Energy+Environmental Economics

Pacific Northwest Low Carbon Scenario Analysis

2018 Scenarios and Sensitivities

June 2018

Arne Olson, Senior Partner
Kush Patel, Partner
Nick Schlag, Director
Kiran Chawla, Consultant
Femi Sawyerr, Associate

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
- PGP Sponsored Scenarios and Results

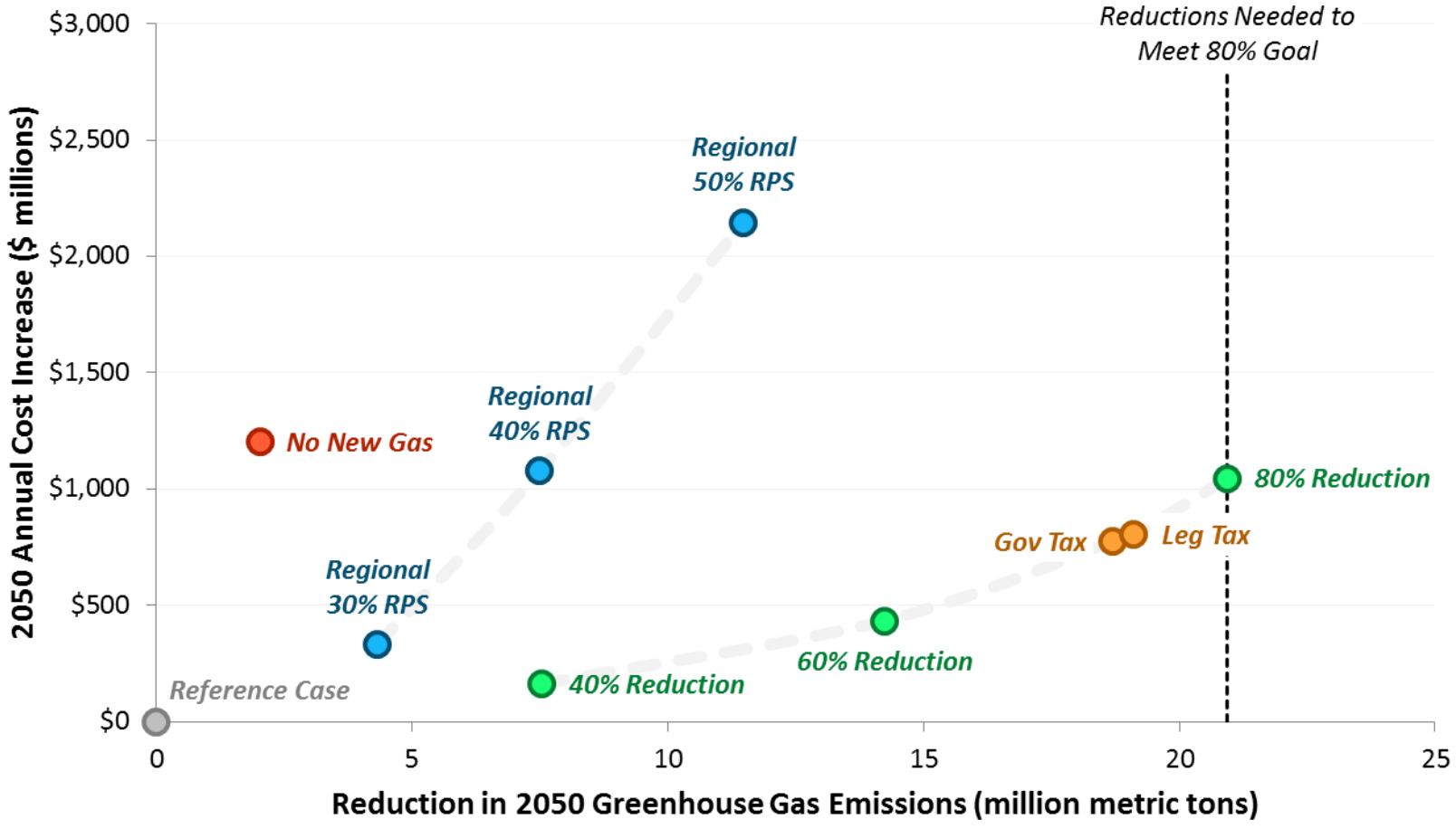
Energy+Environmental Economics

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 CO2 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

Scenario	INPUT ASSUMPTIONS: 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

