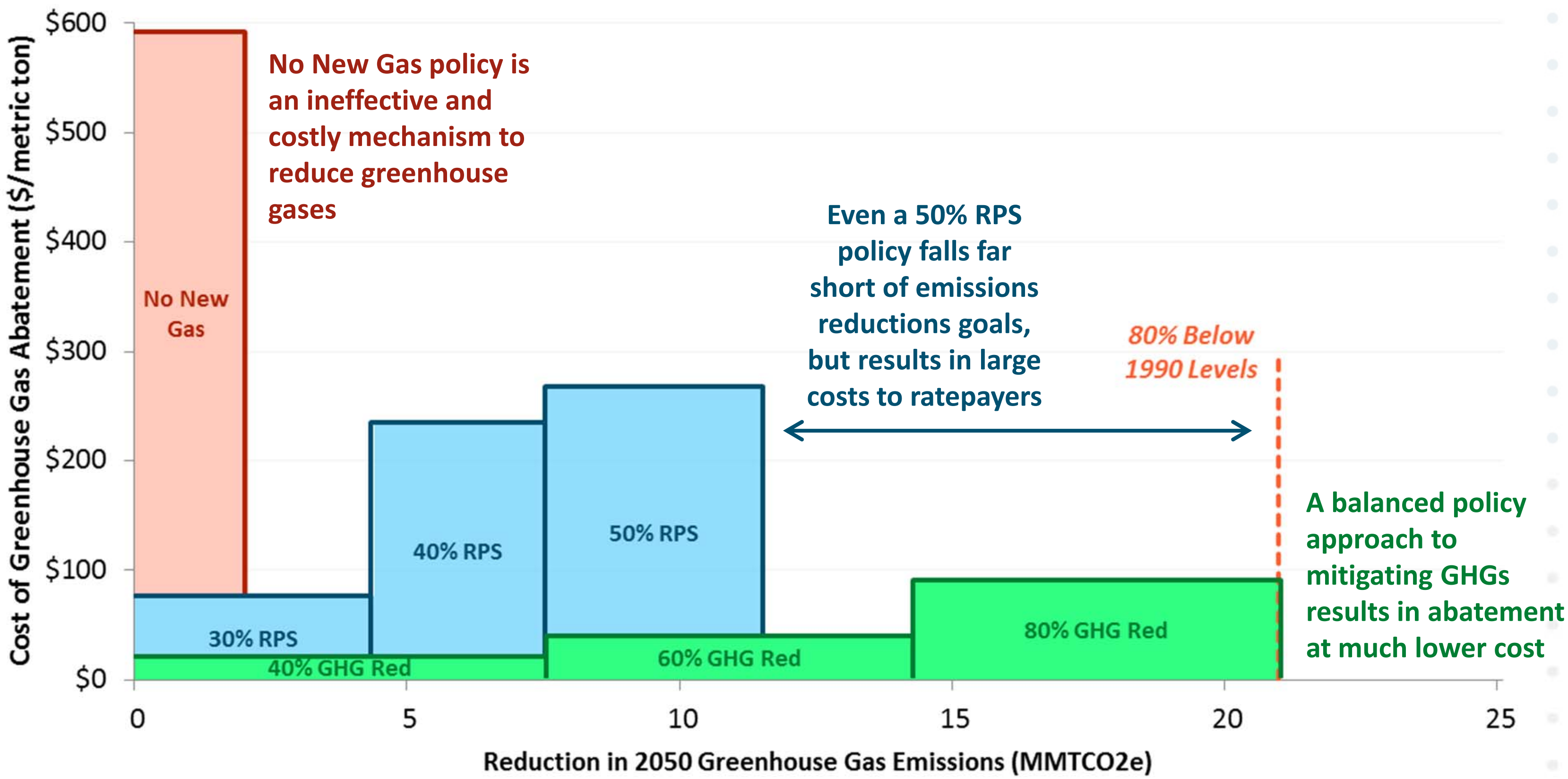
All Cases



Note: Reference Case reflects current industry trends and state policies, including Oregon's 50% RPS goal for IOUs and Washington's 15% RPS for large utilities

Cost of GHG Abatement

+ **Shape of GHG marginal cost curve highlights (1) low-hanging fruit; and (2) high cost of final mitigation measures needed to meet 2050 targets**



2050 Scenario Summary

Scenario	Inc Cost ($MM/yr.)	GHG Reductions (MMT)	Avg GHG Abatement Cost ($/ton)	Effective RPS %	Zero Carbon %	Renewable Curtailment (aMW)
Reference	—	—	—	20%	91%	201
40% Reduction	+$163	7.5	$22	21%	92%	294
60% Reduction	+$434	14.2	$30	25%	95%	364
80% Reduction	+$1,046	20.9	$50	31%	102%	546
30% RPS	+$330	4.3	$77	30%	101%	313
40% RPS	+$1,077	7.5	$144	40%	111%	580
50% RPS	+$2,146	11.5	$187	50%	121%	1,033
Leg Tax ($15-75)	+$804	19.1	$42	28%	99%	437
Gov Tax ($25-61)	+$775	18.7	$41	28%	99%	424
No New Gas	+$1,202	2.0	$592	22%	93%	337

Incremental cost and GHG reductions are measured relative to the Reference Case

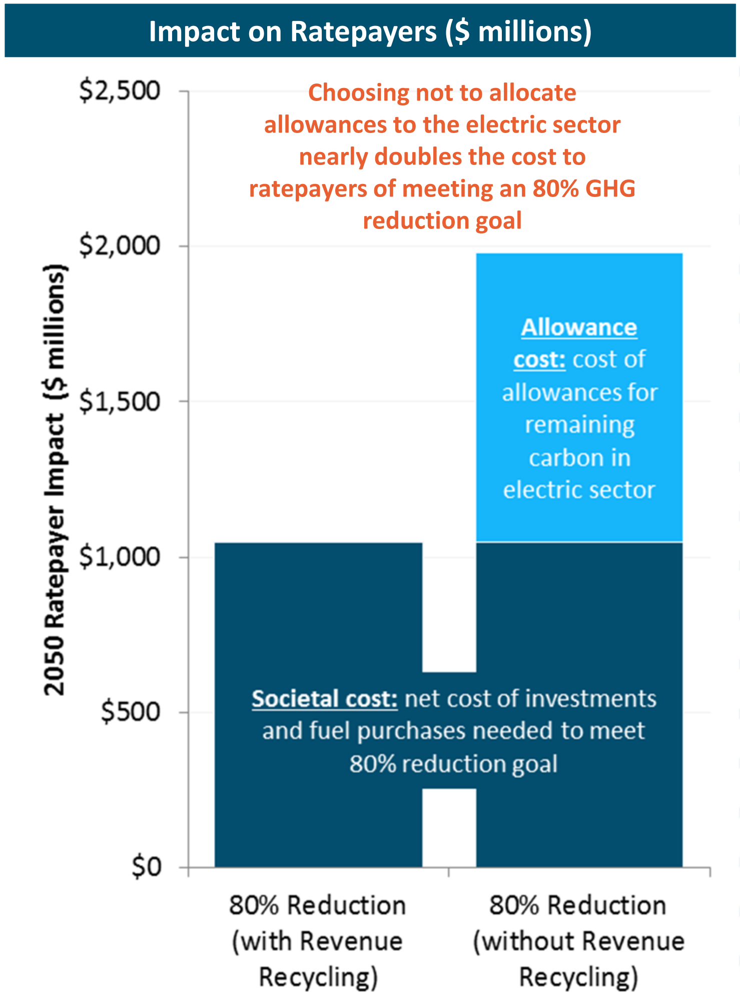
Energy+Environmental Economics

SENSITIVITY RESULTS

No Revenue Recycling

Disposition of Revenues from Carbon Pricing is Important for Cost Mitigation

- **The primary cost metric in this analysis is the incremental societal cost associated with each policy**
  - Reflects costs of burning more expensive fuel and investing in more expensive generation resources
- **Ratepayer costs may not align with societal costs**
  - Returning or "recycling" revenues from cap/tax would mitigate impact on electric ratepayers
  - If revenues from cap/tax are diverted to other uses, ratepayer impact will be larger
- **Most jurisdictions that have implemented carbon pricing have included revenue recycling to mitigate cost to ratepayers**



Energy+Environmental Economics

SENSITIVITY RESULTS

Existing Resource Retirement

Retirement of Existing Zero-Carbon Generation

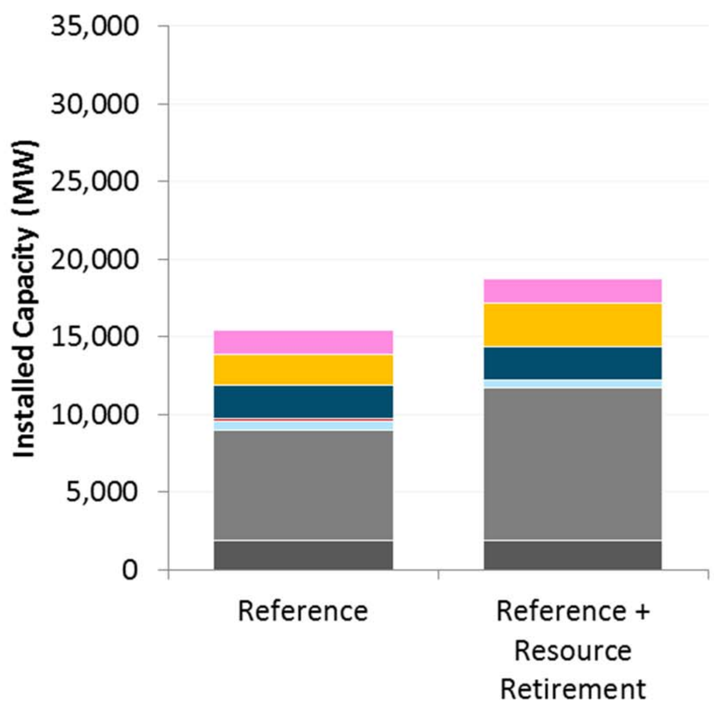
+ **In order to highlight the value of existing zero carbon (non-RPS-qualifying) resources—and their key role in meeting GHG goals—E3 evaluated a sensitivity in which approximately 2,000 aMW of nuclear & hydro was assumed to retire:**
  - Columbia Generating Station (1,207 MW)
  - 1,000 aMW of generic existing hydro
+ **Sensitivity analysis conducted on Reference Case (current policy), 80% GHG Reduction Case and 50% RPS Case**

2050 Portfolio Summary
Reference Case (Existing Resource Retirement)

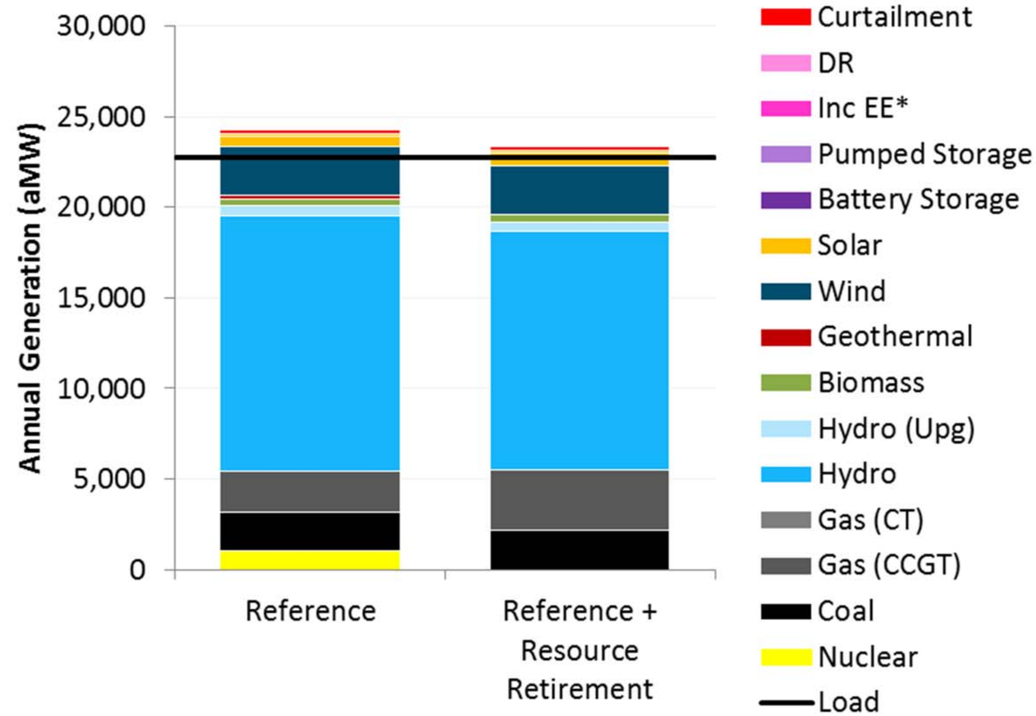
Highlights
- Under Reference Case, retiring resources are replaced with gas generation
- Results in both higher costs and GHG emissions

