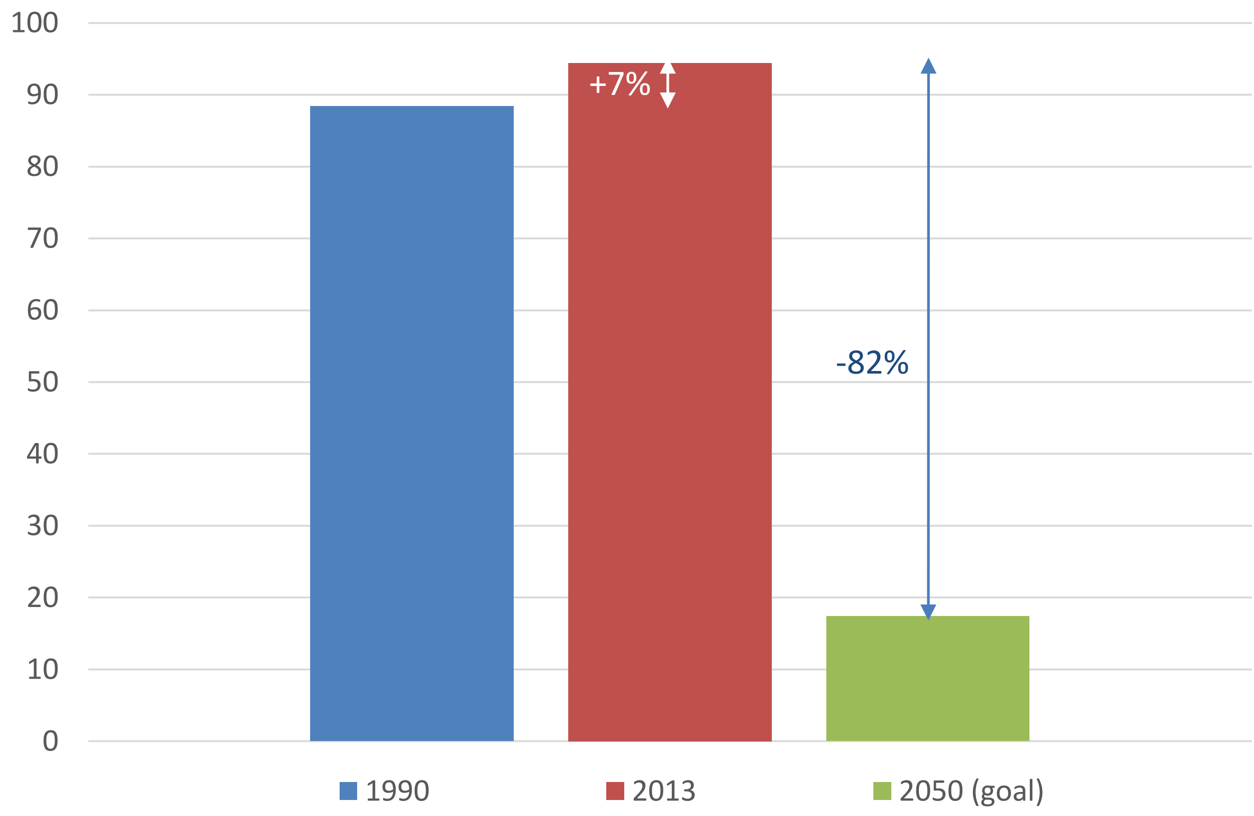
100% Fossil Free Electricity

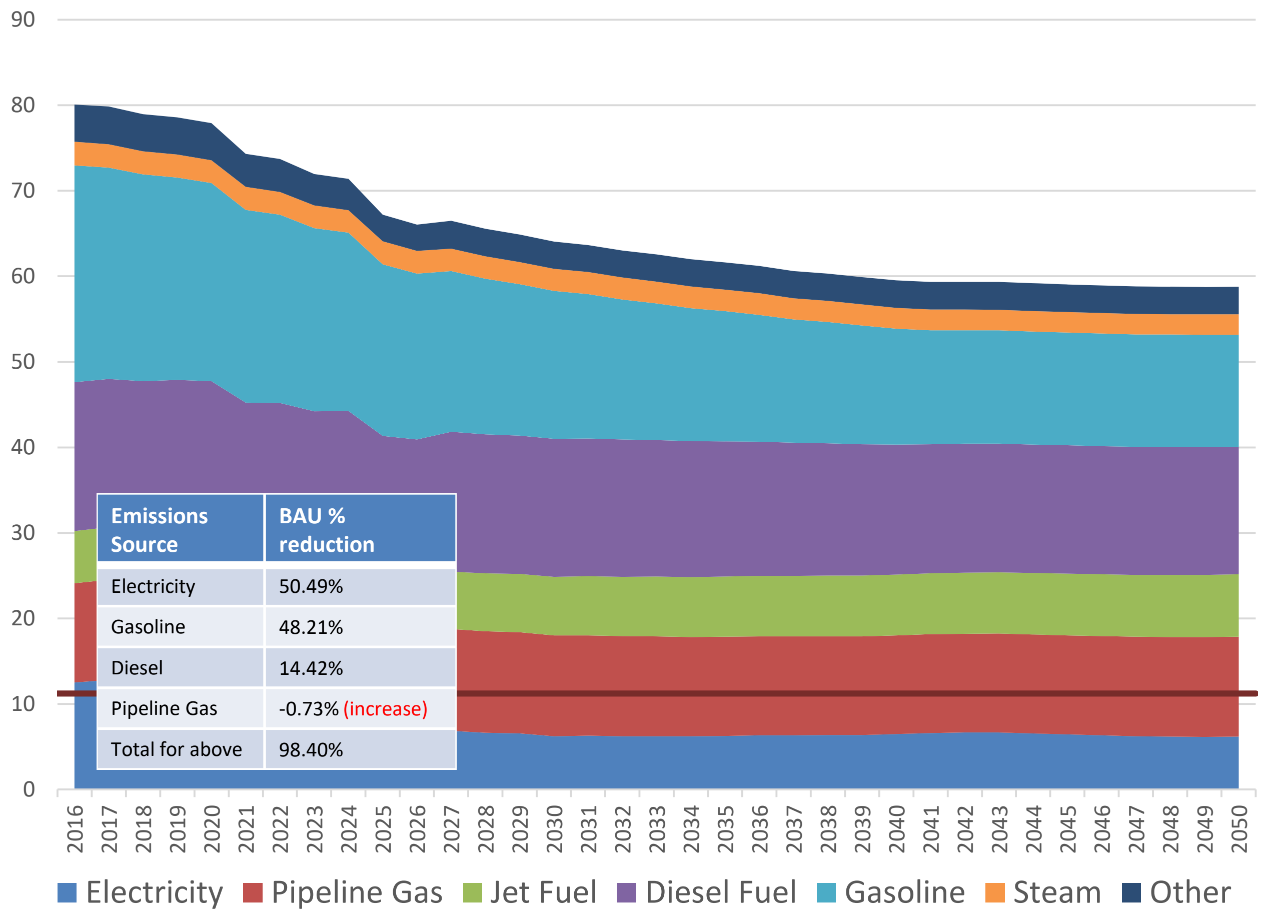
June 27, 2018

Climate Solutions

Current Washington Emissions Levels



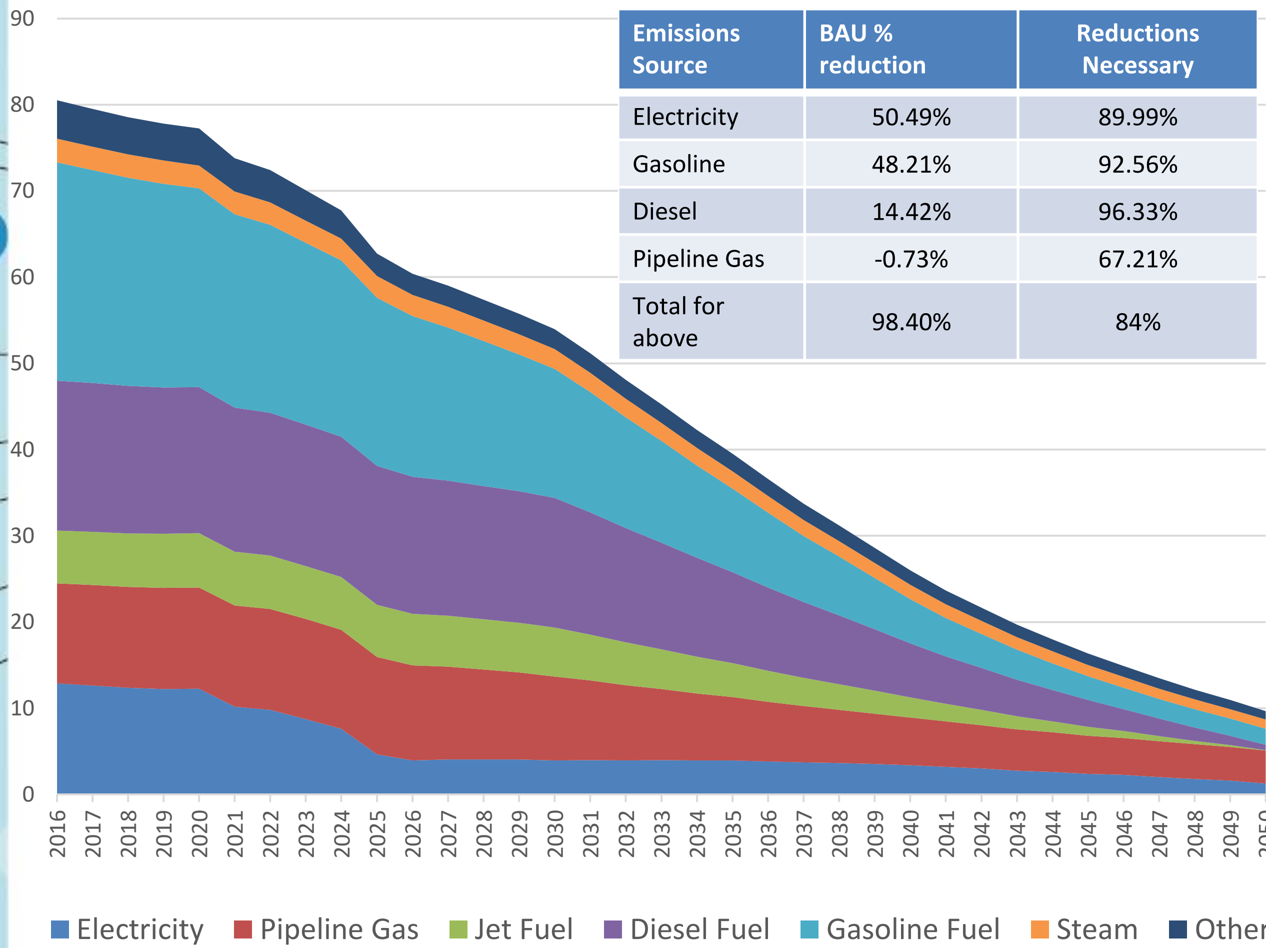
If We Do Nothing



Emissions Source	BAU % reduction
Electricity	50.49%
Gasoline	48.21%
Diesel	14.42%
Pipeline Gas	-0.73% (increase)
Total for above	98.40%

- Some natural reductions including new renewables and expanded electric vehicles
- Without policy, utilities continue to invest in fossil fuel gas and we do not electrify nearly enough transportation
- Continued growth of fossil fuel gas in residential, commercial and industrial sectors