Energy+Environmental Economics

100% Reduction Scenario Individually Requested by PGP and Climate Solutions

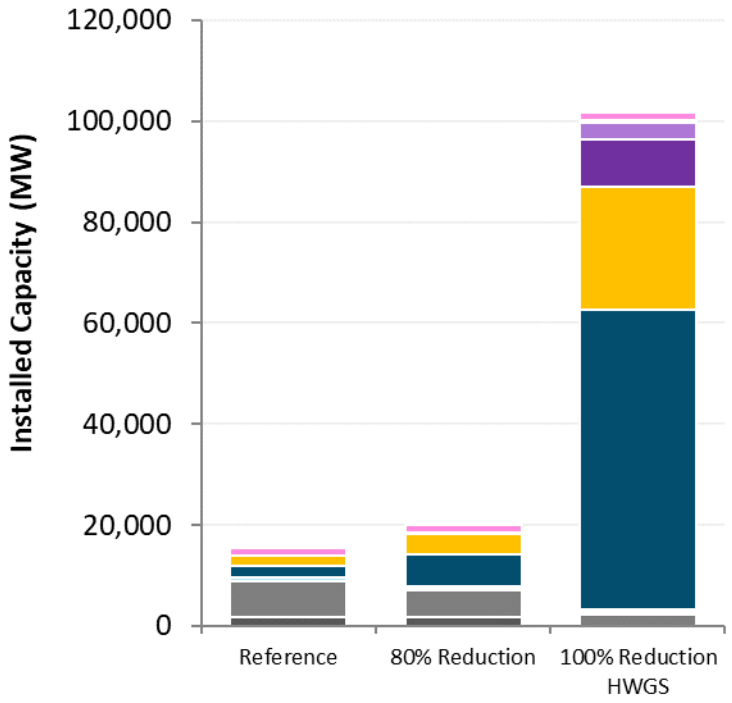
2050 Portfolio Summary - PGP
Carbon Cap Scenarios

Summary

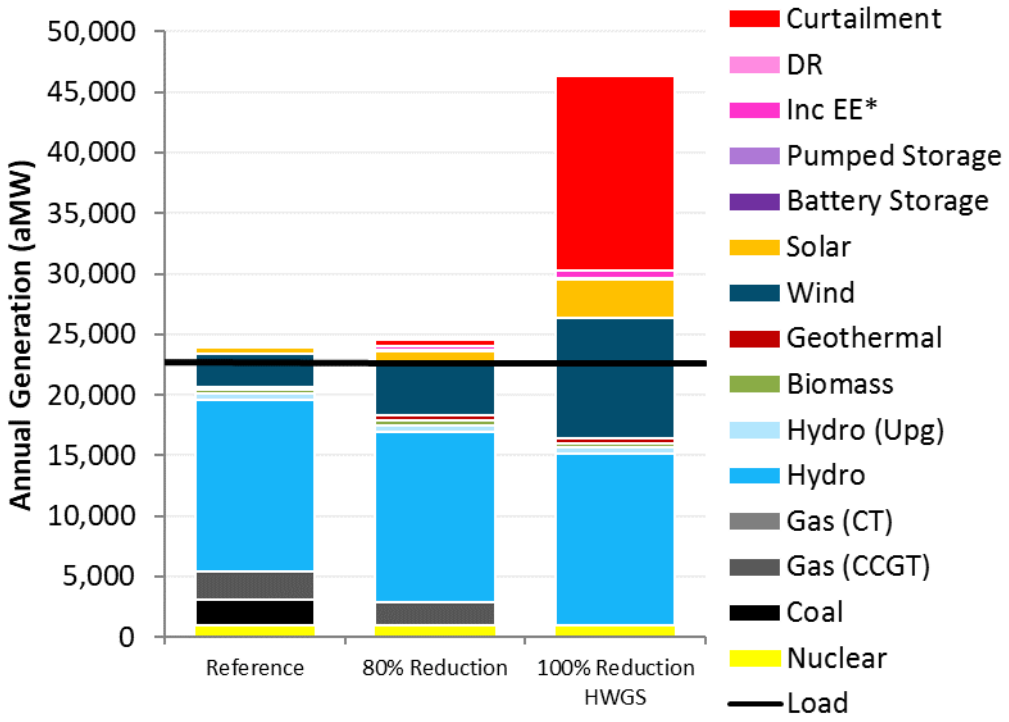
- 84 GW of new renewable capacity added by 2050 in 100% Reduction HWGS scenario
- 10 GW of new storage capacity
- Gas generation eliminated entirely by 2050

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)