Scenario	Inc Cost ($MM/yr.)	GHG Reductions (MMT)	Effective RPS %	Zero CO2 %
Base	—	—	20%	91%
Retirement Case	+$1,071	-5.1	20%	82%
Delta	+$1,071	-5.1	—	-9%

Selected Resources (MW)



Energy Balance (aMW)



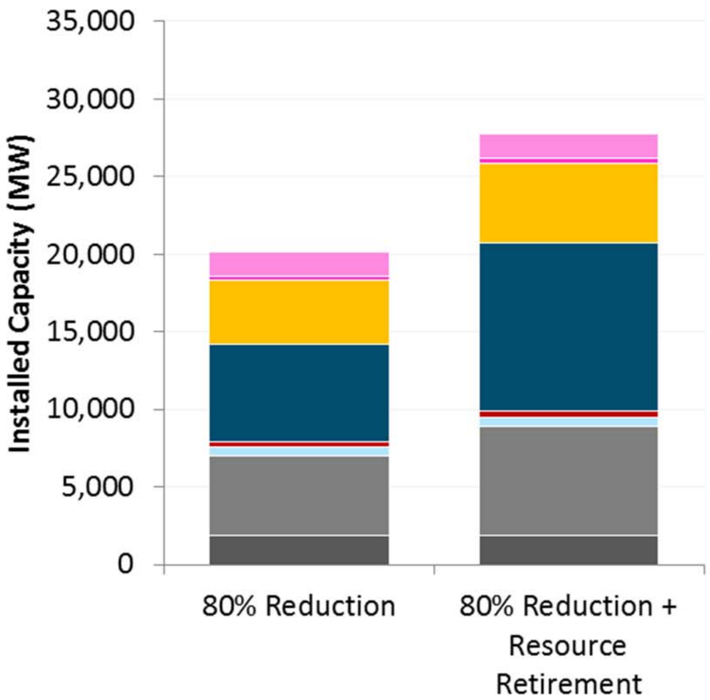
* EE shown here is incremental to efficiency included in load forecast (based on NWPCC 7th Plan)

2050 Portfolio Summary
80% Reduction (Existing Resource Retirement)

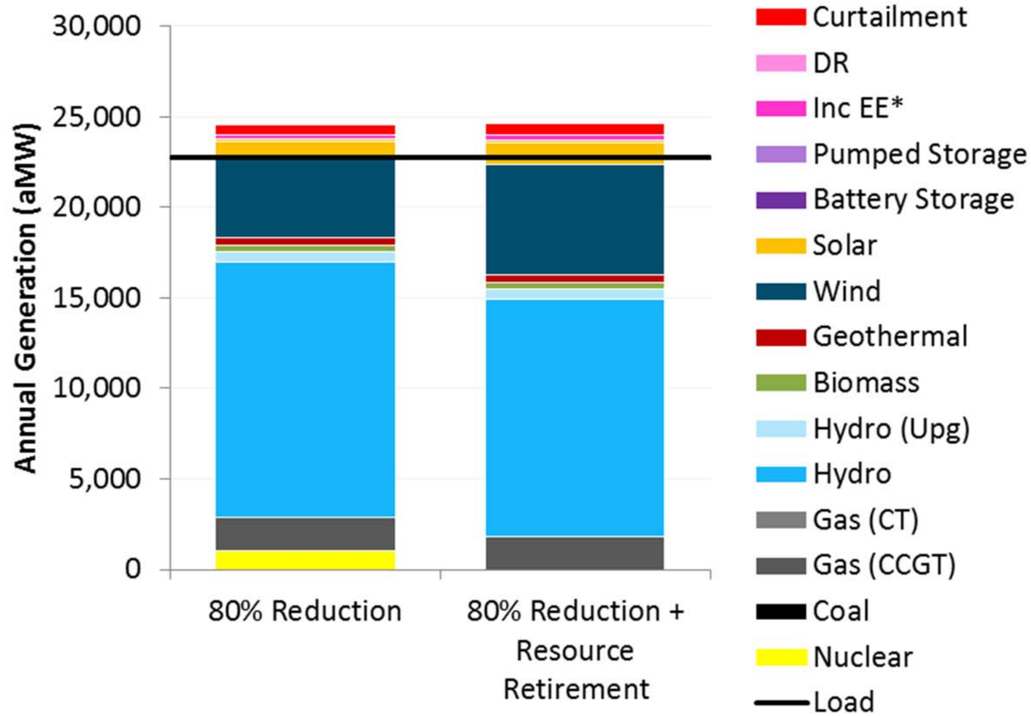
Highlights
- Under 80% GHG reduction scenario, retiring carbon-free resources replaced with 5.5 GW of renewables and 2 GW of gas
- Cost to meet goal increases $1.6 B

Scenario	Inc Cost ($MM/yr.)	GHG Reductions (MMT)	Effective RPS %	Zero CO2 %
Base	+$1,046	20.9	31%	102%
Retirement Case	+$2,652	20.9	40%	102%
Delta	+$1,606	—	+9%	—

Selected Resources (MW)

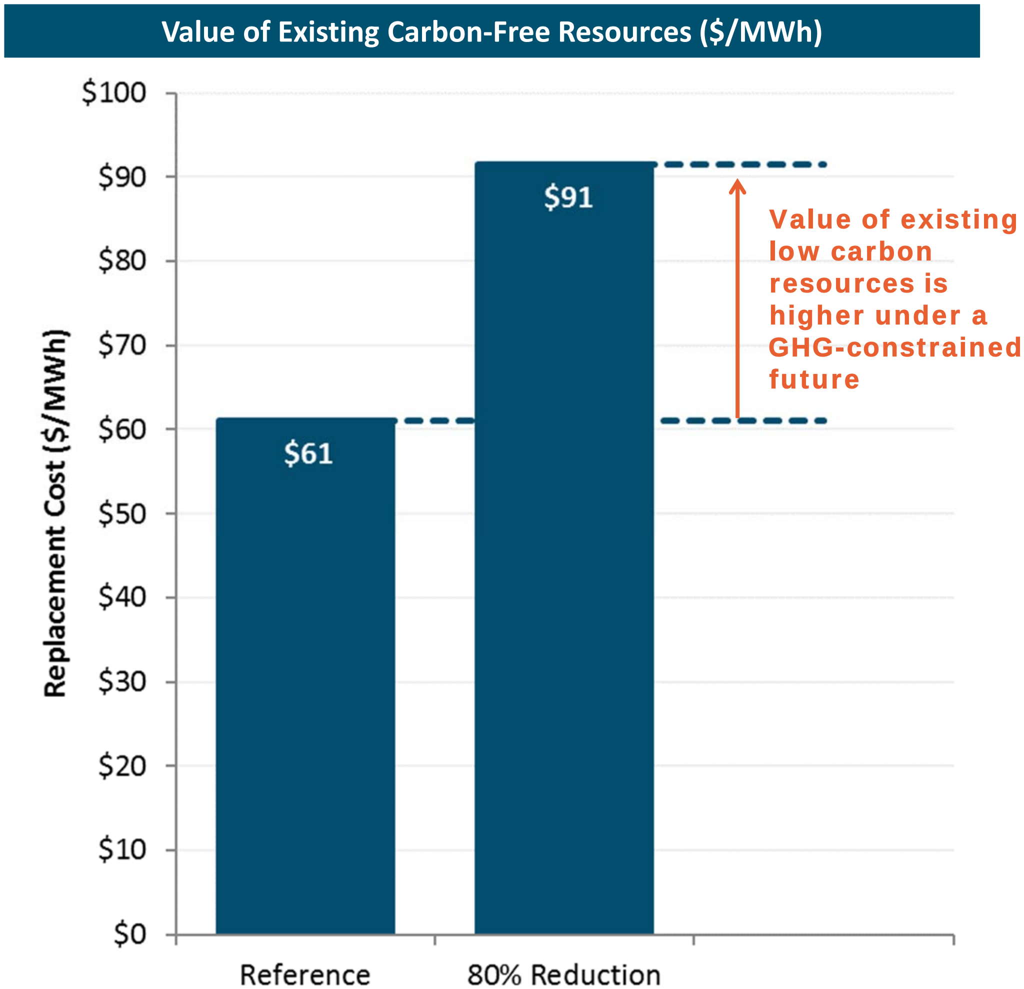


Energy Balance (aMW)



* EE shown here is incremental to efficiency included in load forecast (based on NWPCC 7th Plan)

Value of Existing Zero Carbon Gen Increases Under GHG Constraints



- In the <u>Reference Case</u>, lost capacity and energy is replaced with natural gas generation
- In the <u>80% GHG Reduction Case</u>, lost energy is replaced with 5500 MW of renewables and lost capacity is replaced with 2000 MW of gas generation
- Higher value in a carbon constrained world reflects the significant increase in cost to meet GHG policy goals should existing low carbon resources retire

Energy+Environmental Economics

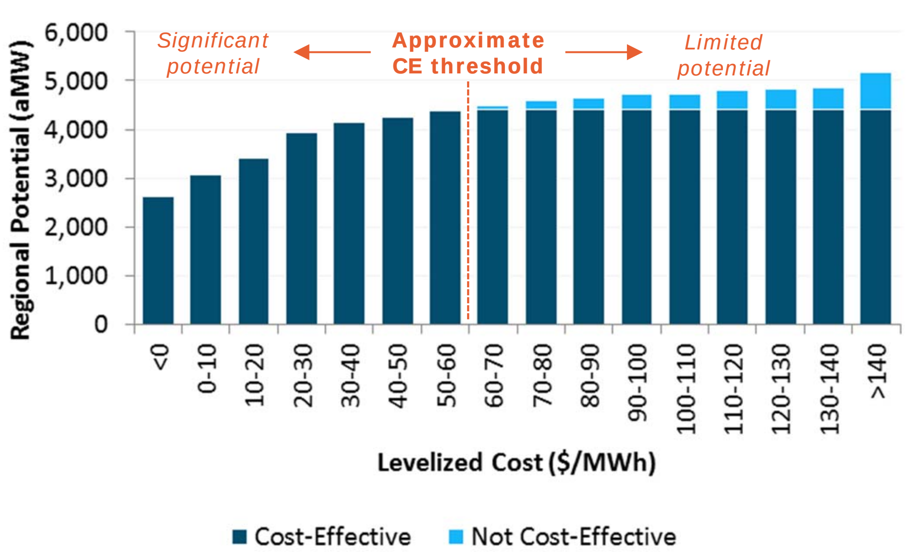
SENSITIVITY RESULTS

High Incremental Energy Efficiency Potential

High Energy Efficiency Sensitivity

+ **This study relies on the NWPCC Seventh Power Plan for its characterization of energy efficiency:**
  - All cost-effective efficiency integrated into demand forecast
  - Additional measures available for selection in RESOLVE
+ **Beyond the cost-effectiveness threshold, NWPCC's supply curve for efficiency measures flattens out—limited additional potential has been identified**
+ **This sensitivity tests the impact of allowing RESOLVE to select additional high-cost EE measures**
  - 1,000 aMW of additional potential at a cost of $110/MWh
+ **Purpose of sensitivity is to explore whether additional focus on EE is merited under GHG policy**

