Energy+Environmental Economics

Pacific Northwest Low Carbon Scenario Analysis

2018 Scenarios and Sensitivities

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Introduction

- **This is a joint report to share the results of independently sponsored studies**
- **Each of the entities in the report independently requested and sponsored additional scenarios and sensitivities to the 2017 PGP Study**
- **Some entities requested the same studies**
  - Those studies were run consistently for each entity

Presentation Structure

+ Background
+ 100% GHG Reduction Scenario
+ Climate Solutions Sponsored Scenarios and Results

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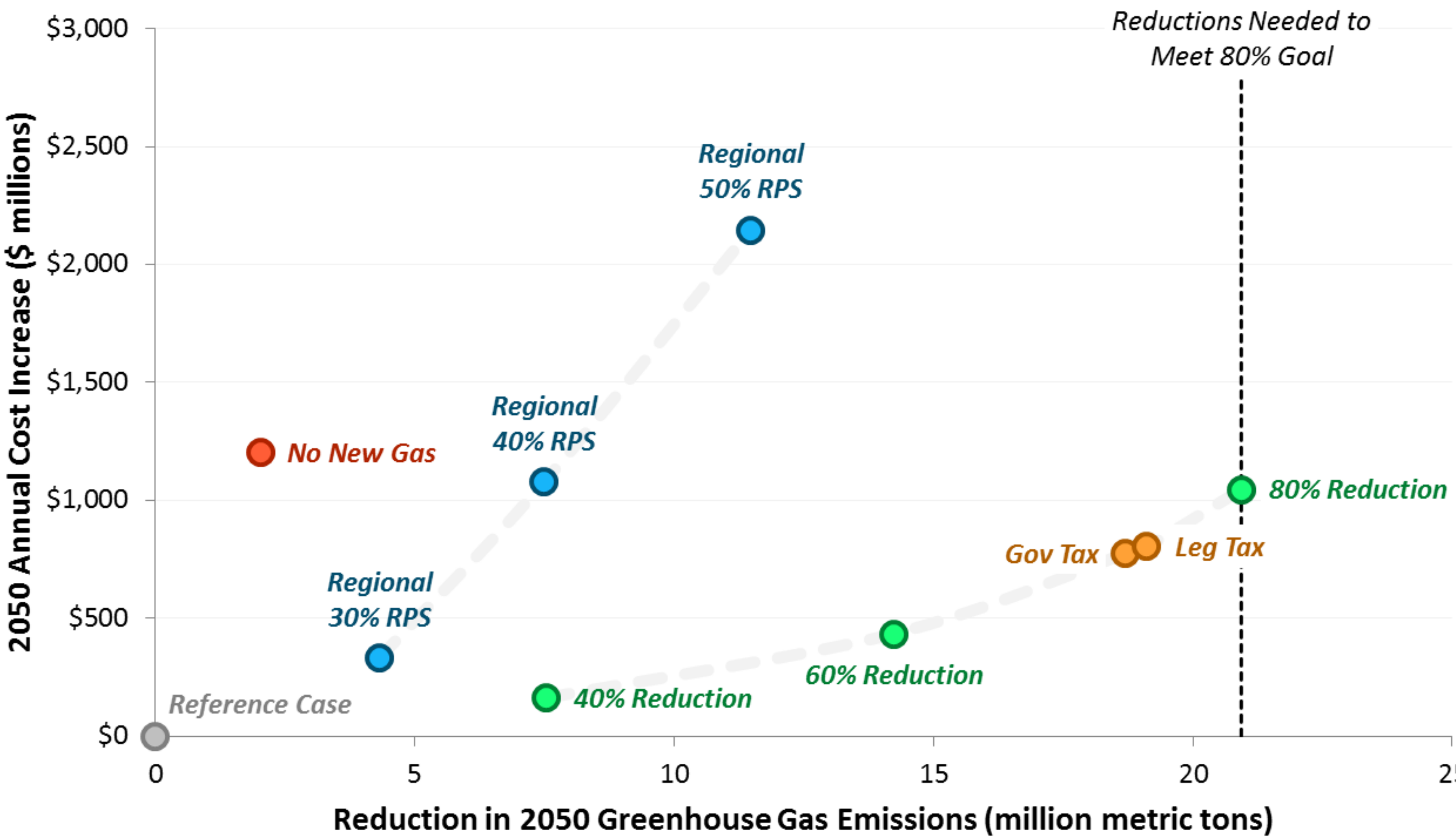
Background and Context

Context of 2018 Analysis

+ **In 2017, the Public Generating Pool (PGP) sponsored the Pacific Northwest Low Carbon Scenario Analysis, a study of alternative policies for achieving reductions in electric sector carbon emissions in the Northwest**
  - The original study can be found here: https://www.ethree.com/e3-completes-study-of-policy-mechanisms-to-decarbonize-the-electric-sector-in-the-northwest/
+ **In 2018, follow-up studies were individually sponsored by three organizations to explore specific questions left unanswered by the original study**
  - Public Generating Pool
  - Climate Solutions
  - National Grid
+ **This document reports on the assumptions and results from these additional studies**

Original Study Results:
Cost & Emissions Impacts in 2050



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

2050 Scenario Summary From the Original Study

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

About the Additional Studies

+ **PGP sponsored additional studies exploring the means for and cost of achieving additional CO_2 emissions reductions beyond the 80% goal assumed in the original study:**
  - 90%, 95% and 100% GHG emissions reductions with varying quantity and price of carbon-free biogas as a substitute for fossil natural gas
+ **Climate Solutions sponsored additional studies exploring 100% GHG emissions reductions:**
  - With and without biogas and small modular nuclear reactors (SMR), under alternative technology costs, and with a ceiling or "off-ramp" on compliance costs
+ **National Grid sponsored additional studies exploring the potential role for pumped hydro storage:**
  - Alternative assumptions about the cost of new pumped hydro facilities and new gas-fired generation, and accelerated coal retirement
+ **All scenarios assume revenue recycling**

Scenario Matrix
– All Sponsored Scenarios and Sensitivities

	INPUT ASSUMPTIONS					
Scenario	Original Study Assumptions	Biogas P&Q Sensitivities	Alternative Technology Costs	Pumped Storage Cost Update	High Gas Capital Costs	Limited New Gas Build
Reference	●		●	●	●	●
40% Reduction	●					
60% Reduction	●					
80% Reduction	●			●	●	●
30% RPS	●					
40% RPS	●					
50% RPS	●					
Leg Tax ($15-75)	●					
Gov Tax ($25-61)	●					
No New Gas	●					
90% Reduction	●					
95% Reduction	●					
100% Reduction with Hydro, Wind Geothermal, and Solar (HWGS)	● ●					
100% Reduction + Biogas	● ●	●	●			
100% Reduction + SMR	●					
100% Reduction + Off Ramp	●					
30% RPS + No Coal	●			●	●	●