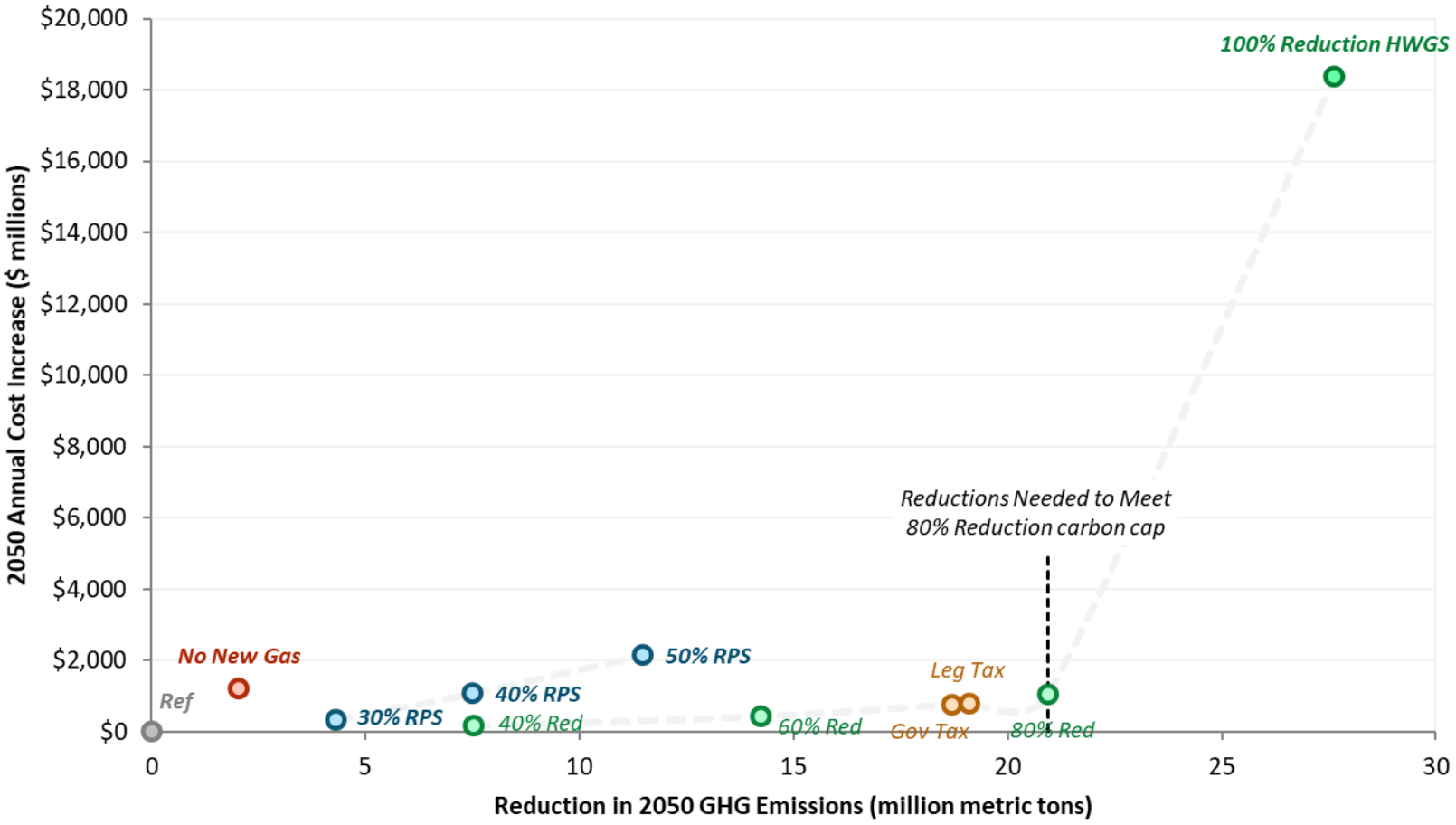
Energy Balance (aMW)



* 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**

Energy+Environmental Economics

PGP Sponsored Scenarios

Summary of Sponsored Scenarios - PGP

Scenario Name	Question Answered	Updates to Model
90% Reduction	Effect of a 90% GHG reduction target	Added 90% GHG reduction trajectory, assuming a straight line reduction from 2016 to 2050
95% Reduction	Effect of a 95% GHG reduction target	Added 95% GHG reduction trajectory, assuming a straight line reduction from 2016 to 2050
100% Reduction + Biogas	Effect of availability of biogas to run in existing natural gas infrastructure	Added 100% GHG reduction trajectory, assuming 60% reduction by 2030 and 100% reduction by 2050. Capacity unconstrained pipeline biogas available for use in natural gas generators at $31/MMBtu cost

Sensitivity Name	Question Answered	Updates to Model
100% Reduction + Biogas 3xP	Effect of availability of biogas to run in existing natural gas infrastructure	Capacity unconstrained pipeline biogas available for use in natural gas generators at $93/MMBtu cost
100% Reduction + Biogas Q/3	Effect of availability of biogas to run in existing natural gas infrastructure	12.5 Tbtu of pipeline biogas available for use in natural gas generators at $31/MMBtu cost
100% Reduction + Biogas 3xP Q/3	Effect of availability of biogas to run in existing natural gas infrastructure	12.5 Tbtu of pipeline biogas available for use in natural gas generators at $93/MMBtu cost

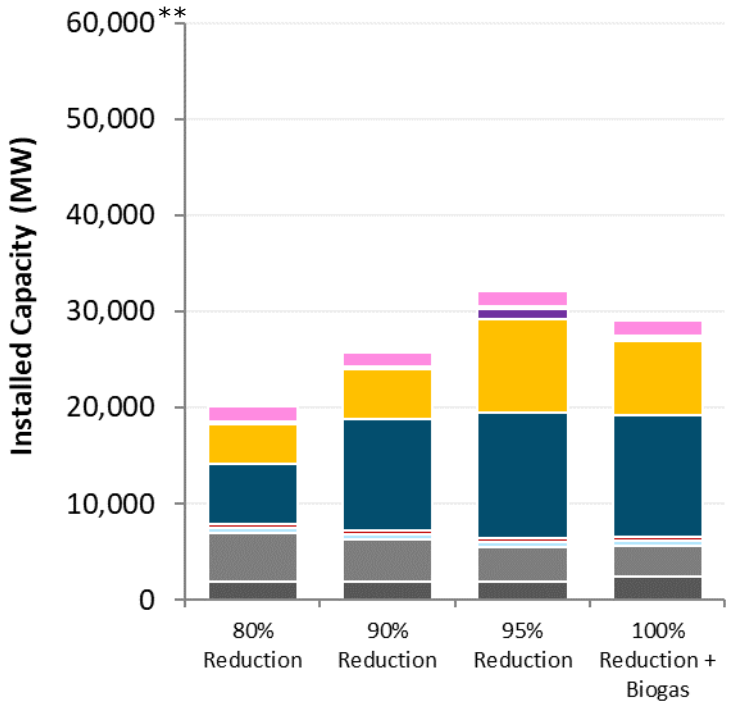
2050 Portfolio Summary - PGP
Carbon Cap Scenarios