NWPCC Energy Efficiency Supply Curve



2050 Portfolio Summary

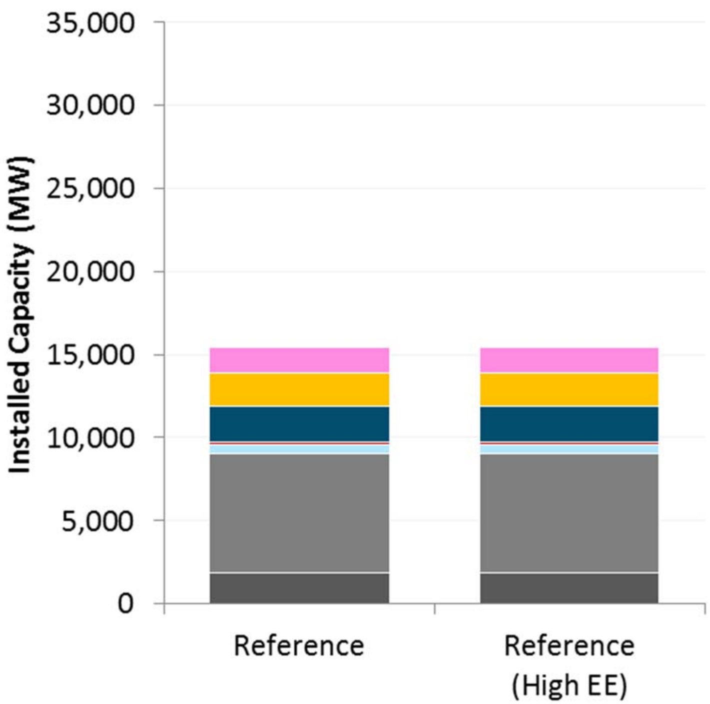
Reference Case (High EE Potential)

Highlights

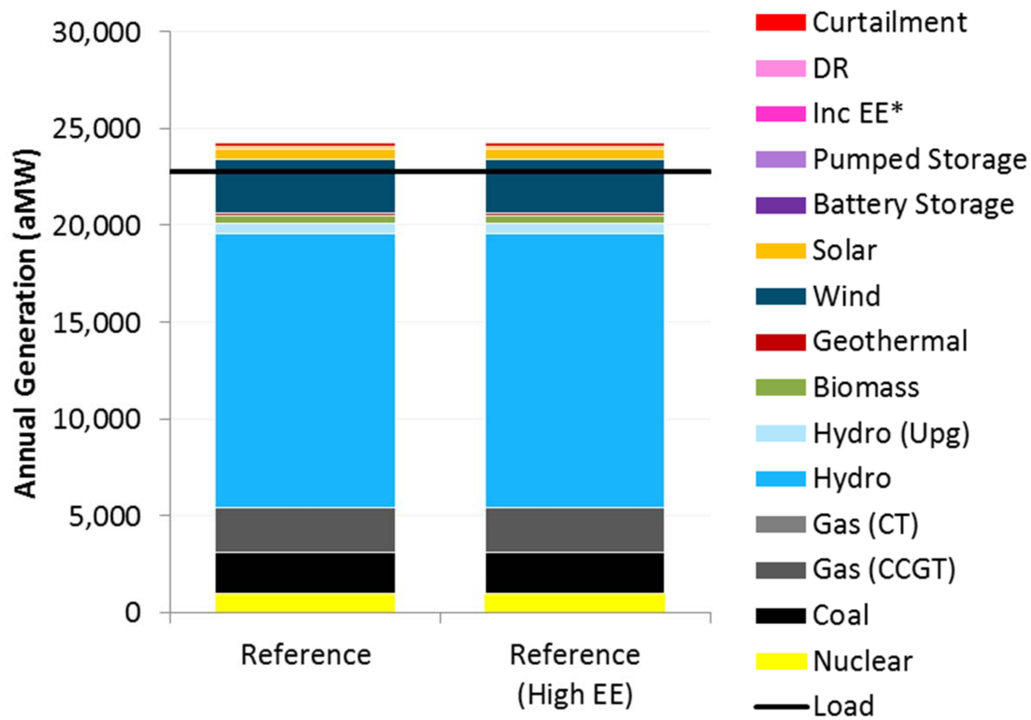
- Additional EE potential at $110/MWh is not selected in the Reference Case

Scenario	Inc Cost ($MM/yr.)	GHG Reductions (MMT)	Effective RPS %	Zero CO2 %
Base	—	—	20%	91%
High EE	—	—	20%	91%
Delta	—	—	—	—

Selected Resources (MW)



Energy Balance (aMW)



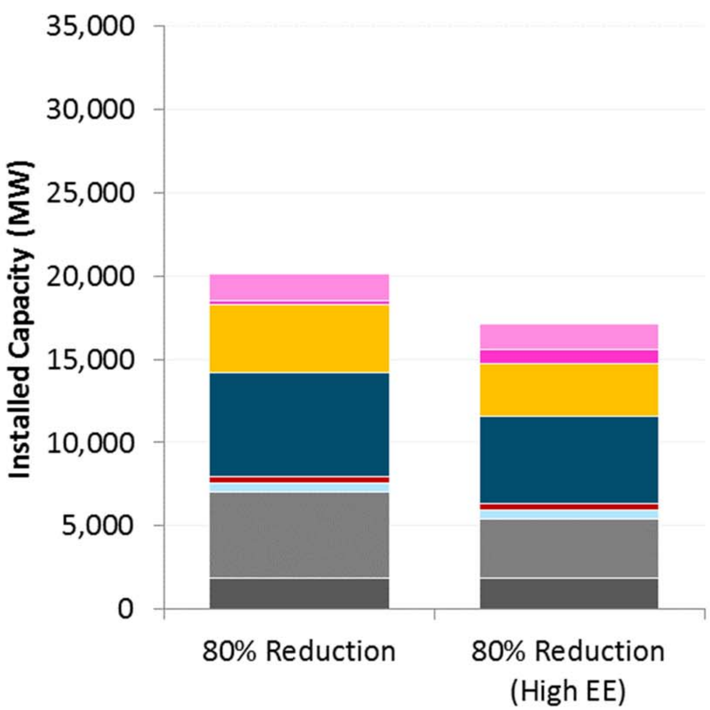
* EE shown here is incremental to efficiency included in load forecast (based on NWPCC 7th Plan)

2050 Portfolio Summary
80% Reduction (High EE Potential)

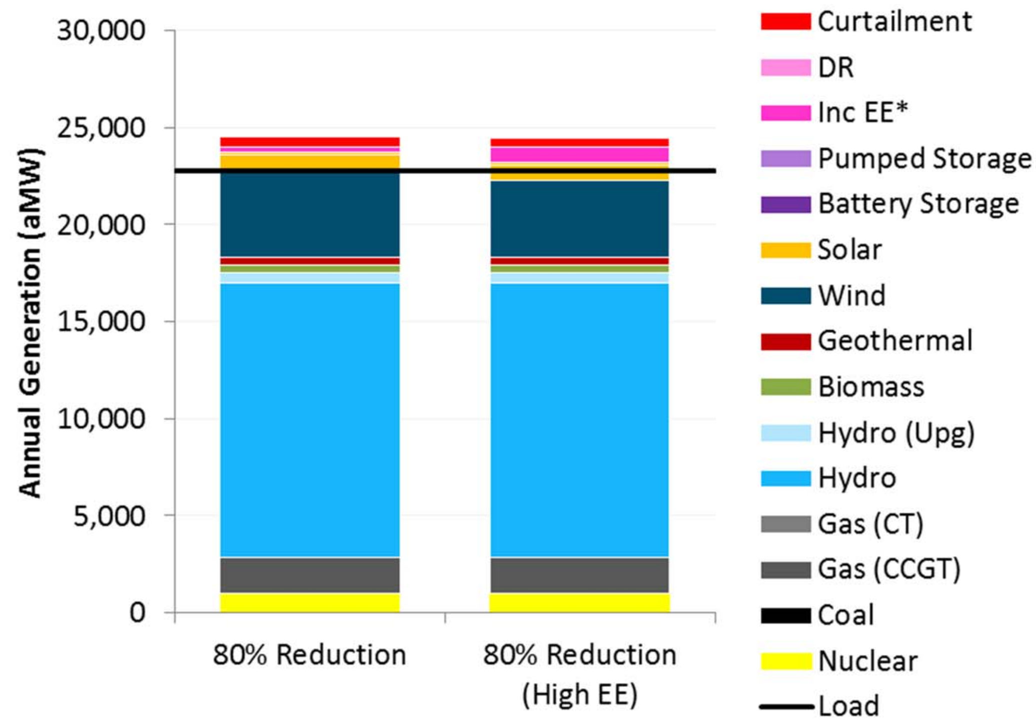
Highlights
- An additional 600 aMW of EE is selected, reducing renewable build by 2,000 MW and thermal build by 1,500 MW

Scenario	Inc Cost ($MM/yr.)	GHG Reductions (MMT)	Effective RPS %	Zero CO2 %
Base	+1,046	20.9	31%	102%
High EE	+$908	20.9	28%	99%
Delta	-$138	—	-3%	-3%

Selected Resources (MW)



Energy Balance (aMW)

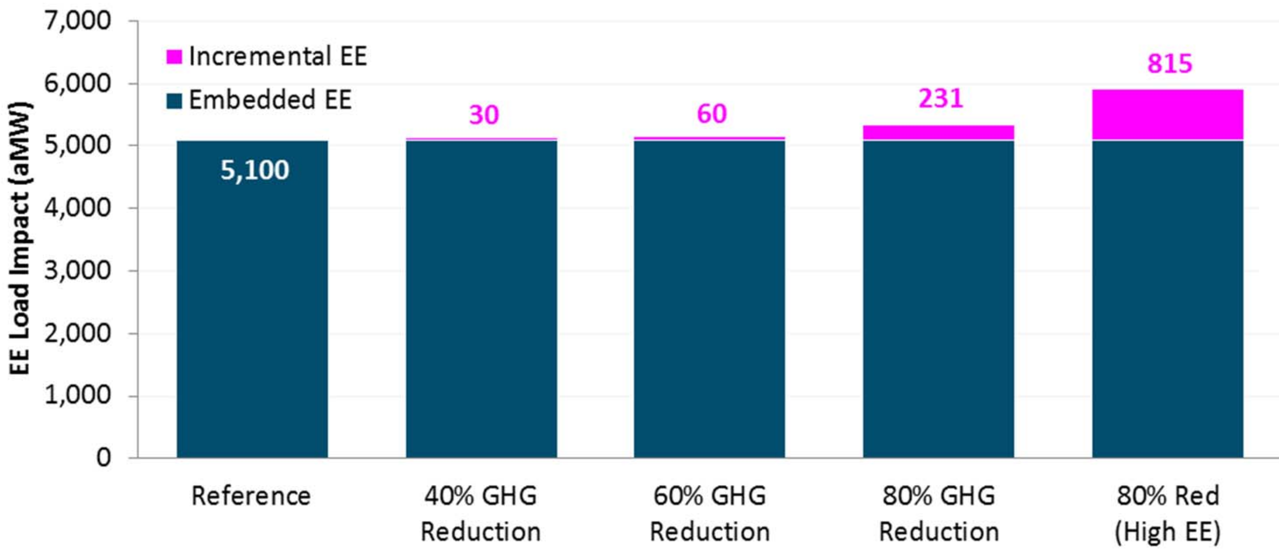


* EE shown here is incremental to efficiency i in load forecast (based on NWPCC 7[th] Plan)

Implications for Future Energy Efficiency Programs

- **Energy efficiency contributes toward meeting policy goals under a carbon pricing system**
  - RPS policy hinders the development of new energy efficiency due to low market pricing
- **Additional R&D is needed to identify new technologies and measures that may be cost-effective in future under GHG constraints**