The Low Carbon Pathway

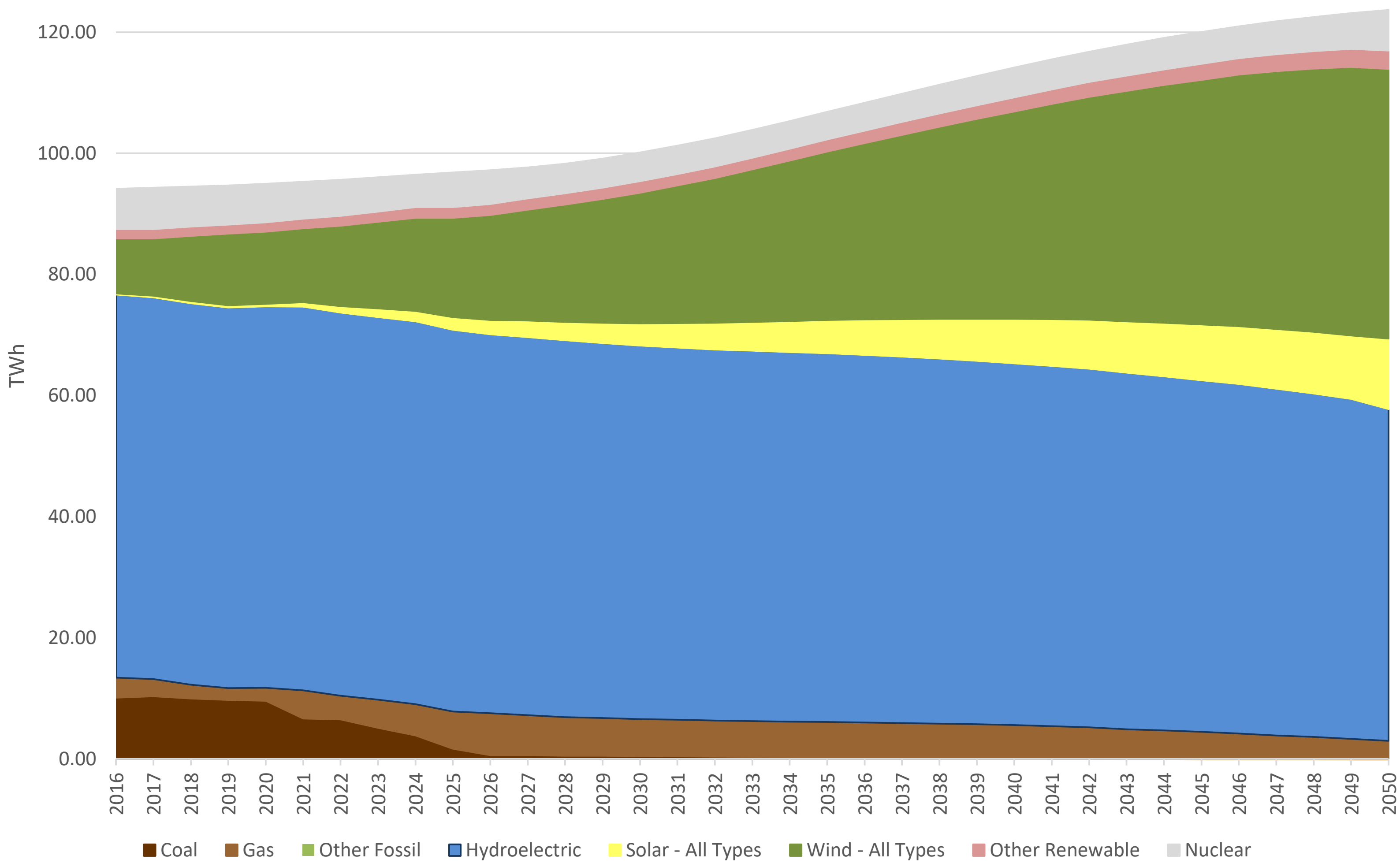


Emissions Source	BAU % reduction	Reductions Necessary
Electricity	50.49%	89.99%
Gasoline	48.21%	92.56%
Diesel	14.42%	96.33%
Pipeline Gas	-0.73%	67.21%
Total for above	98.40%	84%