Summary

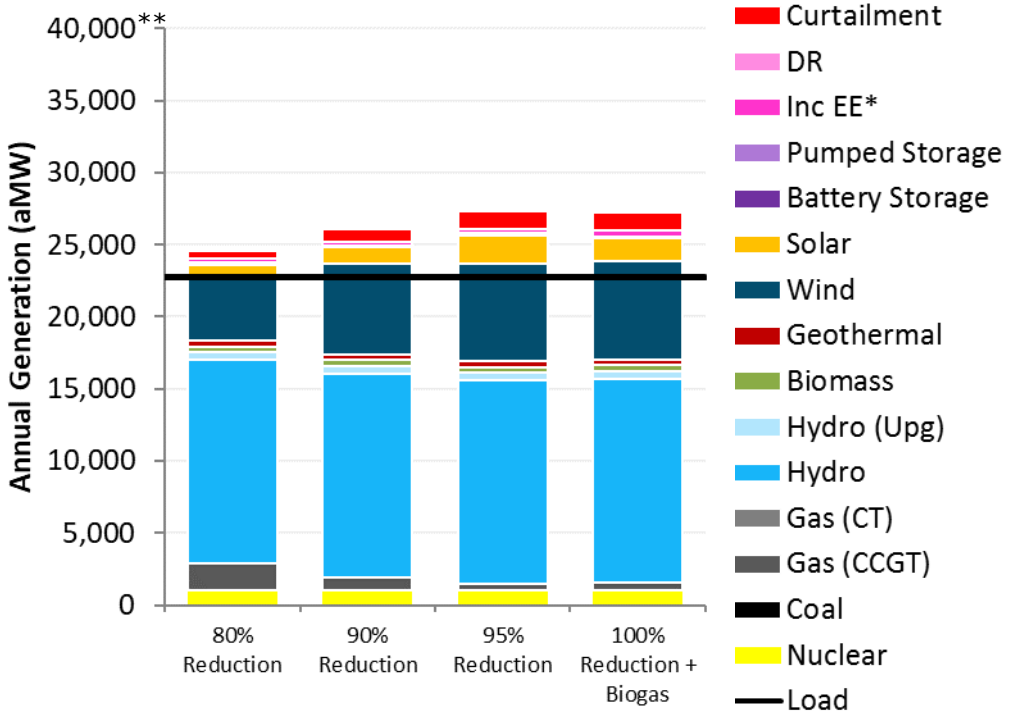
- 17 GW of new renewable capacity added by 2050 in 90% Reduction scenario
- 23 GW of new renewable capacity added by 2050 in 95% Reduction scenario
- 21 GW of new renewable capacity and 41 TBtu of pipeline biogas consumed in 2050 in 100% Reduction + Biogas scenario

Scenario	Inc Cost ($MM/yr.)	GHG Reductions (MMT)	Effective RPS %	Zero CO2 %
80% Reduction	+$1,046	20.9	31%	102%
90% Reduction	+$1,818	24.3	41%	112%
95% Reduction	+$2,612	26.0	47%	117%
100% Reduction + Biogas	+$3,264	27.6	44%	115%

Resources Added (MW)