Total 2050 Energy Efficiency Load Impact Across Multiple Scenarios (aMW)



"Embedded EE" is assumed in all cases and is included in the demand forecast; "Incremental EE" is selected by optimization in RESOLVE

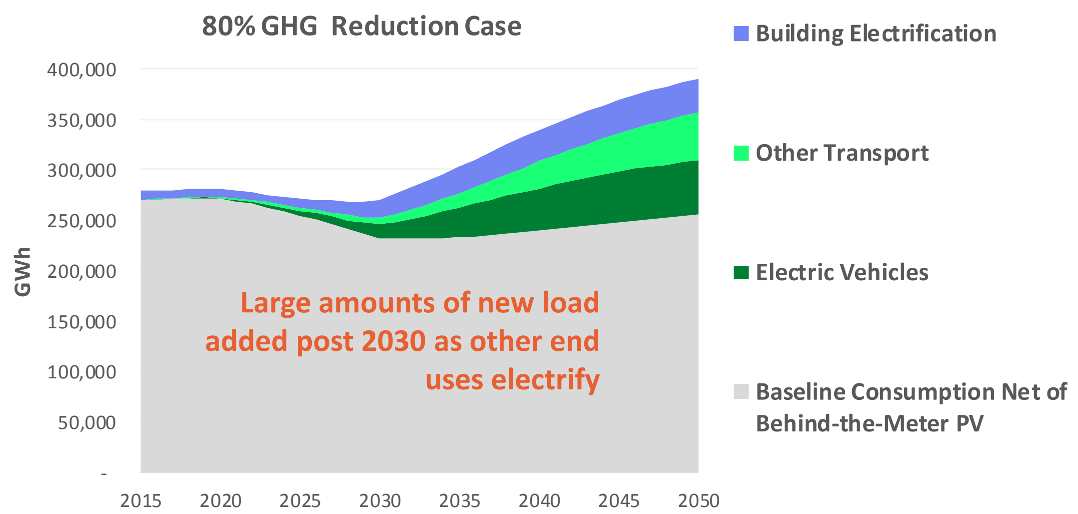
Energy+Environmental Economics

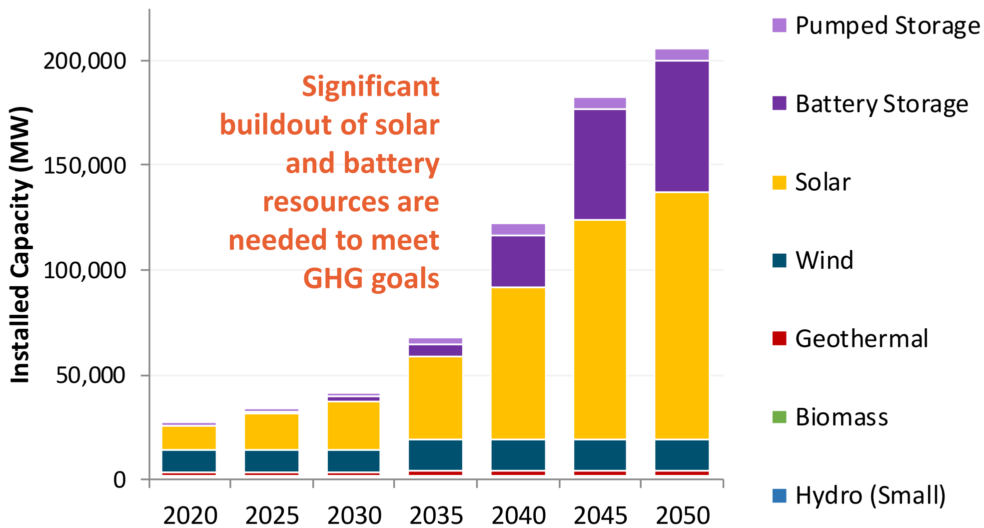
SENSITIVITY RESULTS

High California RPS

Sensitivity Overview
California 100% RPS

California Loads and Renewable Resources





E3 tested the impact of a California 80% GHG reduction scenario on NW buildout and costs associated with meeting GHG goals:

- Increased California loads due to electrification of transportation and buildings
- 100% RPS policy in California (including existing hydro & nuclear)

+ Changes in California policy result in: (1) more frequent curtailment and negative pricing in California; and (2) more volatility in wholesale markets

2050 Portfolio Summary

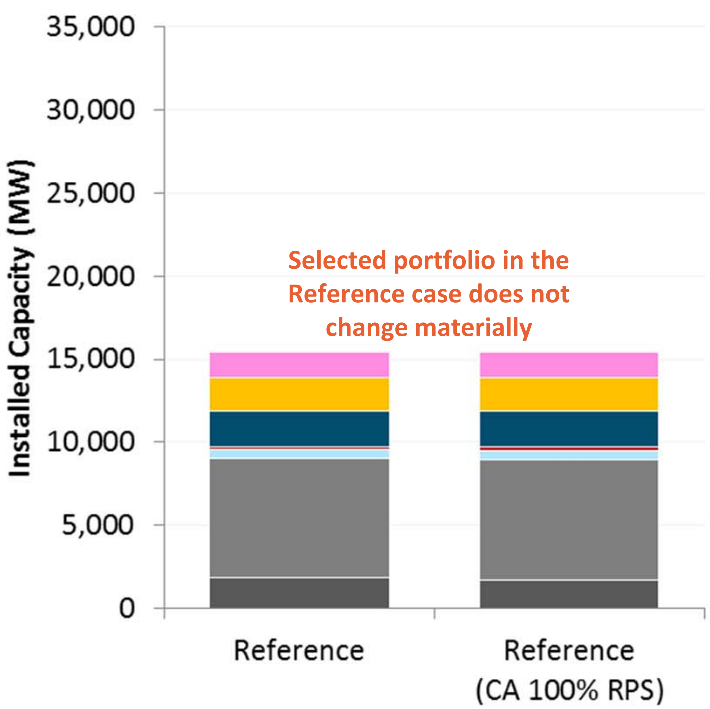
Reference Case (CA 100% RPS)

Highlights

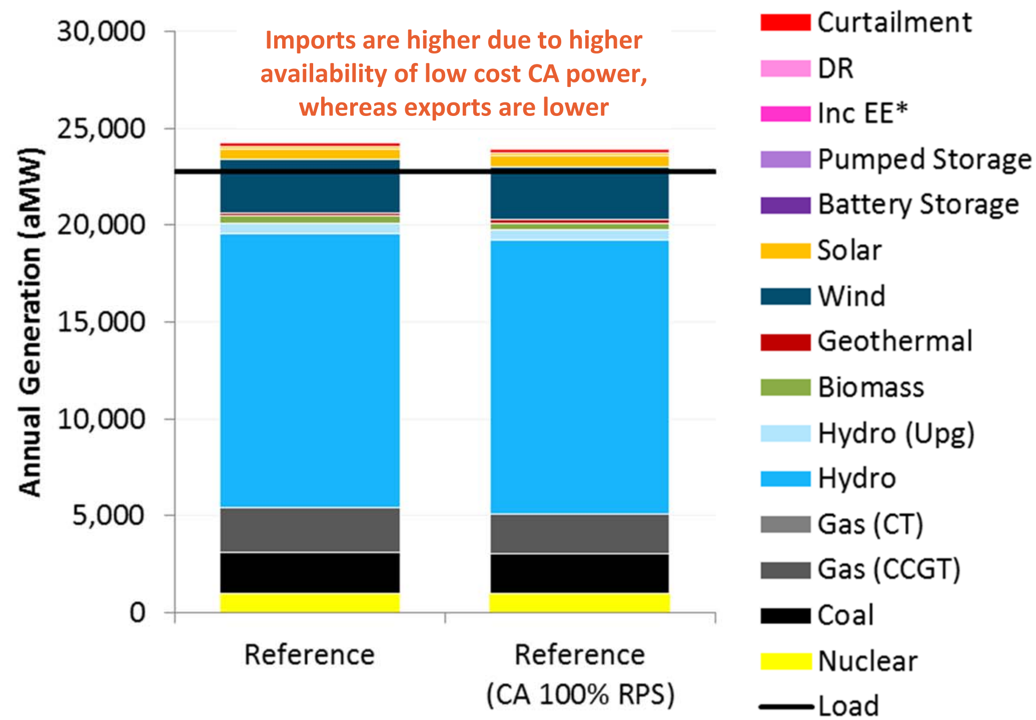
- A 100% RPS in CA increases costs but has a limited impact on the portfolio in the Reference Case
- Slight increase in imports due to negative power prices in CA

Scenario	Inc Cost ($MM/yr.)	GHG Reductions (MMT)	Effective RPS %	Zero CO2 %
Base	—	6.7	20%	91%
CA 100% RPS	+$216	6.7	20%	91%
Delta	+$216	—	—	—

Selected Resources (MW)



Energy Balance (aMW)



* EE shown here is incremental to efficiency included in load forecast (based on NWPCC 7th Plan)

2050 Portfolio Summary

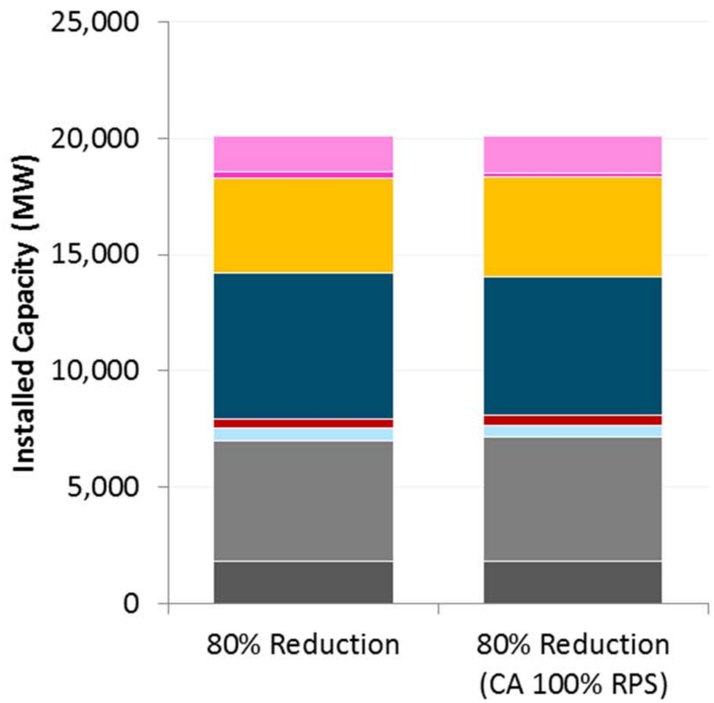
80% Reduction Case (CA 100% RPS)