● Original PGP Study; ● PGP; ● Climate Solutions; ● National Grid

Base Cost Assumptions for Candidate Technologies

Technology	Resource	Unit	2018	2022	2026	2030
Gas	Annual Core NW Fuel Costs	*$/MMBtu*	**$3.24**	**$2.95**	**$3.32**	**$3.82**
	CT-Frame	*$/kW-ac*	**$950**	**$950**	**$950**	**$950**
	CCGT	*$/kW-ac*	**$1,300**	**$1,300**	**$1,300**	**$1,300**
Hydro Upgrades	Non Powered Dam	*$/kW-ac*	**$4,500**	**$4,500**	**$4,500**	**$4,500**
	Upgrades	*$/kW-ac*	**$1,277**	**$1,254**	**$1,206**	**$1,158**
Geothermal	Central Oregon	*$/kW-ac*	**$4,557**	**$4,557**	**$4,557**	**$4,557**
Wind	Columbia River Basin	*$/kW-ac*	**$1,925**	**$1,910**	**$1,896**	**$1,882**
	Montana	*$/kW-ac*	**$1,823**	**$1,810**	**$1,796**	**$1,783**
	Wyoming	*$/kW-ac*	**$1,722**	**$1,709**	**$1,697**	**$1,684**
Solar	WA/OR	*$/kW-ac*	**$1,617**	**$1,558**	**$1,513**	**$1,438**
	WA/OR	*$/kW-dc*	$1,244	$1,199	$1,164	$1,106
Battery Storage (4-hr Storage)	-	*$/kWh*	**$587**	**$455**	**$372**	**$352**
Pumped Storage (10-hr Storage)	-	*$/kWh*	**$261**	**$261**	**$261**	**$261**

Base capital cost assumptions are the same as in the original PGP study
Capital costs are kept flat beyond 2030

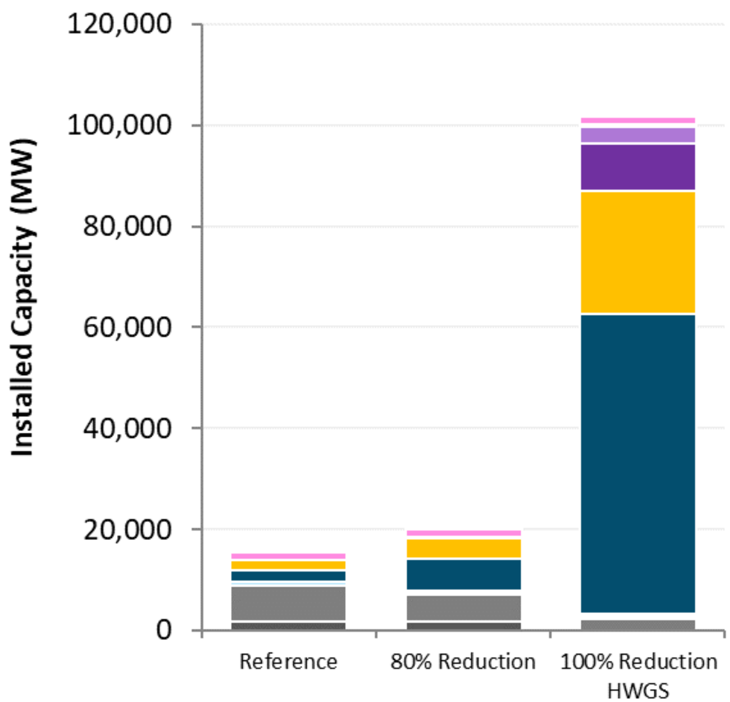
100% Reduction Scenario Individually Requested by PGP and Climate Solutions

2050 Portfolio Summary - PGP
Carbon Cap Scenarios

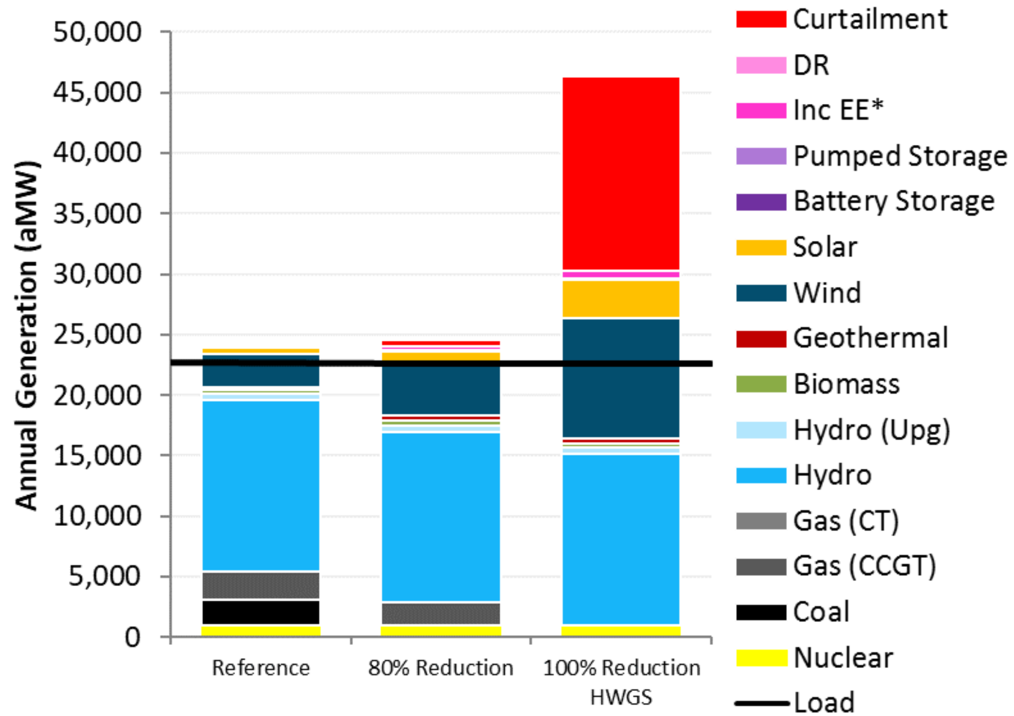
Summary
- 84 GW of new renewable capacity added by 2050 in 100% Reduction HWGS scenario
- 10 GW of new storage capacity
- Gas generation eliminated entirely by 2050