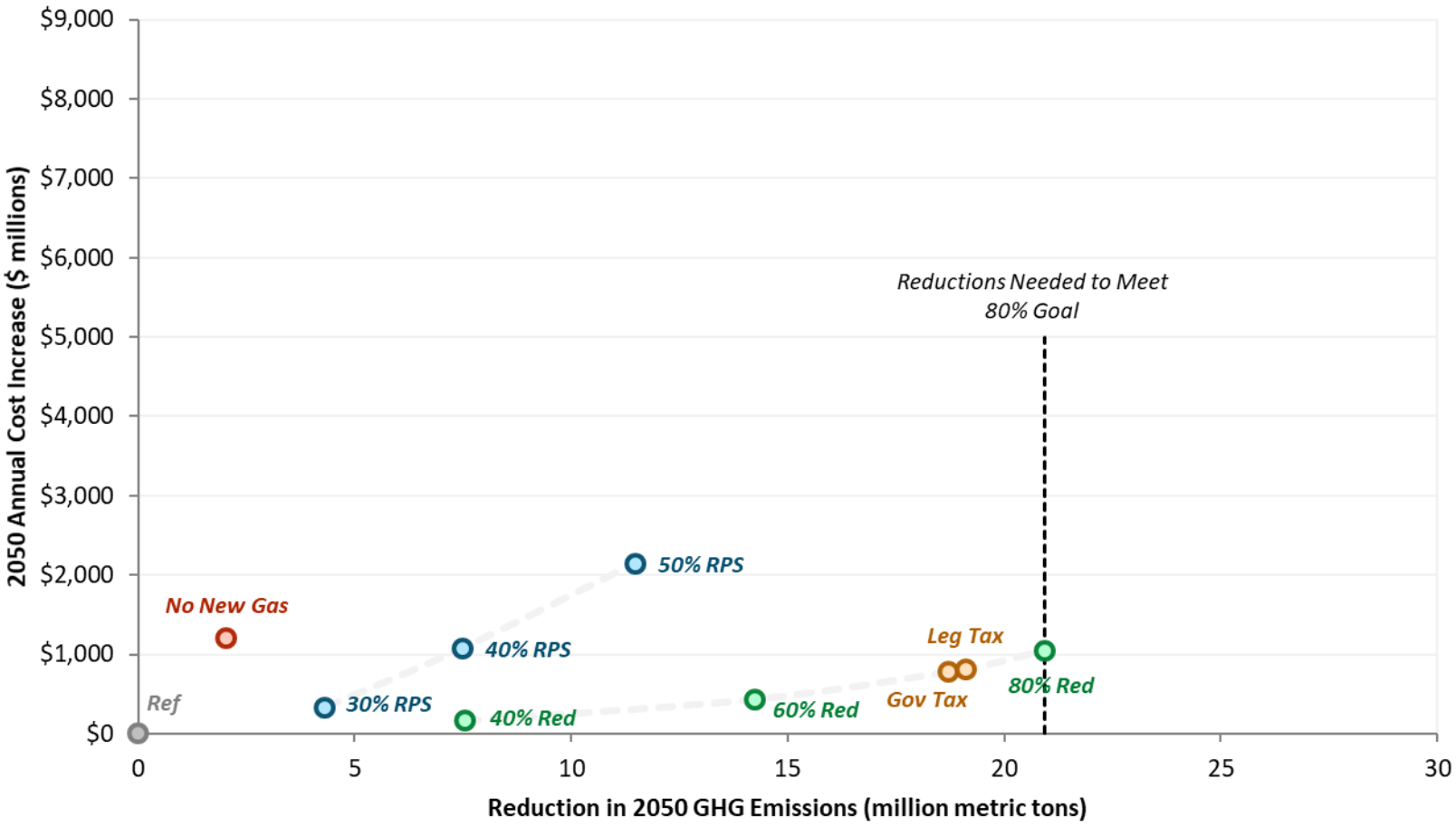
Energy Balance (aMW)



**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)

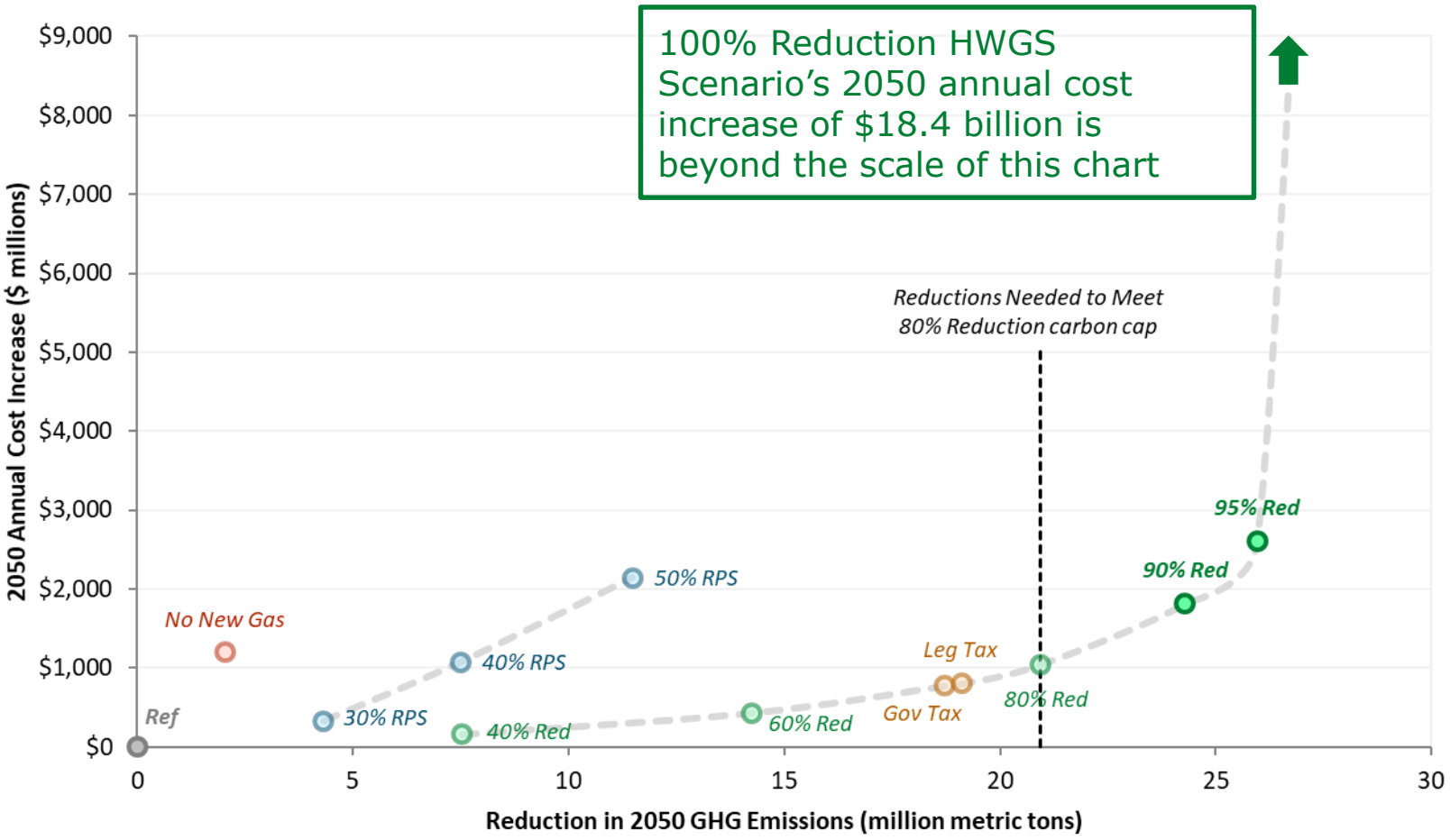
Cost & Emissions Impacts
Original PGP Study Cases