Highlights

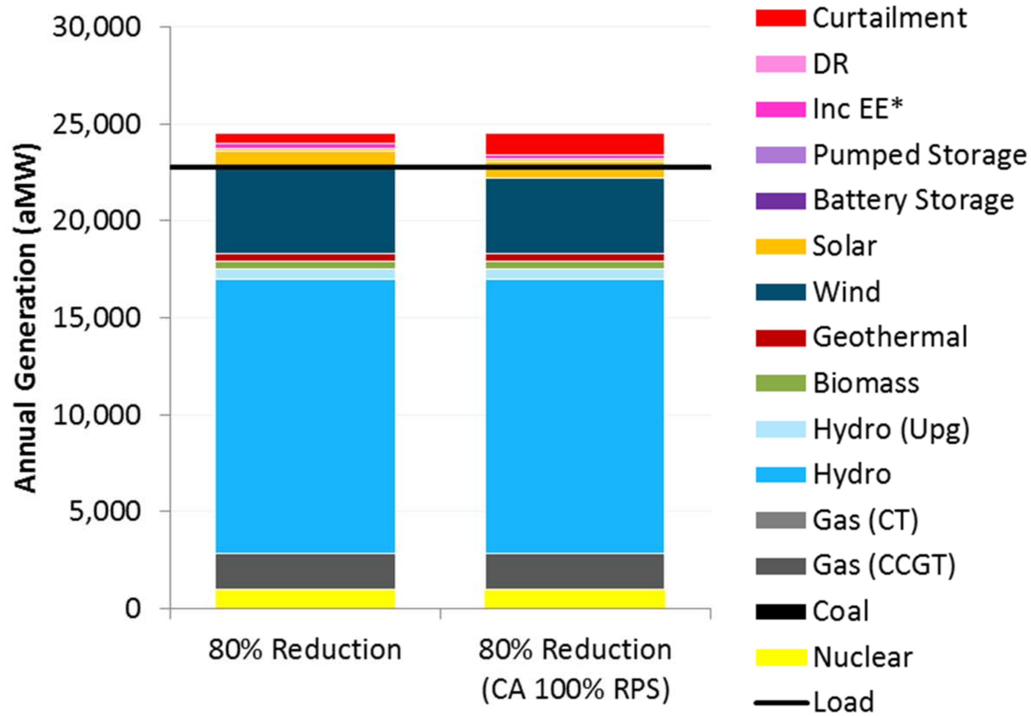
- Limited impact on new resources
- Major impact is an increase in renewable curtailment, as the market for exports to California decreases with high CA RPS

Scenario	Inc Cost ($MM/yr.)	GHG Reductions (MMT)	Effective RPS %	Zero CO2 %
Base	+$1,046	20.9	31%	102%
CA 100% RPS	+$1,266	20.9	29%	99%
Delta	+$220	—	-2%	-3%

Selected Resources (MW)



Energy Balance (aMW)



* EE shown here is incremental to efficiency included in load forecast (based on NWPCC 7th Plan)

Implications of California Policy

+ **Primary impact of California's increasing renewable goals is a reduction in the size of the potential export market for the Northwest—particularly during hydro runoff**
    - Increases likelihood of oversupply & renewable curtailment
+ **Reduction in secondary revenues increases costs in the Northwest—under both Reference Case and GHG Reduction cases**
+ **While not directly modeled, increased renewable goals in California could also create additional market opportunities for Northwest entities (i.e. flexible capacity payments, EIM revenues) if proper arrangements are made**

Energy+Environmental Economics

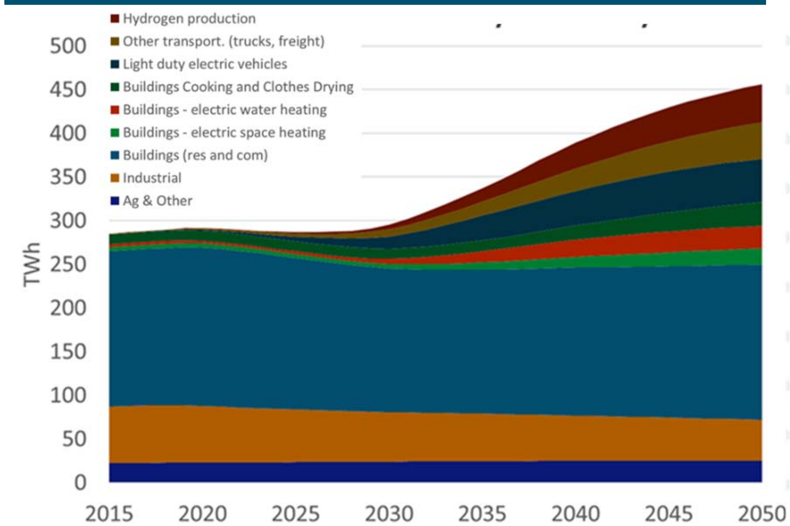
SENSITIVITY RESULTS

High Electric Vehicles

Role of Electrification in Meeting Economy-Wide Carbon Goals

+ **Across multiple studies of long-term carbon goals, electrification of transportation and buildings is consistently identified as a key strategy to meeting long-term carbon goals:**
  - **Deep Decarbonization Pathways Analysis for Washington State** (Evolved Energy Research)
  - **Pathways to Deep Decarbonization in the United States** (E3/LBNL/PNNL)
  - **California PATHWAYS: GHG Scenario Results** (E3)
+ **Long-term scenario planning identifies potentially significant increase in load as a result**

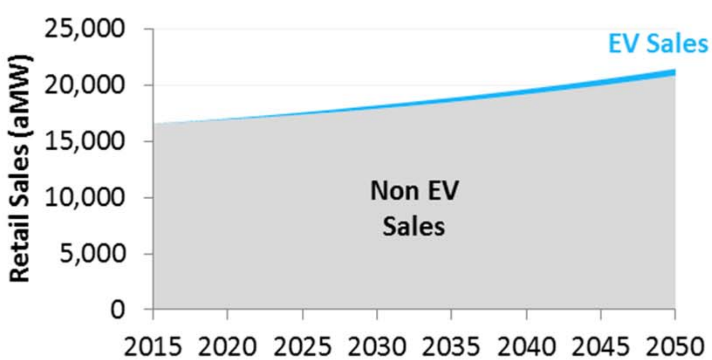
California PATHWAYS Load Forecast



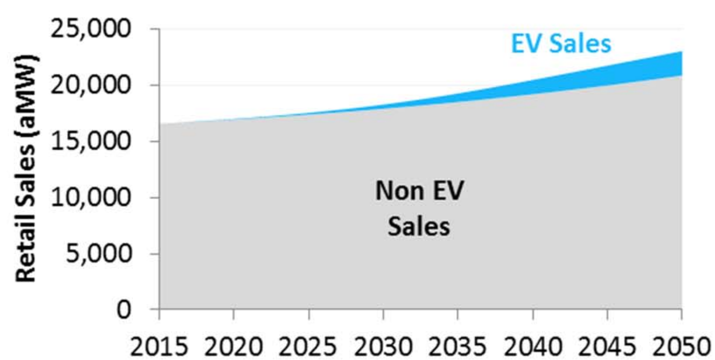
Overview of High EV Sensitivity

- **To explore interactions between electricity and other sectors in the Northwest, this sensitivity tests impact of adding 1,700 aMW of additional new transportation electrification load by 2050**
  - Total light-duty vehicle fleet: 5 million vehicles by 2050; **+3.5 million increase** relative to Base Case
  - Incremental GHG reduction in transportation sector: +**7 million metric tons**
- **Analysis addresses two questions:**
  - What is the cost of meeting incremental loads in the electric sector?
  - What is the **total resource cost** of electric vehicles for carbon abatement?

Base Case Retail Sales Forecast (aMW)

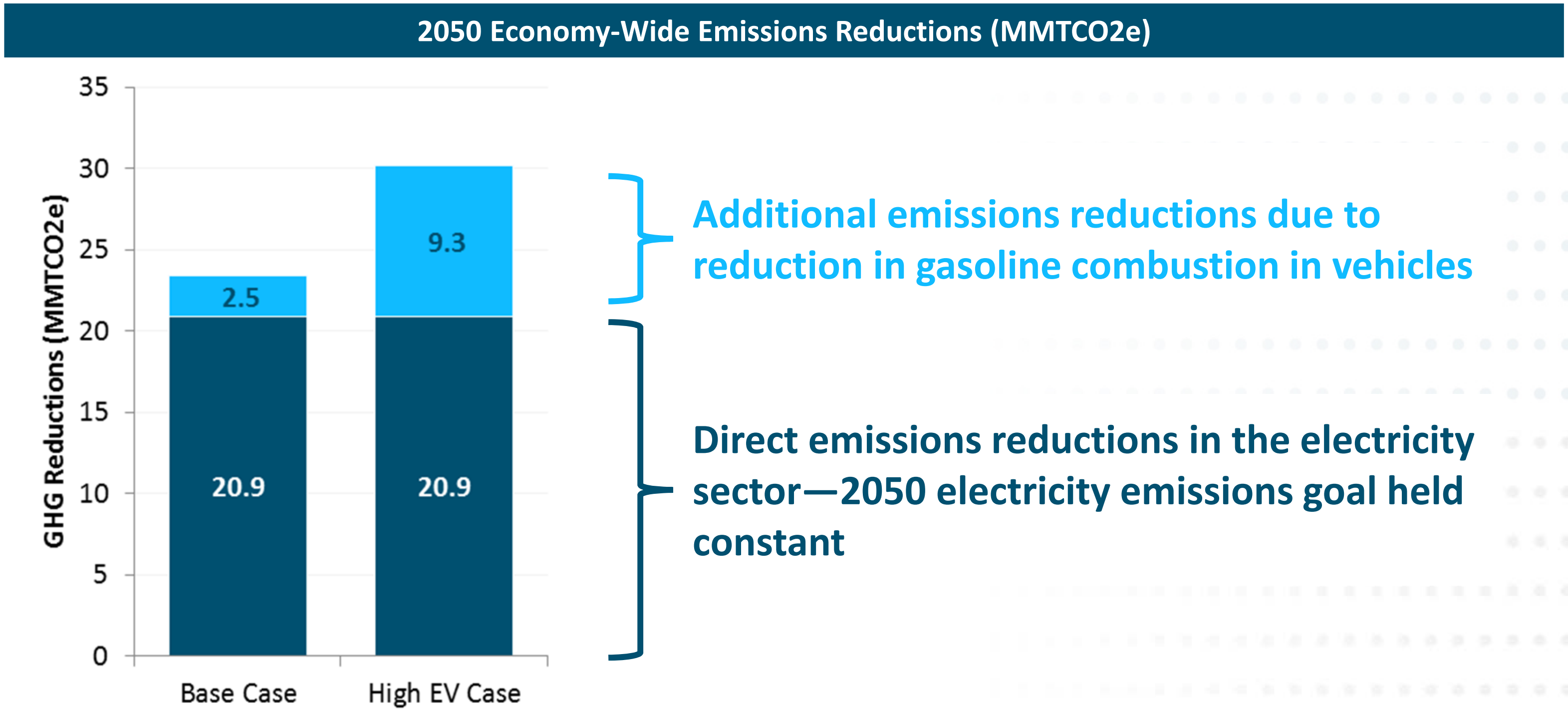


High EV Case Retail Sales Forecast (aMW)



Greenhouse Gas Impacts
High EV Sensitivity

- Electrification of vehicles (and potentially other end uses) provides another mechanism for the electricity sector to contribute to meeting economy-wide decarbonization goals



Costs & Benefits of EV Adoption

+ **Impacts of electric vehicle adoption span beyond the electricity sector, and cost-effectiveness is sensitive to factors external to electricity industry**
  - **Gasoline prices** (analysis assumes $3.12/gal in 2030 and $4.35/gal in 2050)
  - **Incremental vehicle capacity cost** (analysis assumes incremental cost has decreased to zero by 2050)

Item	Category	
Energy & Capacity Cost	Cost	→ Evaluated by RESOLVE
Incremental Vehicle Cost	Cost	Estimated outside of RESOLVE
T&D Cost	Cost	Estimated outside of RESOLVE
Charger Cost	Cost	Estimated outside of RESOLVE
Avoided Gasoline Purchases	Benefit	Estimated outside of RESOLVE
Avoided Vehicle O&M	Benefit	Estimated outside of RESOLVE