Scenario	Inc Cost ($MM/yr.)	GHG Reductions (MMT)	Effective RPS %	Zero CO2 %
Reference	-	-	20%	91%
80% Reduction	+$1,046	20.9	31%	102%
100% Reduction HWGS	+$18,377	27.6	62%	135%

Resources Added (MW)

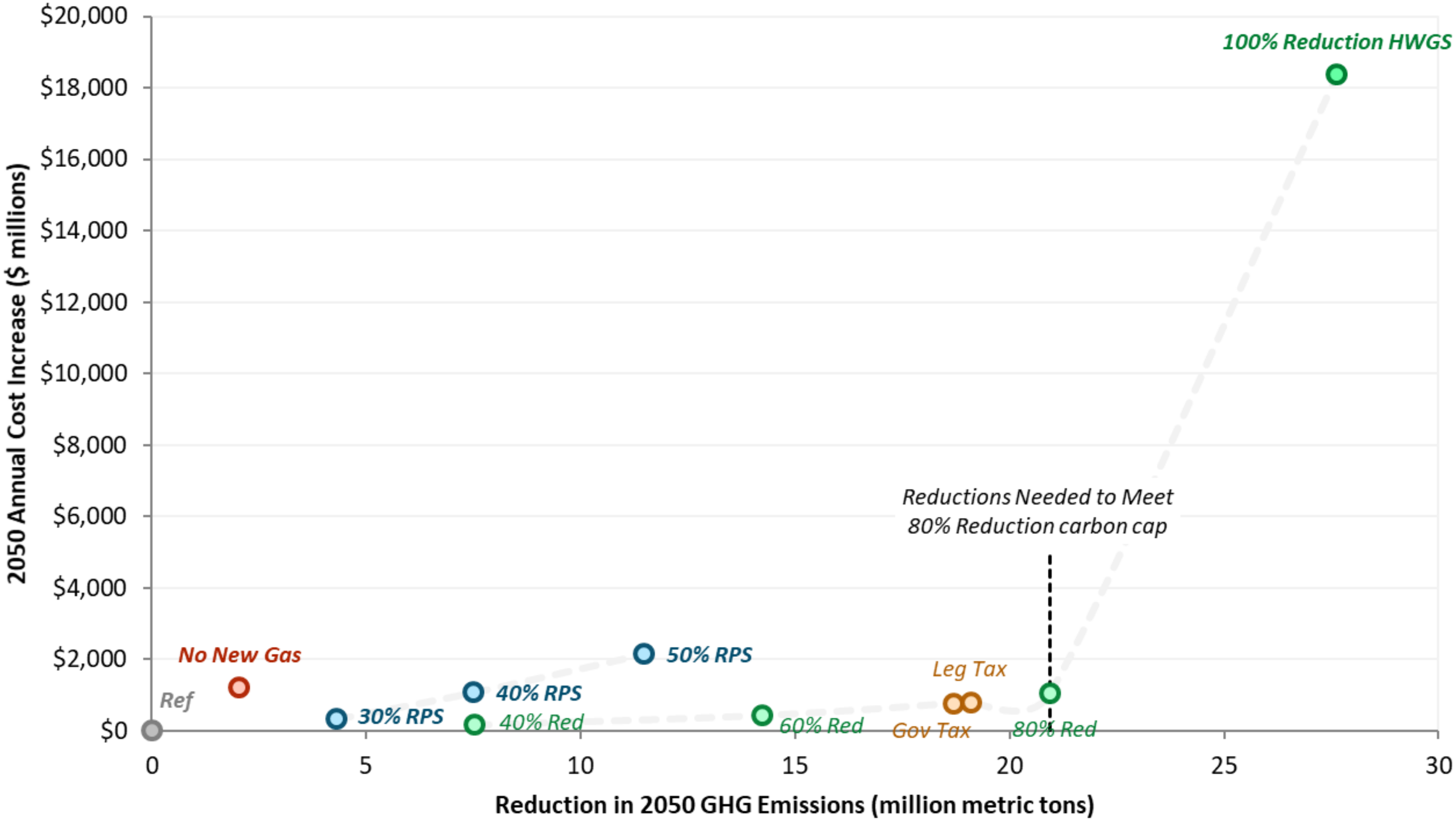


Energy Balance (aMW)



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

Cost & Emissions Impacts
All Cases – Original PGP Study + 100% Reduction HWGS



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

There are significant *reliability* challenges under a scenario without dispatchable thermal generation

- **The scenario considers the effect of a 100% GHG reduction cap with only hydro upgrades, wind, geothermal, solar, and electric energy storage available as new resources**
- **Without dispatchable thermal generation capacity, it may be difficult to meet load under extreme weather conditions**
  - E.g., extended cold-weather period with low wind and solar production that occurs during a drought year
  - This challenge would only increase under a scenario with significant electrification of building and vehicle loads to meet long-term carbon goals

There are significant ***modeling*** challenges under a scenario without dispatchable thermal generation

- **The current version of RESOLVE was not designed to consider cases without some form of dispatchable capacity**
  - The model does not provide sufficiently robust examination of unusual weather conditions that drive the need for dispatchable capacity
  - The model cannot consider multi-day energy storage as a potential solution to the energy constraints that are encountered
  - The model does not consider land-use or other environmental limitations on resource supply or transmission capacity
- **More study is needed to examine resource availability and transmission requirements**
- **More study is needed to analyze whether the system as modeled meets reliability expectations**

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Climate Solutions Sponsored Scenarios

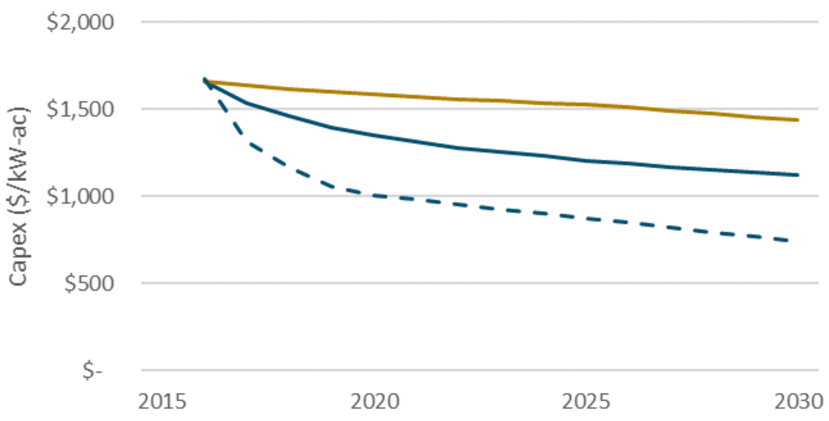
Summary of Sponsored Scenarios – Climate Solutions