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

Original PGP Study + Additional Carbon Cap Scenarios



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

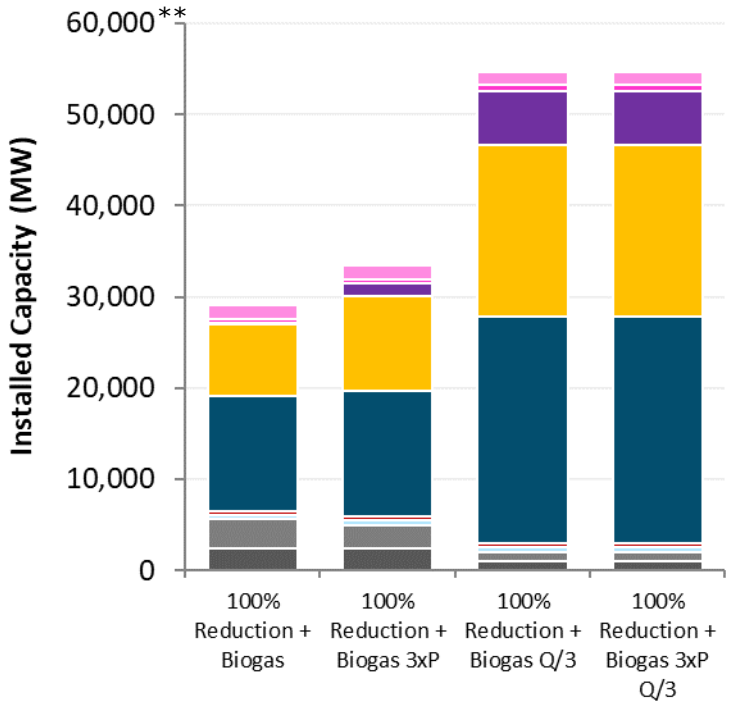
2050 Portfolio Summary - PGP
100% Reduction + Biogas Sensitivities

Summary

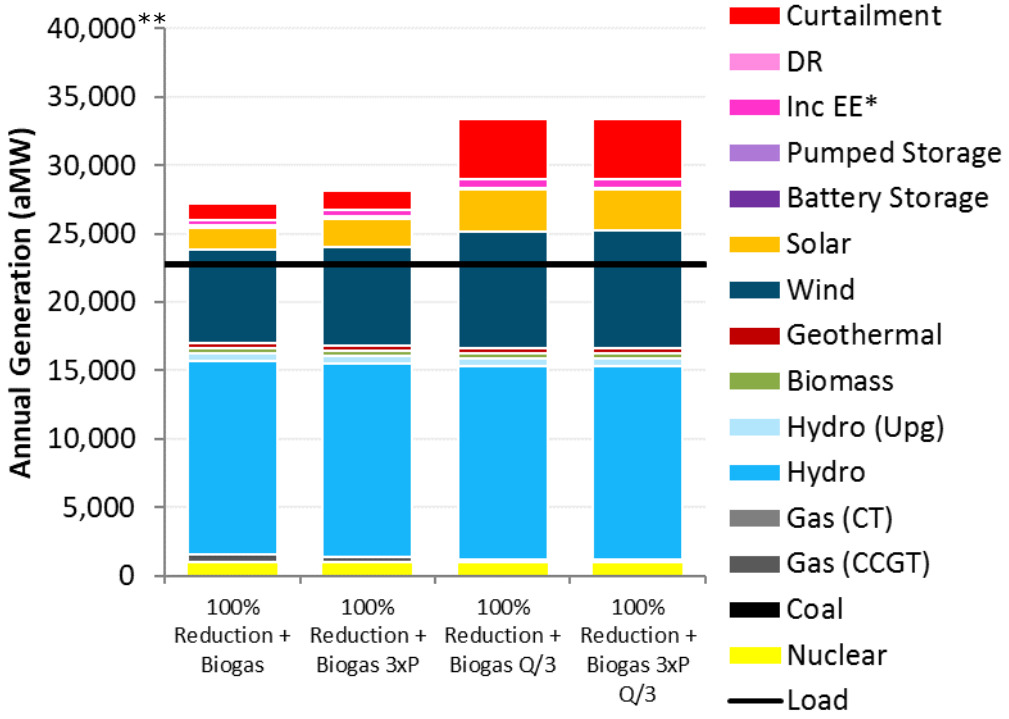
- 24 GW of new renewable capacity added by 2050 and in the 100% + Biogas 3xP sensitivity
- 44 GW of new renewable capacity added by 2050, 12.5 TBtu of pipeline biogas is used in 2050, and about 300 GWh of unserved energy in both the 100% Reduction + Biogas Q/3 and 100% Reduction + Biogas 3xP Q/3 sensitivities