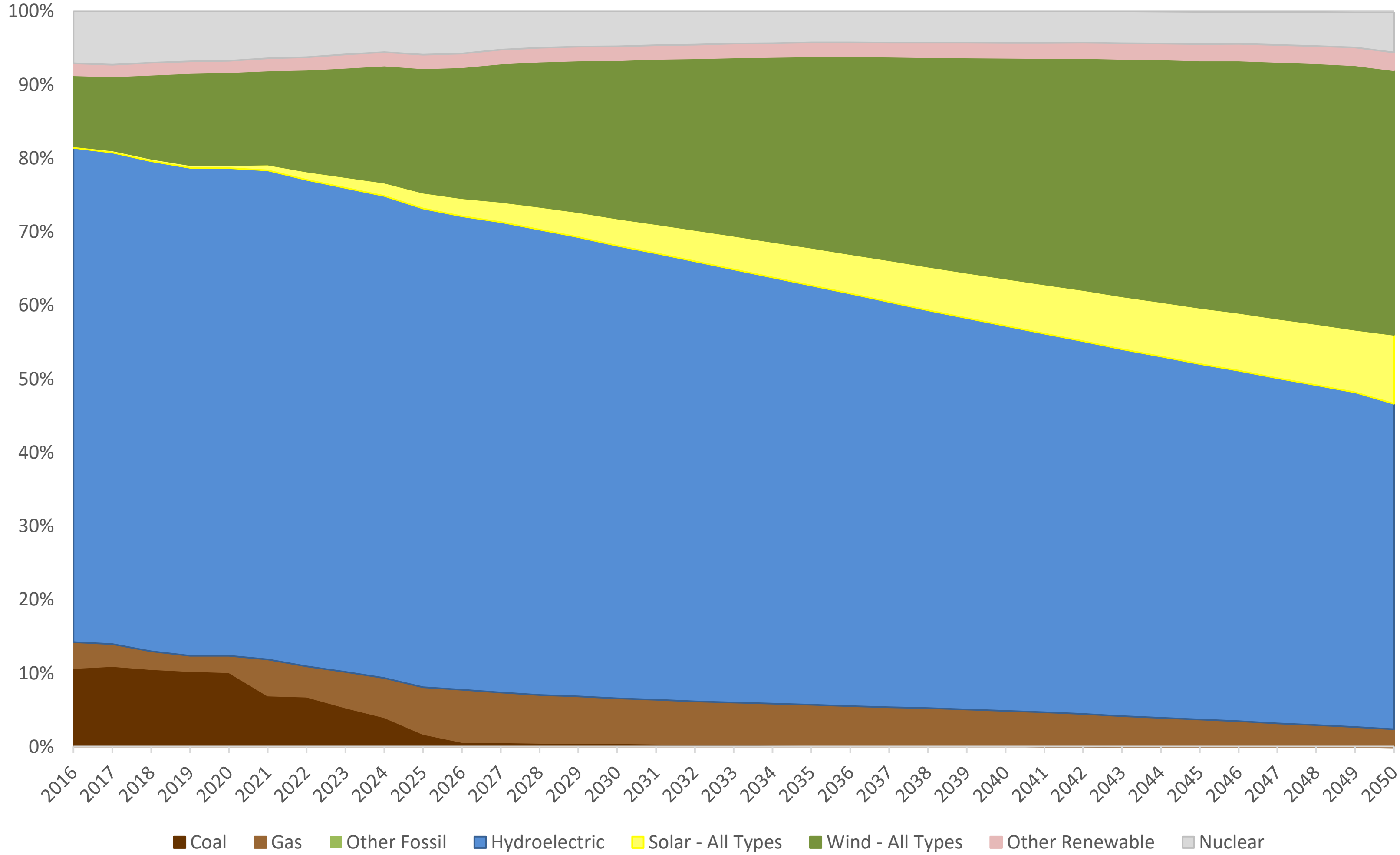
To succeed we must:

- Expand electrification of transportation
- Reduce electric sector emissions to near zero (electricity becomes largest source of energy)
- Expand energy efficiency
- Stop investing in direct use of gas