Scenario Name	Question Answered	Updates to Model
100% Reduction + Off-ramp	Effect of a 100% GHG reduction target with a $200/ton off-ramp	Added 100% GHG reduction trajectory, assuming 60% reduction by 2030 and 100% reduction by 2050. $200/ton off-ramp in 2050
100% Reduction + Biogas	Effect of a 100% GHG reduction target with pipeline biogas as zero CO fossil resource	Added 100% GHG reduction trajectory, assuming 60% reduction by 2030 and 100% reduction by 2050. Pipeline biogas available for use in natural gas generators at $31/MMBtu cost
100% Reduction + SMR	Effect of a 100% GHG reduction target with flexible small modular nuclear reactors	Added 100% GHG reduction trajectory, assuming 60% reduction by 2030 and 100% reduction by 2050. New nuclear candidate resource at $100/MWh all-in cost. Retires all fossil plants in 2049
Sensitivity Name	**Question Answered**	**Updates to Model**
Alternative Technology Costs	Effect of potential technological breakthrough in cost reductions for emerging technologies	Solar PV costs updated using NREL 2017 Annual Technology Baseline (ATB)*. Relative to Base Case wind costs reduced by 20%; battery costs reduced by 70%; and biogas fuel cost reduced by 20%

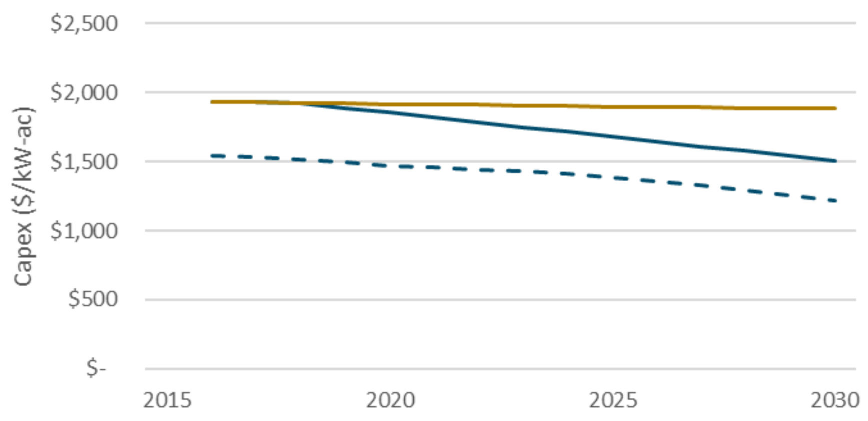
*NREL 2017 Annual Technology Baseline: https://atb.nrel.gov/electricity/2017/

Low Technology Cost Trajectories

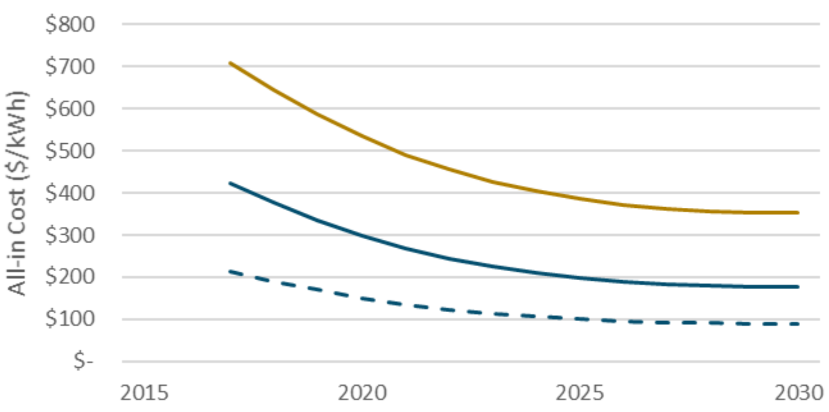
Solar PV – WA/OR



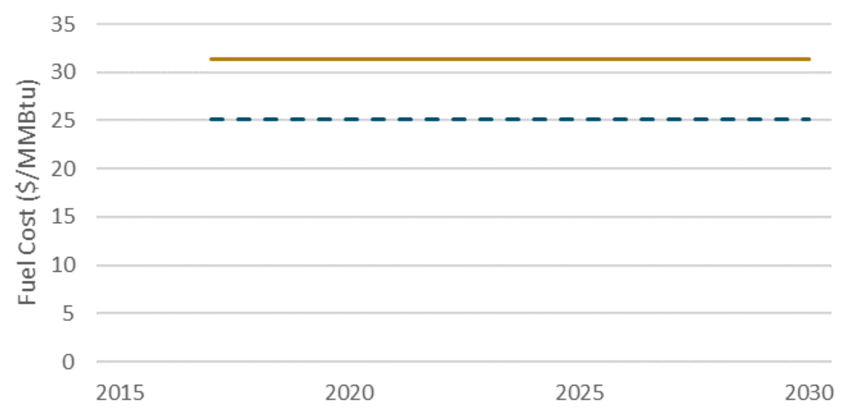
Land Based Wind – Columbia River Basin



Battery Storage – 4-hr Storage



Pipeline Biogas



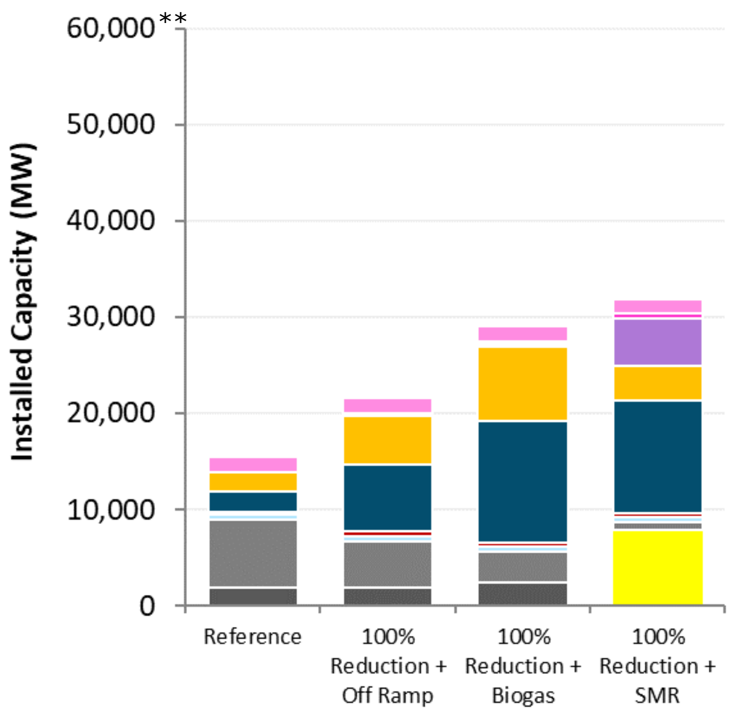
– Original PGP Study Base; – Original PGP Study Low Tech Costs; **- - - Climate Solutions Alt. Tech Costs**