Scenario	Inc Cost ($MM/yr.)	GHG Reductions (MMT)	Effective RPS %	Zero CO2 %
100% Red. + Biogas (Base)	+$3,264	27.6	44%	115%
100% Red. + Biogas 3xP	+$4,950	27.6	50%	120%
100% Red. + Biogas Q/3	+$6,834	27.6	59%	130%
100% Red. + Bio. 3xP Q/3	+$7,640	27.6	59%	130%

Resources Added (MW)



Energy Balance (aMW)

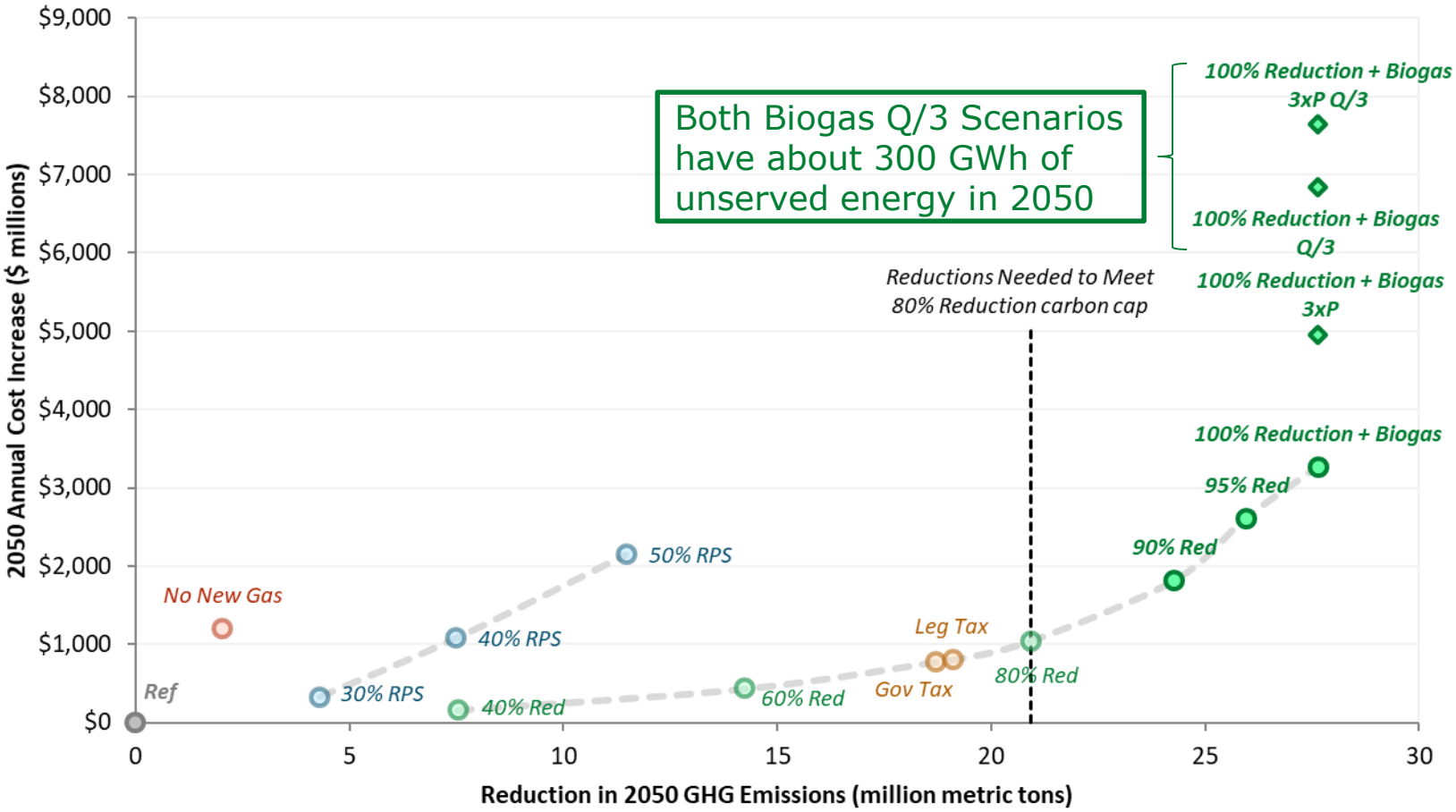


**Note the change in the Y-axis scale change

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

Cost & Emissions Impacts

All Cases –Original PGP Study + All PGP Additional



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 Summary of Results from PGP Sponsored Scenarios