Electricity Mix to Achieve WA Goals



Electricity Mix to Achieve WA Goals



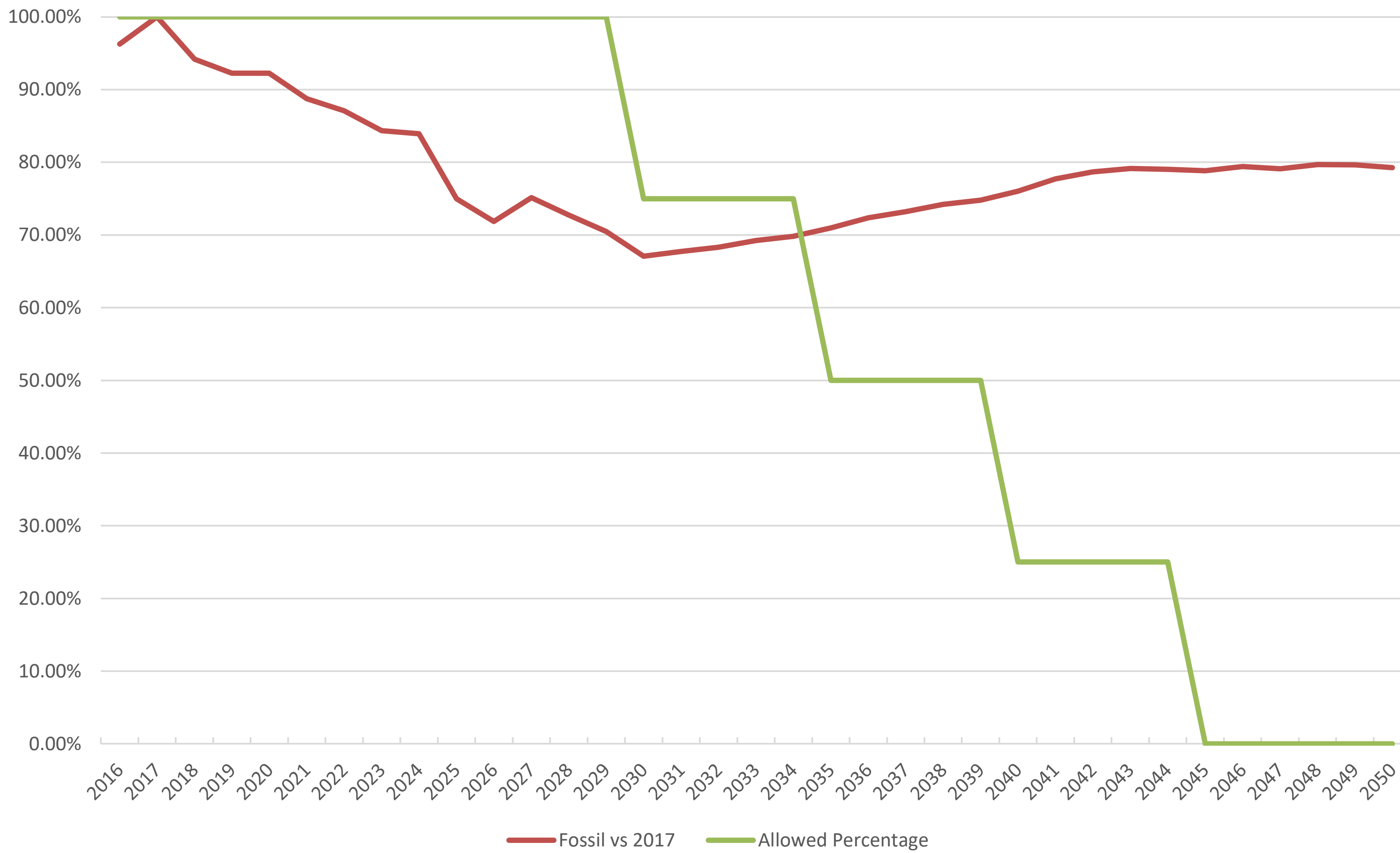
Policy Outline

Year	Fossil Fuel Reduction Requirement	Penalty for exceeding ($/MWh)
2030	*Coal Phase Out*	
2030	25%	$50
2035	50%	$50
2040	75%	$75
2045	100%	$100

Revenue from penalty directed to:

- 1/3 to mitigating low income impacts
- 2/3 to preventing use of the penalty in the future

Impact



100.00%
90.00%
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50.00%
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Fossil vs 2017
Allowed Percentage