2050 Portfolio Summary – Climate Solutions
Carbon Cap Scenarios

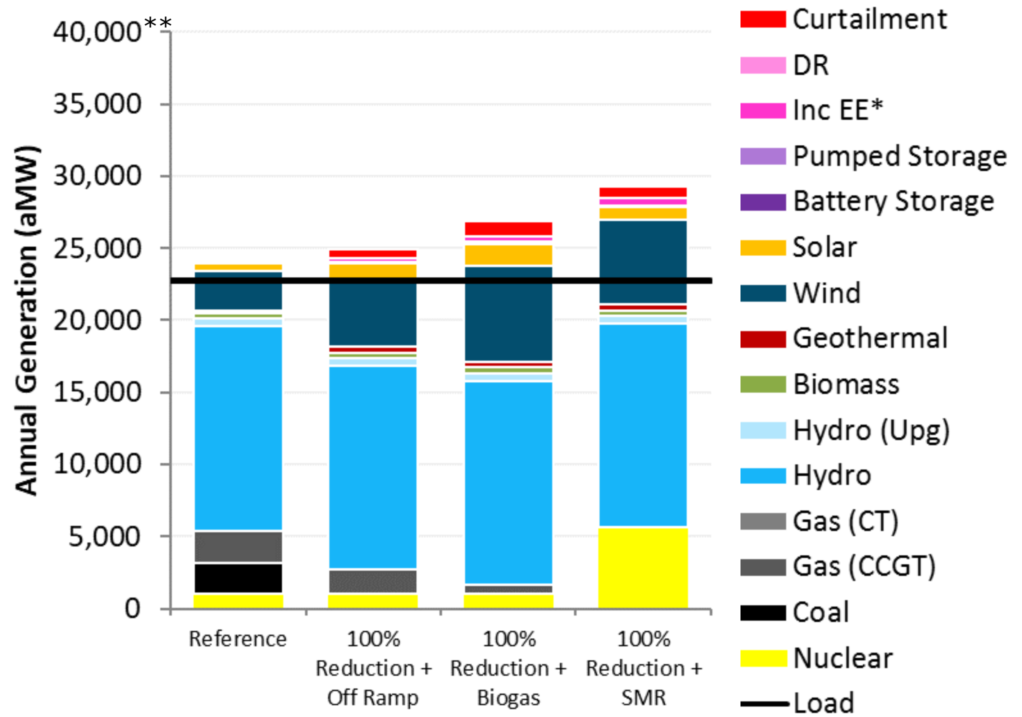
Summary
- 7 GW of gas capacity added by 2050 in Off-ramp Scenario
- 21 GW of new renewable capacity added by 2050 in 100% Reduction + Biogas Scenario
- 8 GW of new SMR capacity and 5 GW of pumped storage capacity added by 2050 in 100% Reduction + SMR Scenario

Scenario	Inc Cost ($MM/yr.)	GHG Reductions (MMT)	Effective RPS %	Zero CO2 %
Reference	-	-	20%	91%
100% Reduction + Off-ramp	+$1,148	21.8	33%	104%
100% Reduction + Biogas	+$3,264	27.6	44%	115%
100% Reduction + SMR	+$6,574	27.6	37%	130%

Resources Added (MW)



Energy Balance (aMW)