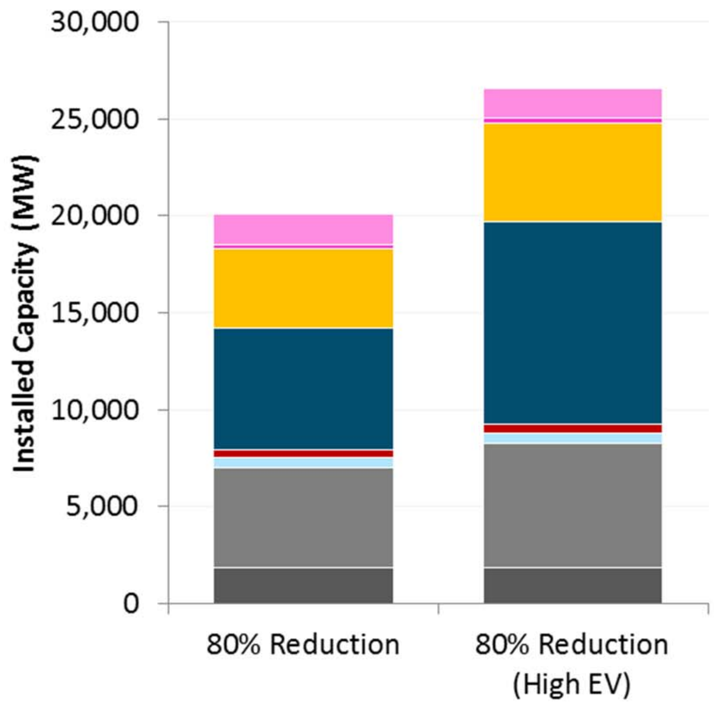
2050 Portfolio Summary
80% Reduction (High EV Adoption)

Highlights
- **New electrification load stimulates additional investment in renewables & storage—5 GW of additional wind and solar relative to Base Case**

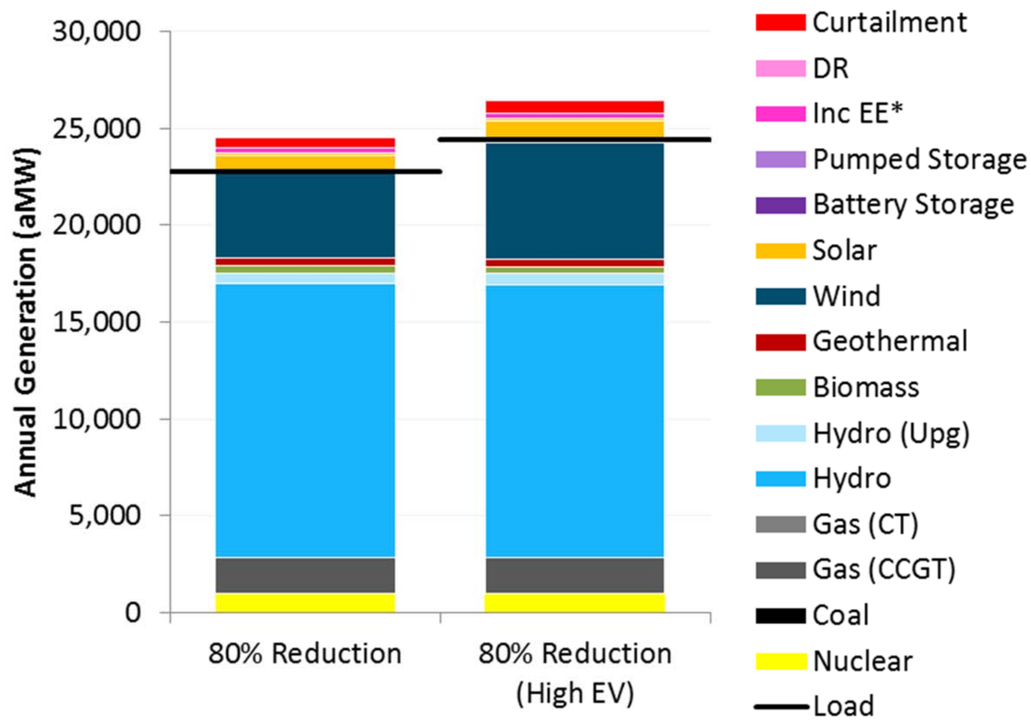
Scenario	Inc Cost* ($MM/yr.)	GHG Reductions* (MMT)	Effective RPS %	Zero CO2 %
Base	+$1,046	20.9	31%	102%
High EV	+$2,498	20.9	37%	103%
Delta	+$1,452	—	+6%	+1%

* Costs and GHG results reflect only the impact on the electric sector

Selected Resources (MW)



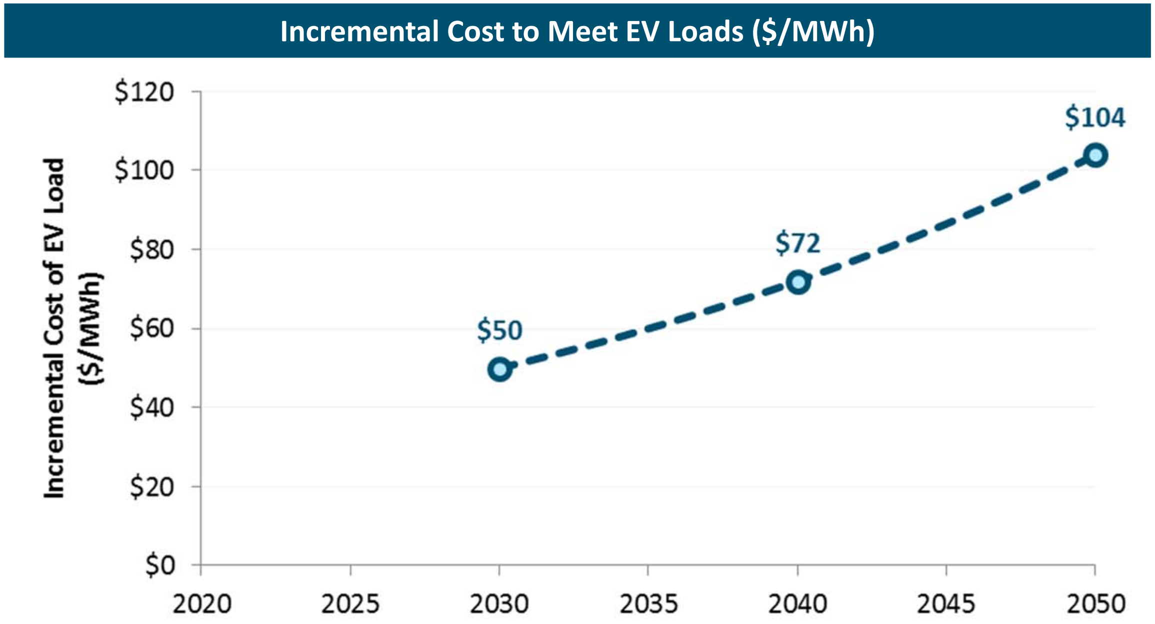
Energy Balance (aMW)



* EE shown here is incremental to efficiency included in load forecast (based on NWPCC 7th Plan)

Cost to Supply EV Loads

+ **The cost to supply EV loads with carbon-free power increases through time as the system becomes increasingly greenhouse gas constrained**

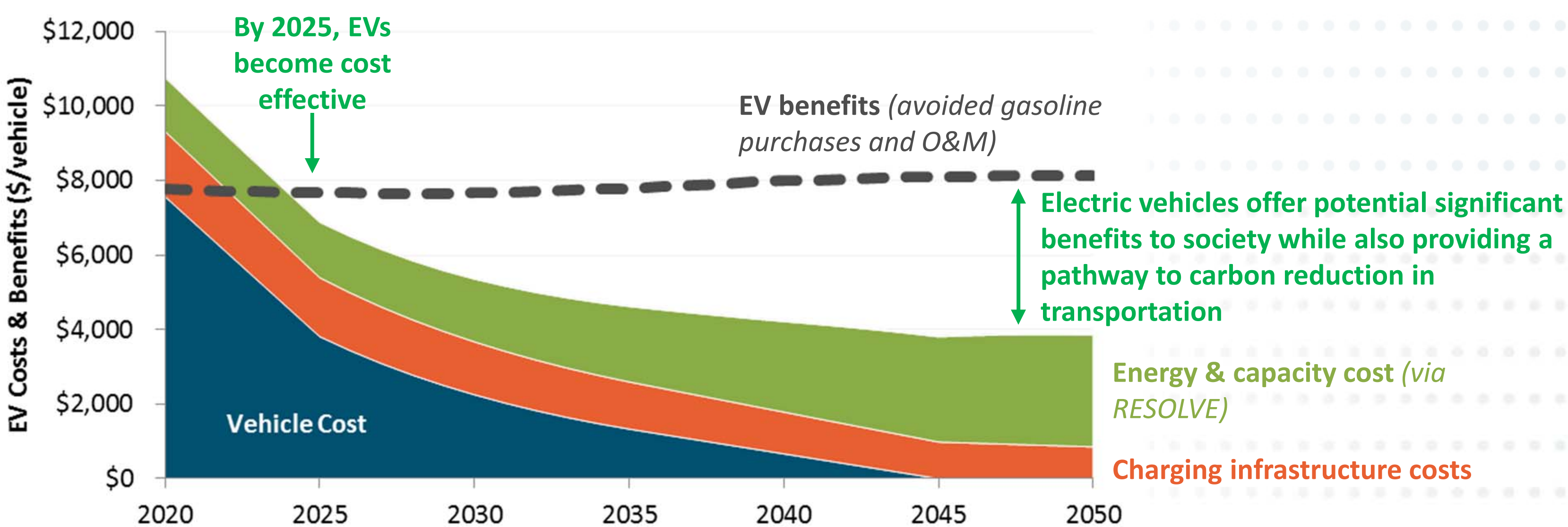


As system becomes constrained on greenhouse gases, cost to supply loads increases

Comparison of Total Resource Costs & Benefits

+ **Despite increasing cost to supply energy and capacity, electric vehicles provide net TRC benefits in all years beyond 2030—implying a negative cost of carbon abatement**
    - **-$117 / ton** in 2030
    - **-$291 / ton** in 2050
+ **While not cost-effective at today's vehicle prices, long-term support for adoption of electric vehicles is a potential low-hanging fruit to achieve economy-wide carbon reductions**

Snapshots of Electric Vehicle Cost Effectiveness ($/vehicle)



Implications for Electrification

- **Transportation electrification appears to be a promising strategy for furthering regional greenhouse gas goals**
  - Significant greenhouse gas reduction potential
  - Long-term net benefits to society, even ignoring GHG savings
- **With current high costs of electric vehicles, policy support may be needed initially to encourage adoption and ensure adequate supporting infrastructure**
  - General agreement in industry that vehicle costs will decrease rapidly and eventually reach parity with gasoline vehicles
- **Electrification of transportation and buildings requires more renewable development under a GHG policy framework**
  - Under a GHG policy, renewables are added to meet 100% of the new electrification energy requirements
  - Under an RPS policy, renewables are added only up to the specified RPS %

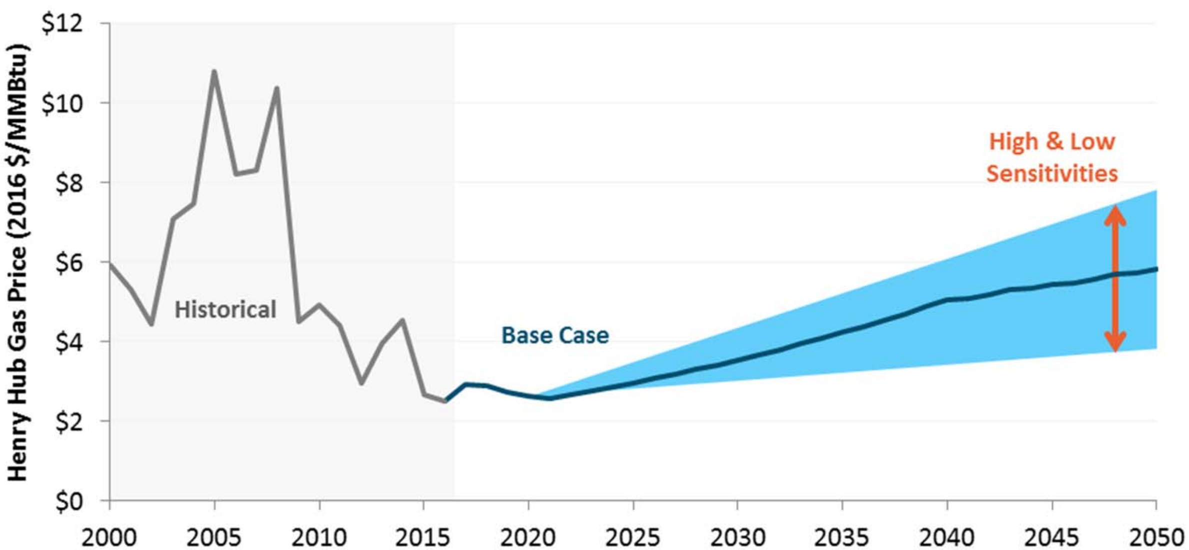
SENSITIVITY RESULTS

High & Low Gas Prices

Gas Price Sensitivity

- Future cost of natural gas is a key uncertainty; analysis high and low gas price forecasts demonstrates sensitivities of key results to this assumption
- All "Core Policy Scenarios" simulated with high and low gas prices (+ / - 2 / MMBtu relative to Base Case in 2050) to highlight how directional relationships among scenarios change