Modeling pathways to 100% Fossil-Free Grid

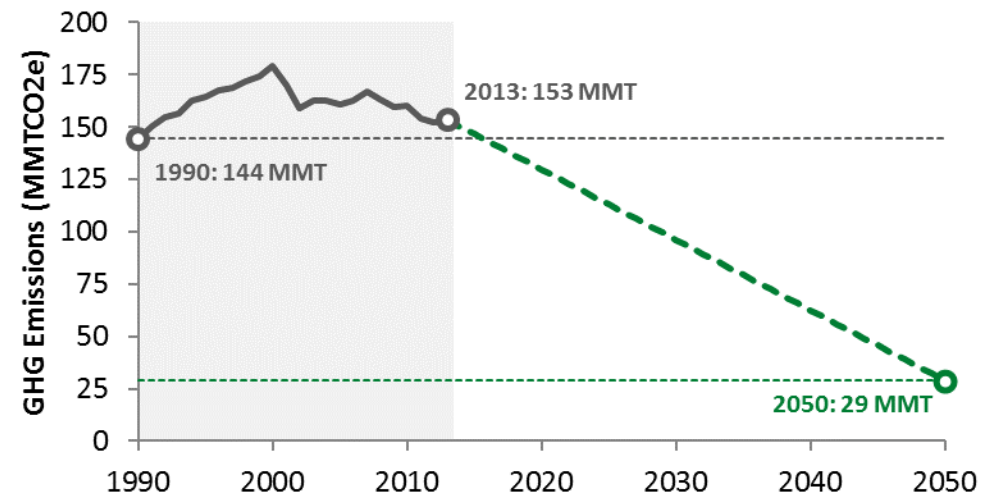
Context of Follow-Up Analysis

+ **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, Climate Solutions sponsored a follow-up study to explore specific questions left unanswered by the original study**
+ **This document reports on the assumptions and results from the additional analysis**

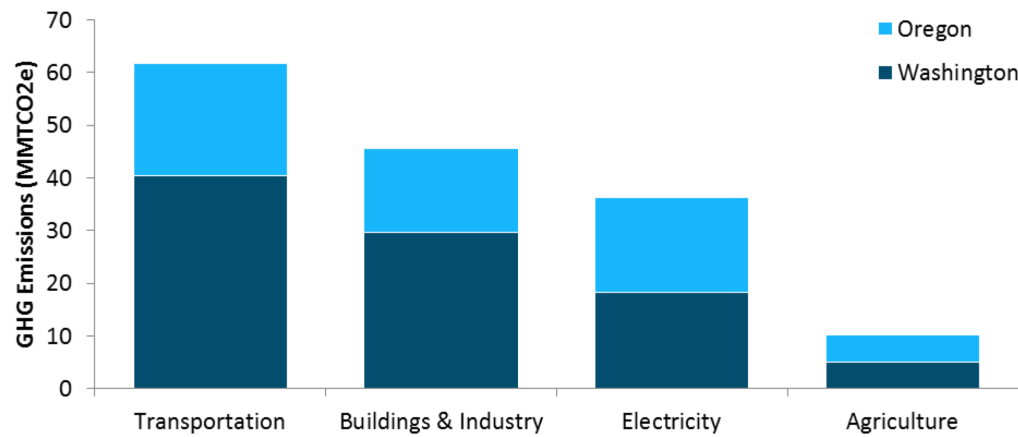
About The Original PGP Study

- **Oregon and Washington are currently exploring potential commitments to deep decarbonization in line with international goals:**
  - 80-91% economy wide reductions below 1990 levels by 2050 (proposed)
- **The study was conceived to provide information to policymakers**
  - How can we reduce carbon in the electricity sector at the lowest cost in Oregon and Washington?
  - What is the role of wind, solar, energy storage, natural gas and other resources for generation?
  - What is the importance of the region's existing base of carbon-free hydro generation?

Historical and Projected GHG Emissions for OR and WA



2013 CO2 Emissions for Oregon and Washington



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

Study used E3's RESOLVE model to develop optimal resource portfolios for the Northwest

- **RESOLVE is an optimal capacity expansion model used in resource planning**
  - Designed for high renewable systems
  - Utilized in several jurisdictions including California, Hawaii and New York
- **Selects combination of renewable and conventional resources to minimize operational and investment costs over time**
  - Simulates operations of the Northwest electricity system including existing hydro and thermal generators
  - Adds new resources as needed
  - Complies with renewable energy and carbon policy targets
  - Meets electricity system reliability needs

Resource Type	Examples of New Resource Options
Natural Gas Generation	• Simple cycle gas turbines • Reciprocating engines • Combined cycle gas turbines • Repowered CCGTs
Renewable Generation	• Geothermal • Hydro upgrades • Solar PV • Wind
Energy Storage	• Batteries (>1 hr) • Pumped Storage (>12 hr)
Energy Efficiency	• HVAC & appliances • Lighting
Demand Response	• Interruptible tariff (ag) • DLC: space & water heating (res)

Information about E3's RESOLVE model can be found here:
https://www.ethree.com/tools/resolve-renewable-energy-solutions-model/

Model Limitations

- The RESOLVE model is conservative, overestimating the difficulty of achieving reductions and overestimating the cost
- Major limitations
  - Energy efficiency supply curve is limited to NWPCC’s, which has consistently underestimated EE acquisition by 10%+.
  - Demand response is limited to ~1,600MW and restricted to an ag/industrial interruptable rate and space/water heating in residential settings.
  - Model balances over individual days, precluding multi-day storage.
  - Doesn’t model deeper market coordination across Western US
  - Doesn’t consider technological innovation for generation, efficiency or other opportunities