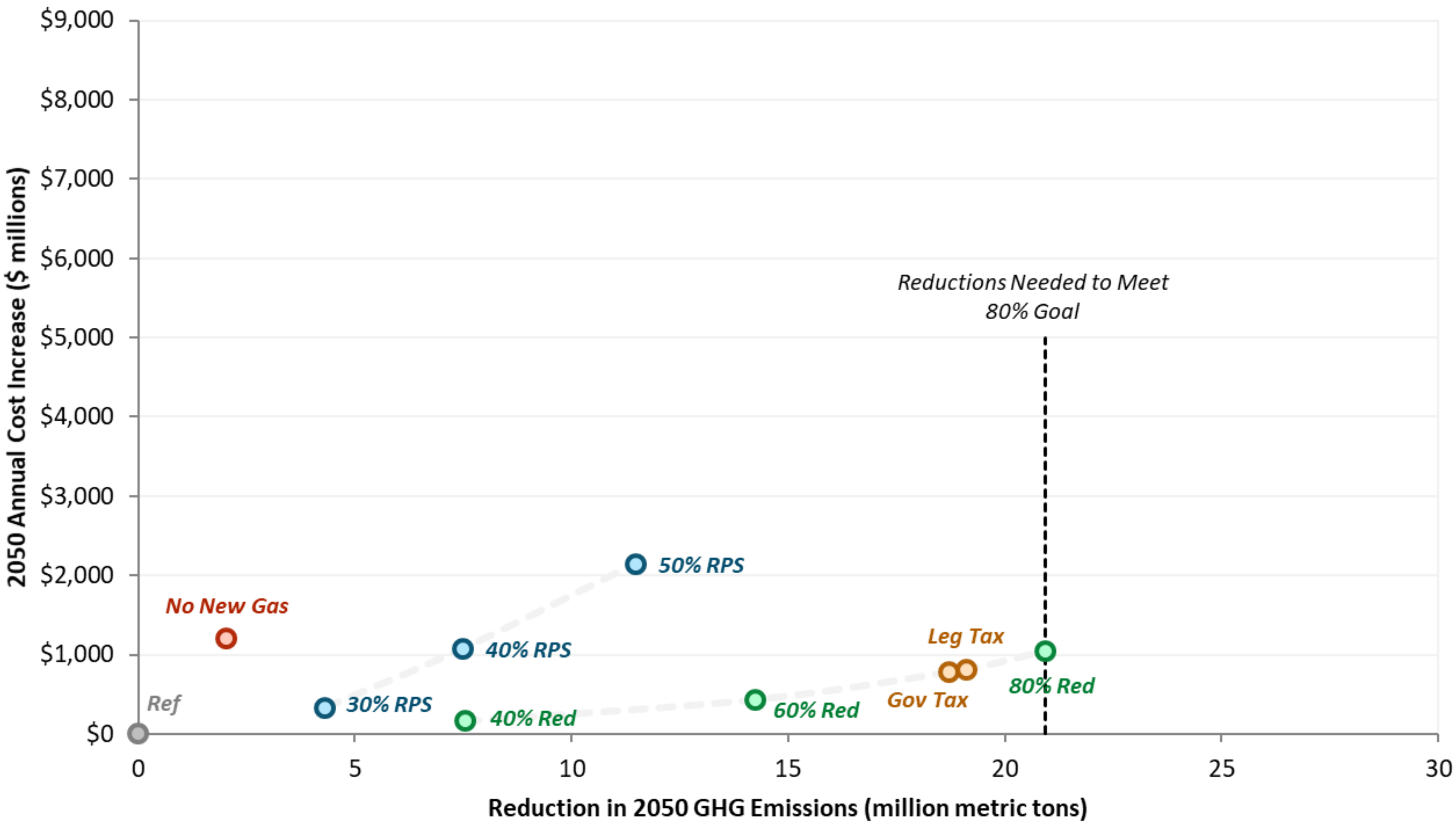


**Note the change in the Y-axis scale change

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

Cost & Emissions Impacts

Original PGP Study Cases



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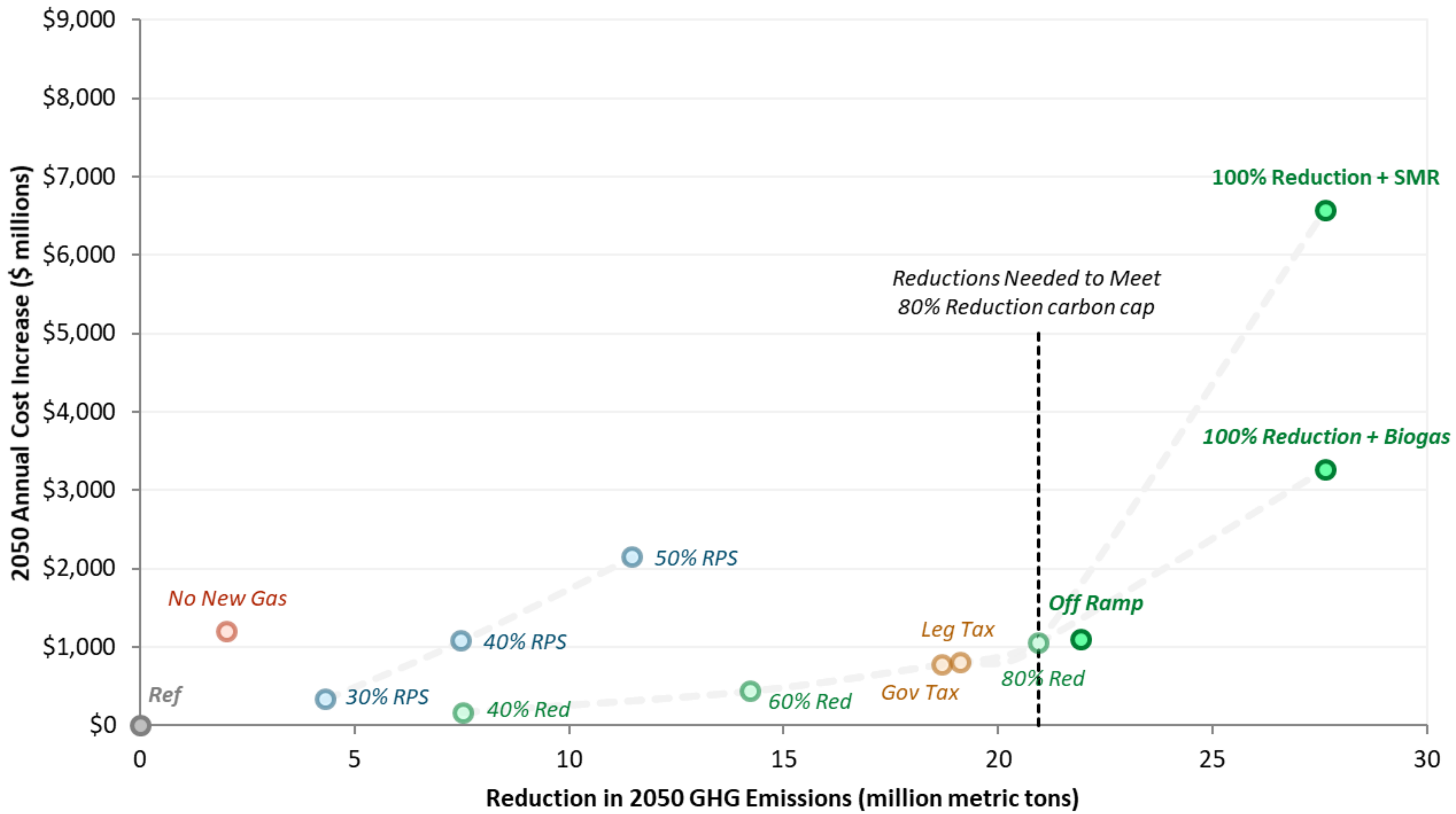
Cost & Emissions Impacts

All Cases – Original PGP Study + Climate Solutions Updates



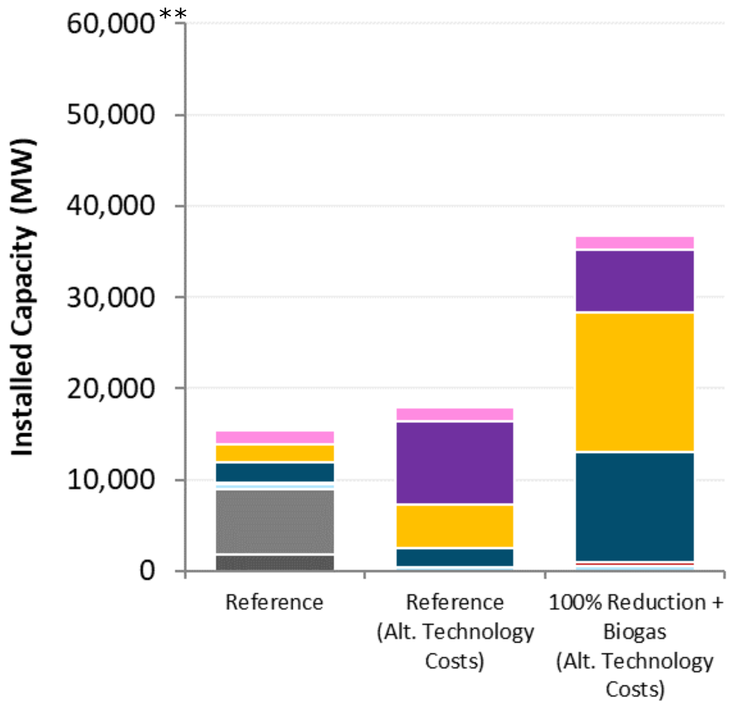
Note: Reference Case reflects current industry trends and state policies, including Oregon's 50% RPS goal for IOUs and Washington's 15% RPS for large utilities