Scenario	Inc Cost ($MM/yr.)	GHG Reductions (MMT)	Avg GHG Abatement Cost ($/ton)	Effective RPS %	Zero Carbon %	Renewable Curtailment (aMW)
Reference	—	—	—	20%	91%	201
80% Reduction	+$1,046	20.9	$50	31%	102%	546
90% Reduction	+$1,818	24.3	$75	41%	112%	884
95% Reduction	+$2,612	26.0	$100	47%	117%	1,200
100% Reduction + Biogas	+$3,264	27.6	$118	44%	115%	1,082
PGP Biogas P & Q Sensitivities						
100% Reduction + Biogas 3xP	+$4,950	27.6	$179	50%	120%	1,481
100% Reduction + Biogas Q/3	+$6,834	27.6	$247	59%	130%	4,328
100% Reduction + Biogas 3xP Q/3	+$7,640	27.6	$277	59%	130%	4,289

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

Summary of GHG Reductions from PGP Sponsored Scenarios

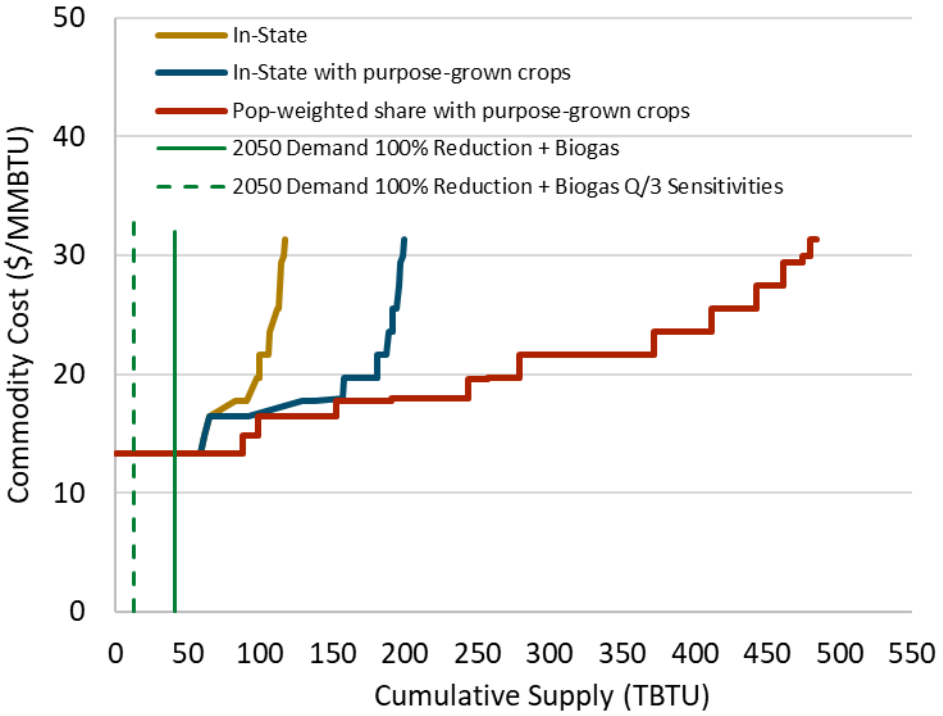
Scenario	Unit	2020	2030	2040	2050
Original Study Assumptions					
90% Reduction	*MMtCO2*	—	2.2	11.9	24.3
95% Reduction	*MMtCO2*	—	2.9	13.0	26.0
100% Reduction + Biogas	*MMtCO2*	1.3	11.3	18.6	27.6
PGP Biogas P & Q Sensitivities					
100% Reduction + Biogas 3xP	*MMtCO2*	1.3	11.3	18.6	27.6
100% Reduction + Biogas Q/3	*MMtCO2*	1.3	11.3	18.6	27.6
100% Reduction + Biogas 3xP Q/3	*MMtCO2*	1.3	11.3	18.6	27.6

GHG reductions are measured relative to the Reference case

Pipeline Biogas Potential Assumptions

- **The pipeline biogas consumed in the unconstrained 100% Reductions + Biogas scenarios 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 (Tbtu)



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

Energy+Environmental Economics

Thank You!

Energy and Environmental Economics, Inc. (E3)
101 Montgomery Street, Suite 1600
San Francisco, CA 94104
Tel 415-391-5100
Web http://www.ethree.com

Arne Olson, Senior Partner (arne@ethree.com)
Kush Patel, Partner (kushal.patel@ethree.com)
Nick Schlag, Director (nick@ethree.com)
Kiran Chawla, Consultant (kiran@ethree.com)
Femi Sawyerr, Associate (femi@ethree.com)