Energy+Environmental Economics

Additional Scenarios

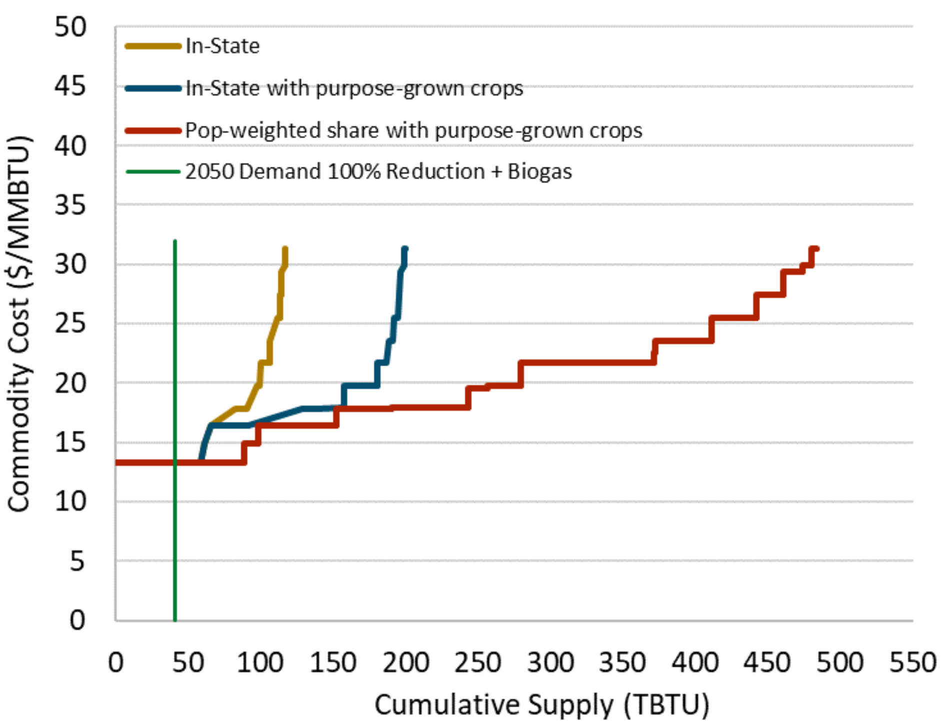
New Climate Solutions Scenarios

- **Scenario 1: 100% Fossil Fuel reductions**
  - Assumes biogas and SMRs are not available
- **Scenario 2: 100% Reductions + Biogas**
  - Assumes unconstrained pipeline biogas is available for combustion in gas generators at a cost of $31/MMBtu
- **Sensitivity: Alt. Technology Costs 100% Reductions + Biogas**
  - Updates solar and battery costs with more recent studies
  - Reduces wind costs by 20% -- still conservative based on regional IRP estimates
  - Reduces biogas costs by 20% consistent with existing Canadian markets
- **Scenario 3: 100% Reductions + Off-Ramp**
  - Allows biogas as in Scenario 1
  - Carbon cap used to drive investments towards a 100% GHG emissions reductions with an off-ramp of $200 per ton of CO_2 in 2050

Pipeline Biogas Potential Assumptions

+ **The pipeline biogas consumed in the 100% GHG Reductions + Biogas scenario is about a third of the combined Oregon and Washington in-state potential**
  - In a scenario where economy-wide decarbonization is ongoing, 30% of in-state supply may be an upper limit for the available biogas potential that can be dedicated to the electricity sector
  - Assumes no purpose-grown crops
  - Assumed market price of $31/MMBtu reflects other uses