2050 Portfolio Summary – Climate Solutions
Alternative Technology Costs Sensitivity

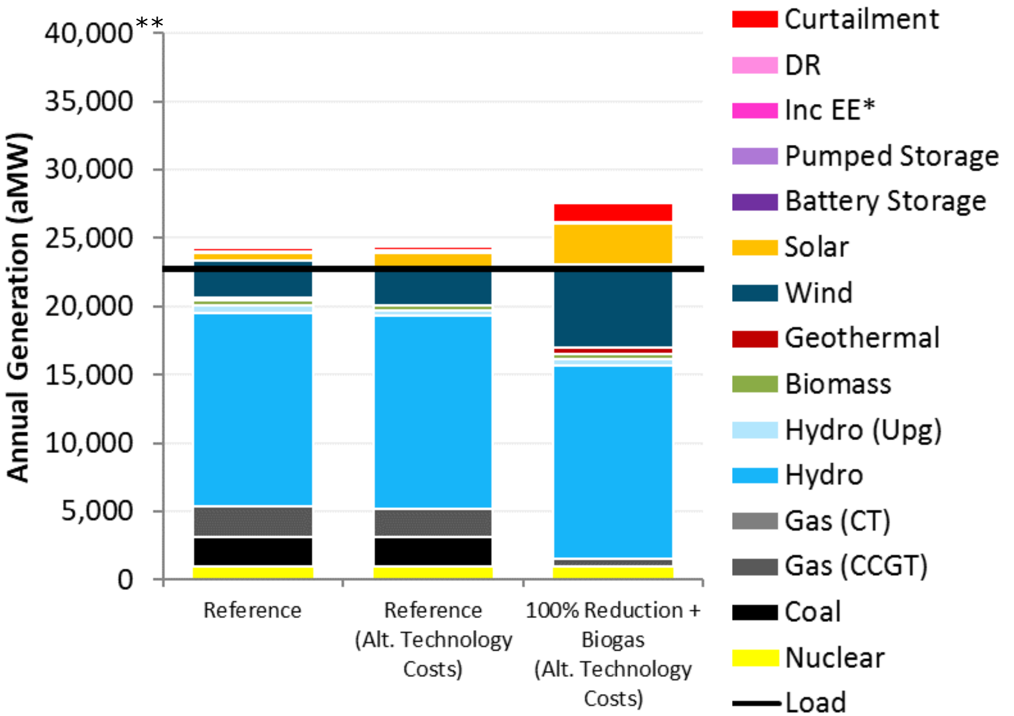
Summary
- 7 GW of renewable capacity and 9 GW of storage capacity are added by 2050 in the Reference Scenario
- 28 GW of renewable capacity and 7 GW of storage capacity are added by 2050 in the 100% Reduction + Biogas Scenario

Scenario	Inc Cost ($MM/yr.)	GHG Reductions (MMT)	Effective RPS %	Zero CO2 %
Reference (Base)	-	-	21%	91%
100% Red. + Biogas *(Alt. Technology Costs)*	+$1,317	27.6	47%	119%
Reference *(Alt. Technology Costs)*	-	-	21%	92%
100% Red. + Biogas *(Alt. Technology Costs)*	+$2,165	27.3	47%	119%

Resources Added (MW)



Energy Balance (aMW)



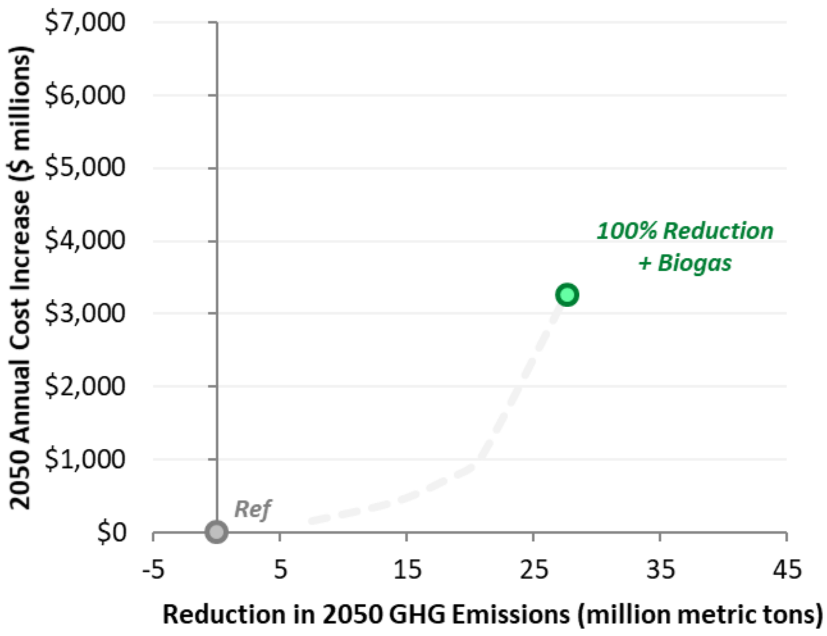
**Note the change in the Y-axis scale change