Range of Long-Term Gas Price Forecasts Studied

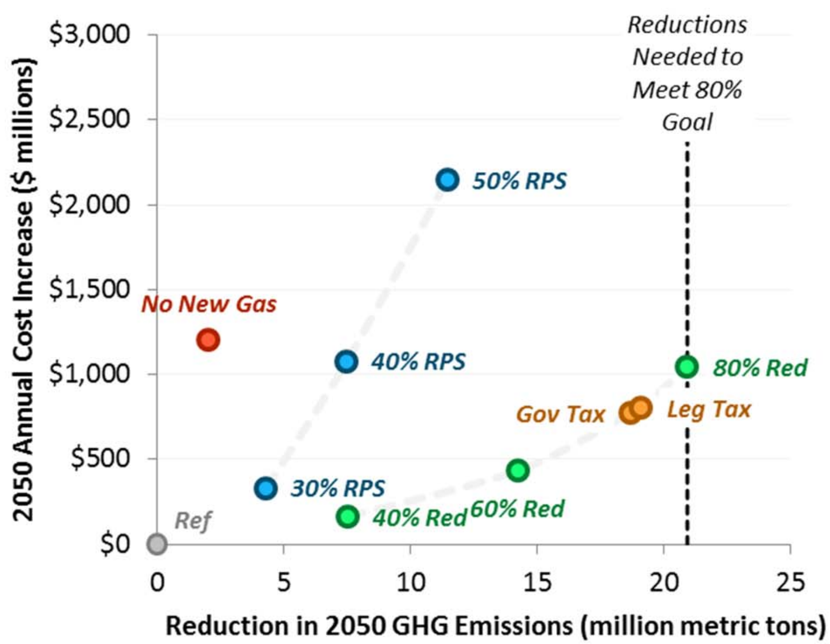


Cost & Emissions Impact

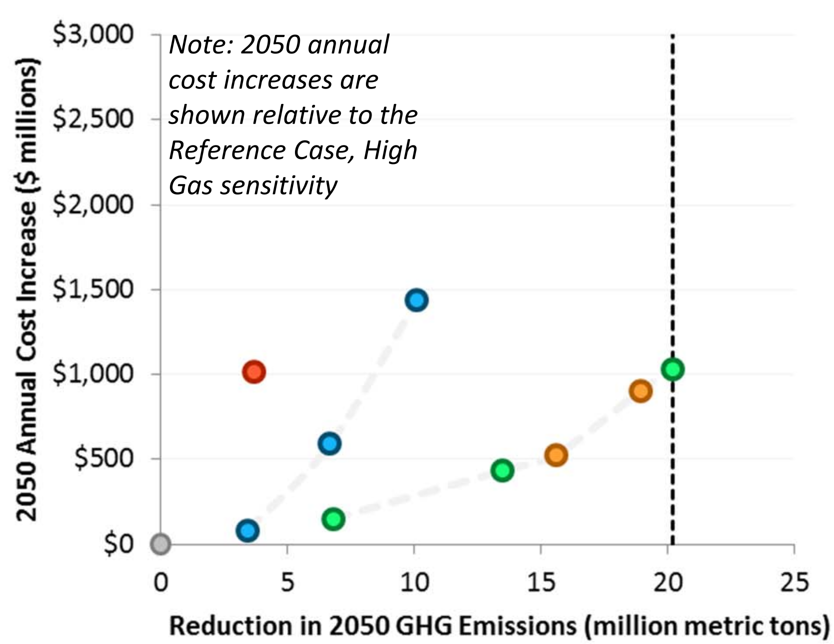
High Gas Price Sensitivity

+ **High Gas Price sensitivity reduces the cost of meeting high RPS targets, but has little impact on the cost of meeting greenhouse gas goals**

Cost & Emissions Impact, Base Case



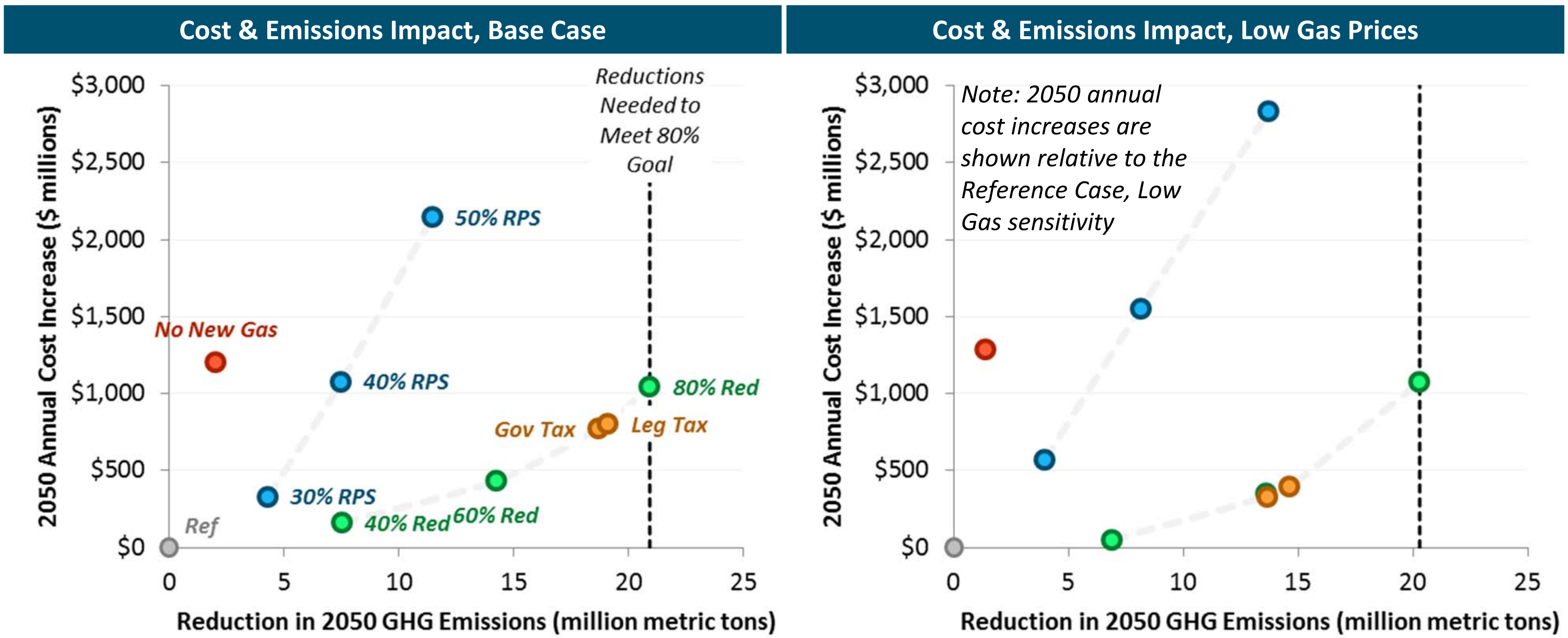
Cost & Emissions Impact, High Gas Prices



Cost & Emissions Impact

Low Gas Price Sensitivity

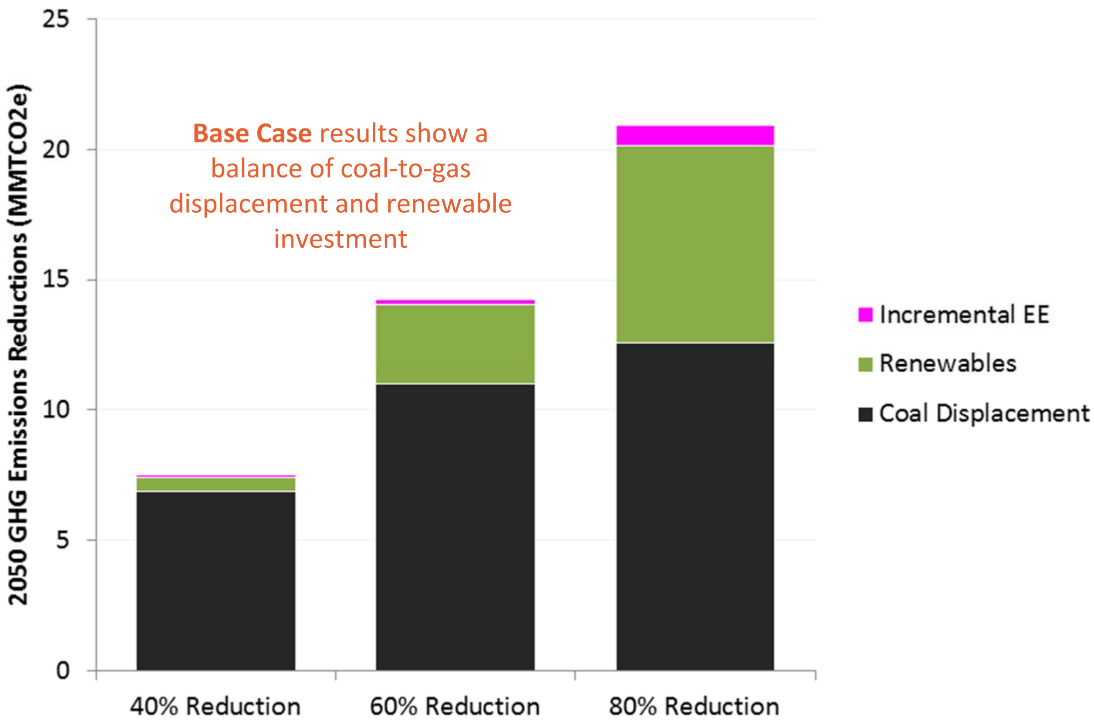
+ **Low Gas Price sensitivity results in substantial additional costs to meet higher RPS goals, but has little impact on the cost of meeting GHG**



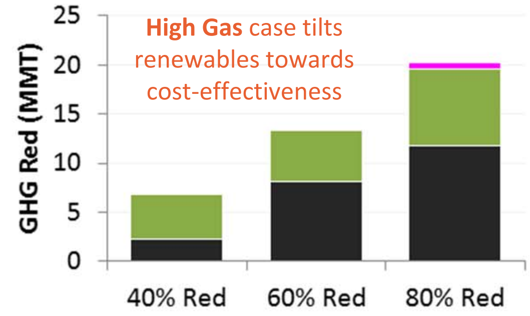
Sources of Carbon Reductions

+ **Gas price sensitivities highlight importance of a technology-neutral policy for GHG reductions, as least-cost measures for GHG abatement will depend on a range of factors**

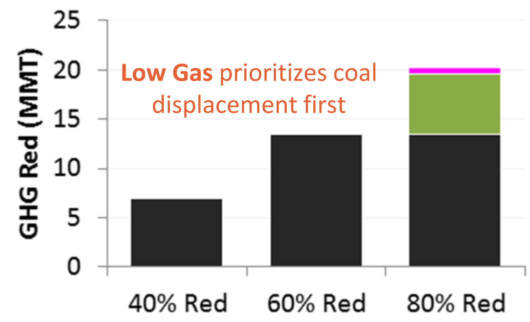
Sources of Carbon Reductions, Base Case (MMTCO2e)



High Gas Case (MMTCO2e)



Low Gas Case (MMTCO2e)



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SENSITIVITY RESULTS

Low Technology Costs

Low Technology Cost Sensitivity

- **In the Low Technology Cost sensitivity, this study explores potential increased cost reductions for emerging technologies:**
  - **Solar PV and wind:** capital costs reduced by 20% relative to the Base Case
  - **Battery storage:** capital costs reduced by 45% relative to the Base Case
- **Sensitivity captures the potential impact of technological breakthrough on the optimal renewable portfolio for the Northwest**

2050 Portfolio Summary

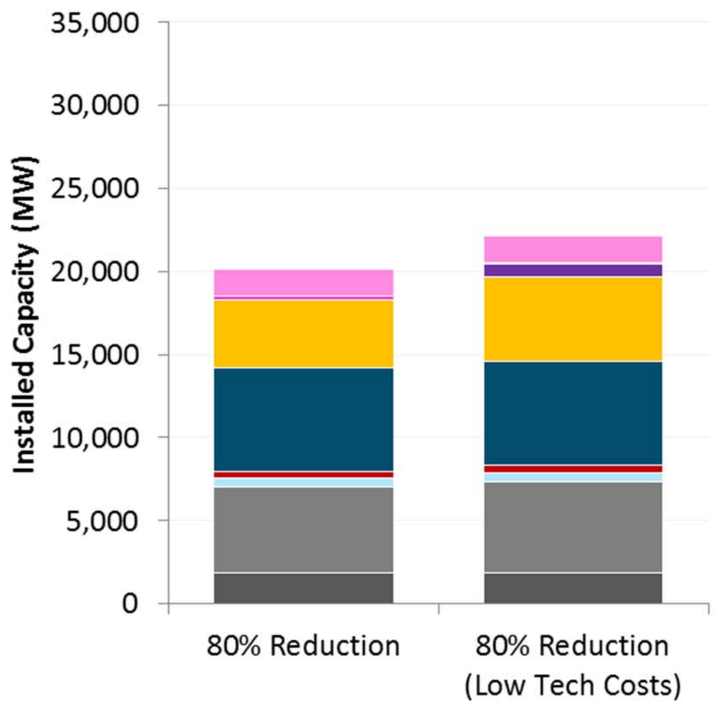
80% Reduction (Low Technology Costs)

Highlights

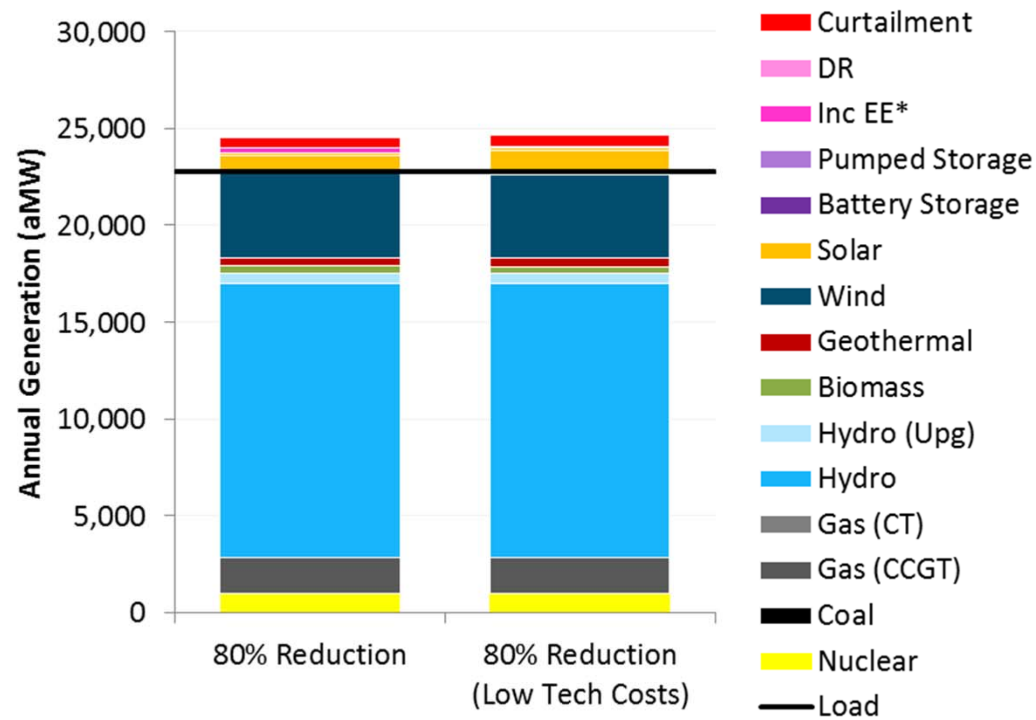
- Portfolio shifts slightly towards solar PV + battery storage to meet clean energy needs
- Relative cost to achieve 80% reduction goal drops slightly

Scenario	Inc Cost ($MM/yr.)	GHG Reductions (MMT)	Effective RPS %	Zero CO2 %
Base	+$1,046	20.9	31%	102%
Low Tech Costs	+$900	20.9	32%	103%
Delta	-$146	—	+1%	+1%

Selected Resources (MW)



Energy Balance (aMW)



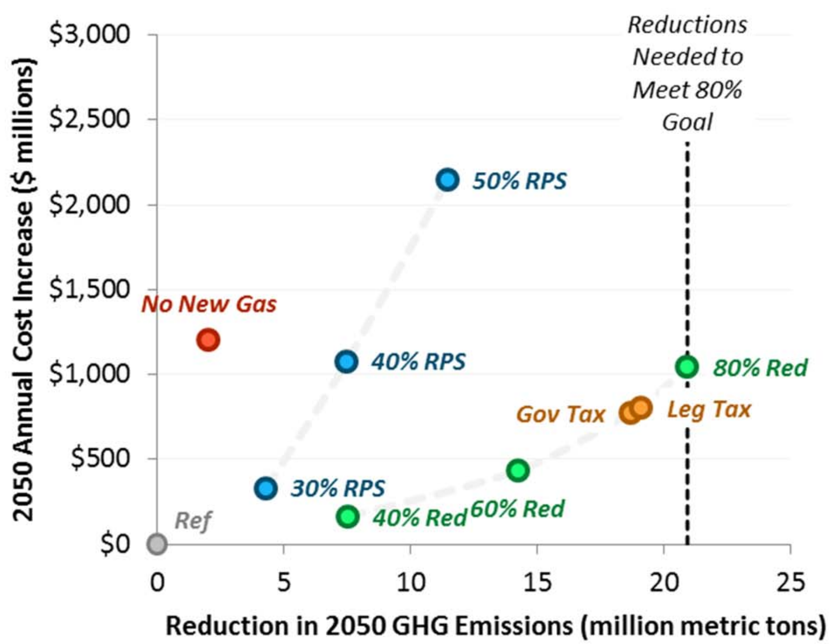
* EE shown here is incremental to efficiency included in load forecast (based on NWPCC 7th Plan)

Cost & Emissions Impact

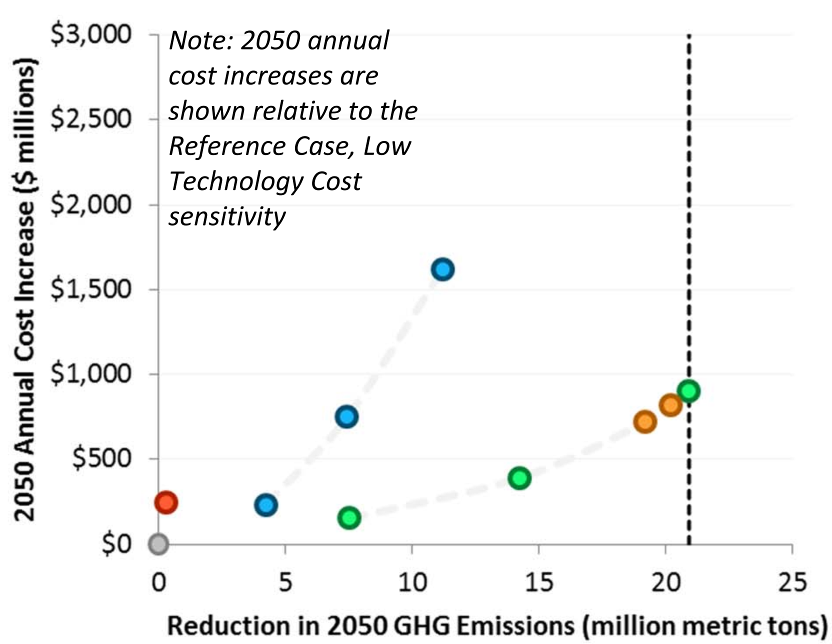
Low Technology Costs Sensitivity

- Low technology cost sensitivity reduces cost of meeting RPS goals, as large investments in wind and solar are available at a lower cost
- Availability of low cost batteries reduces cost premium of No New Gas case—but greenhouse gas reductions are minimal

Cost & Emissions Impact, Base Case



Cost & Emissions Impact, Low Technology Costs



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CONCLUSIONS & KEY FINDINGS

Key Findings (1 of 3)

1. **The most cost-effective opportunity for reducing carbon in the Northwest is to displace coal generation with a combination of energy efficiency, renewables and natural gas**
   - Coal generation produces approximately 80% of the Northwest's electricity-sector GHG emissions today
   - A technology-neutral policy that focuses on carbon provides incentives for leveraging the lowest-cost GHG emissions reductions
2. **Renewable generation is an important component of a low-carbon future, however a Renewables Portfolio Standard results in higher costs and higher carbon emissions than a policy that focuses directly on carbon**
   - RPS policy has been successful at driving investment in renewables but ignores other measures such as energy efficiency and coal displacement
   - RPS policy has unintended consequences such as oversupply and negative wholesale electricity prices that create challenges for reinvestment in existing zero-carbon resources

Key Findings (2 of 3)

3. **Prohibiting the construction of new natural gas generation adds significant cost but does little to save GHG emissions**
   - Older gas plants run at a higher capacity factor and generate more carbon emissions
   - More study is needed to determine whether the system modeled has sufficient energy and capacity to meet resource adequacy requirements
   - Building new gas resources for capacity is part of a least-cost portfolio even under carbon-constrained scenarios
4. **Meeting decarbonization goals becomes significantly more challenging and costly should existing zero-carbon resources retire**
   - Replacing 2,000 aMW of existing hydro or nuclear generation would require nearly 6,000 MW of new wind and solar generation and 2,000 MW of natural gas generation at an annual cost of $1.6 billion by 2050
   - A policy that encourages the retention of existing zero-carbon generation resources will help contain costs of meeting carbon goals

Key Findings (3 of 3)

5. **Returning revenues raised under a carbon pricing policy to the electricity sector is crucial to mitigate higher costs**
   - This is a common feature of carbon pricing programs adopted in other jurisdictions
   - This helps ensure that electricity ratepayers are not required to pay twice: first for the cost of investments in GHG abatement measures, and second for the emissions that remain
6. **Research and development is needed for the next generation of Energy Efficiency measures**
   - Higher-cost measures that have not traditionally been considered may become cost-effective in a carbon-constrained world
7. **Vehicle electrification is a low-cost measure for reducing carbon emissions in the transportation sector**
   - Electrification has benefits for society as a whole, but may increase costs in the electric sector

Next Steps

- **This study considered many scenarios and sensitivities, however, additional research is indicated in the following areas:**

  1. Economy-wide analysis of deep decarbonization pathways for the Pacific Northwest that examines the role of electric vehicles, building electrification, biofuels, hydrogen, and other potential GHG abatement measures
  2. The role of natural gas in buildings and electric generation in meeting economy-wide GHG abatement goals
  3. The role of energy storage in meeting capacity needs in a hydro-dominated region such as the Pacific Northwest, particularly under cases with restrictions on gas generation
  4. The potential benefits of greater regional coordination in electricity system operations, renewable resource procurement, transmission planning and carbon allowance trading

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Thank You!

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