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

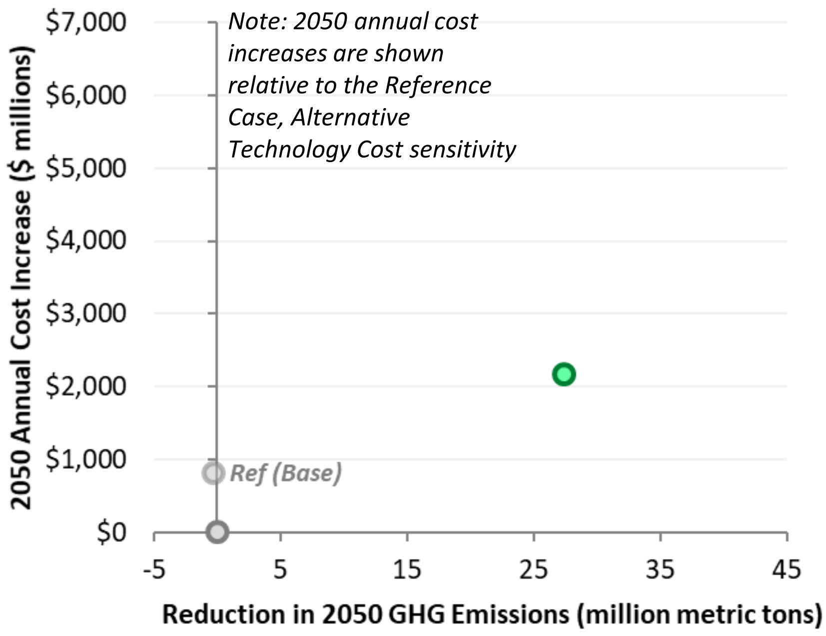
Cost & Emissions Impact – Climate Solutions
Alternative Technology Costs Sensitivity

- Alternative Technology Costs Sensitivity reduces the incremental cost of meeting the 100% reduction carbon cap target by $1 billion

Cost & Emissions Impact, Base Case



Cost & Emissions Impact, Alternative Technology Costs



2050 Summary of Results from Climate Solutions Sponsored Scenarios

Scenario	Inc Cost ($MM/yr.)	GHG Reductions (MMT)	Avg GHG Abatement Cost ($/ton)	Effective RPS %	Zero Carbon %	Renewable Curtailment (aMW)
Original Study Assumptions						
Reference	—	—	—	20%	91%	201
100% Reduction + Off-ramp	+$1,148	21.8	$53	33%	104%	591
100% Reduction + Biogas	+$3,264	27.6	$118	44%	115%	1,082
100% Reduction + SMR	+$6,574	27.6	$238	37%	130%	852
Climate Solutions Alternative Technology Cost Sensitivity						
Reference	+$818	-0.3	—	20%	91%	201
Reference	—	—	—	21%	92%	277
100% Reduction + Biogas	+$2,165	27.3	$79	47%	119%	1,354

Incremental cost and GHG reductions are measured relative to the respective Reference cases

Negative GHG reductions value means emissions are higher relative to the reference scenario

Summary of GHG Reductions from Climate Solutions Sponsored Scenarios

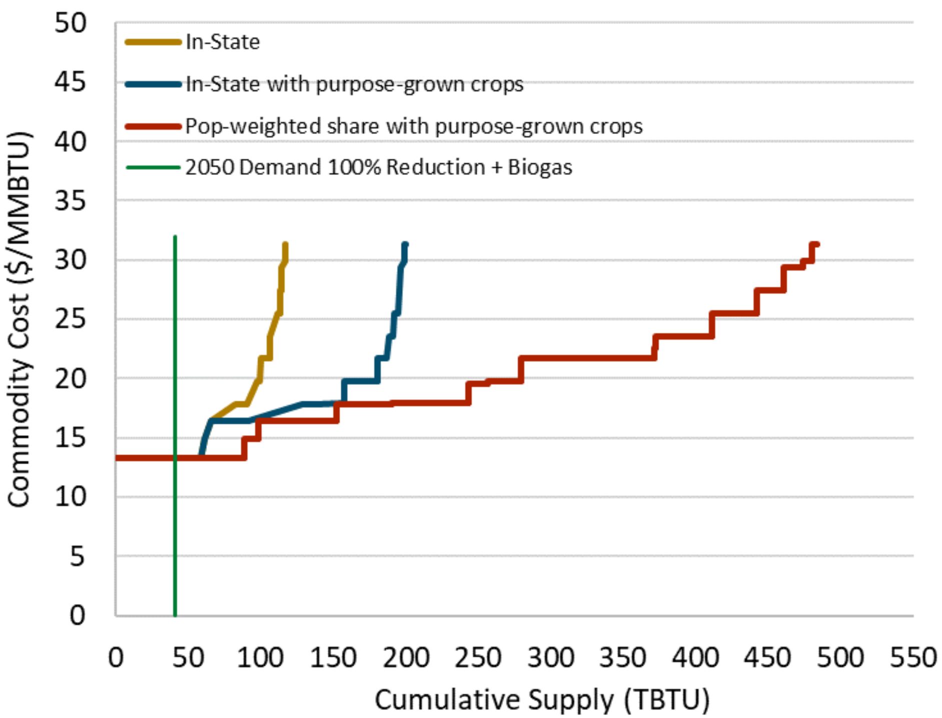
Scenario	Unit	2020	2030	2040	2050
Original Study Assumptions					
100% Reduction + Off-ramp	*MMtCO2*	1.3	11.3	18.6	21.8
100% Reduction + Biogas	*MMtCO2*	1.3	11.3	18.6	27.6
100% Reduction + SMR	*MMtCO2*	1.3	11.3	18.6	27.6
Climate Solutions Alternative Technology Cost Sensitivity					
100% Reduction + Biogas	*MMtCO2*	1.8	11.6	18.8	27.3

GHG reductions are measured relative to the respective Reference cases

Pipeline Biogas Potential Assumptions

- **The pipeline biogas consumed in the 100% Reduction + Biogas base scenario is about a third of the combined Oregon and Washington in-state potential**
  - Assumes no purpose-grown crops
  - Assumed market price of $31/MMBtu reflects other uses
  - Pipeline biogas potential available for use in electricity sector requires more study

Estimated 2040 Oregon and Washington Biomethane Potential



*Potential estimates are based on DOE Billion Ton Study Update of 2016: https://www.energy.gov/eere/bioenergy/2016-billion-ton-report

Reliability analysis is needed for energy limited systems with high levels of storage as a capacity resource

- **Thermal fleet retirements in 100% GHG reductions scenarios coupled with load growth create a need for replacement capacity to ensure resource adequacy**
  - In the alternative technology costs scenarios the primary source of capacity added 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 systems with significant storage capacity as modeled meet reliability expectations**
  - The alternative technology costs scenarios meet the current reserve margin requirement with the addition of new energy storage (1 MW of 10-hr storage capacity is assumed equivalent to 1 MW of natural gas capacity)
  - However, it is unclear how much energy storage can contribute to Resource Adequacy in the Pacific Northwest

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Thank You!

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