Estimated 2040 Oregon and Washington Biomethane Potential



*Potential estimates are based on DOE Billion Ton Study Update of 2016

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

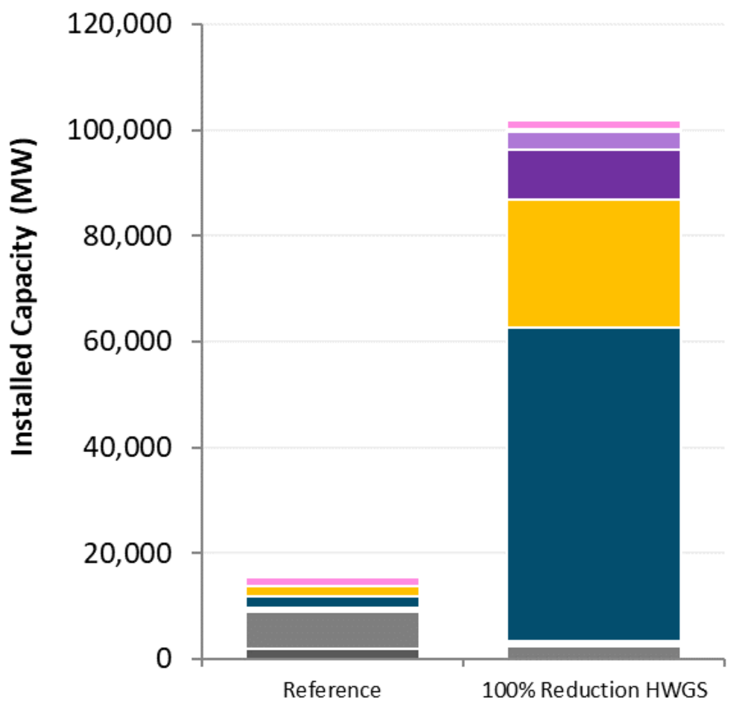
RESULTS

2050 Portfolio Summary
100% Reduction HWGS

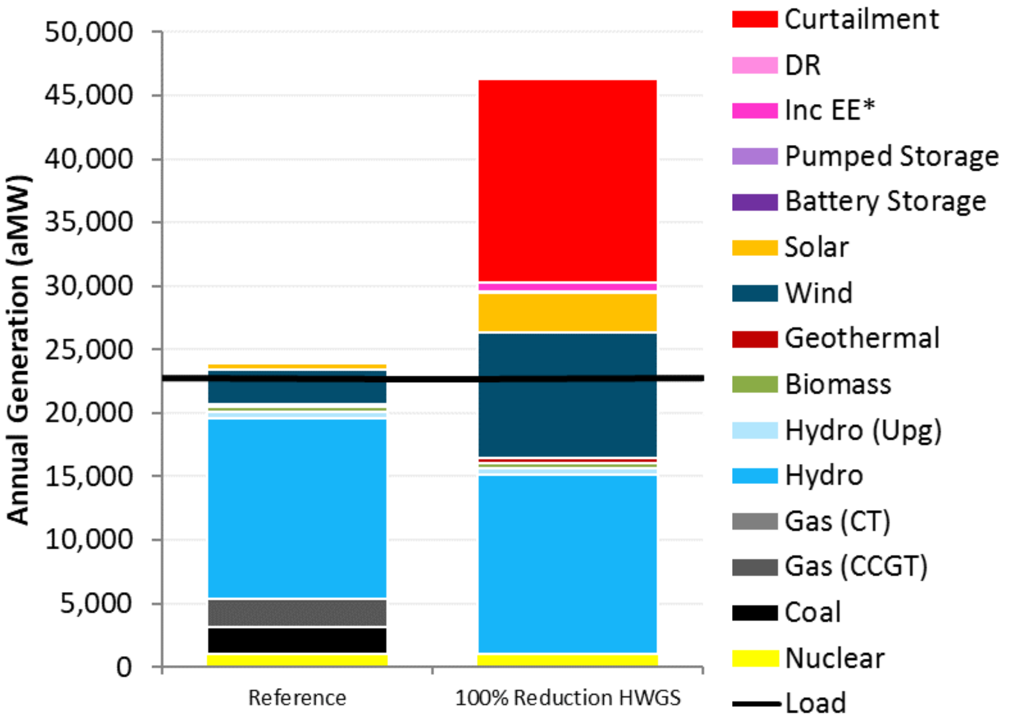
Summary
- 84 GW of new renewable capacity added by 2050 in 100% Reduction HWGS scenario
- 10 GW of new storage capacity
- Gas generation eliminated entirely by 2050

Scenario	Inc Cost ($MM/yr.)	GHG Reductions (MMT)	Effective RPS %	Zero CO2 %
Reference	-	-	20%	91%
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)

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**

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

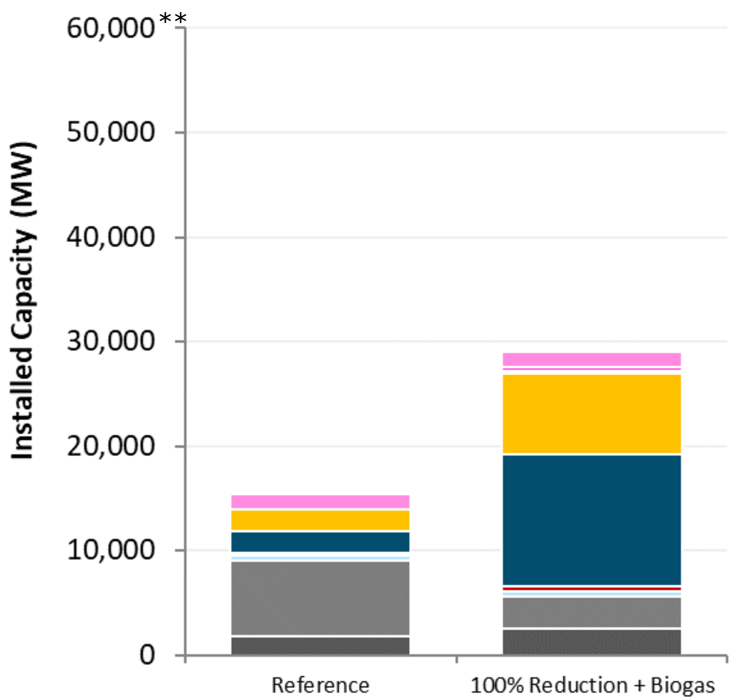
2050 Portfolio Summary
100% Reduction + Biogas Scenario

Highlights

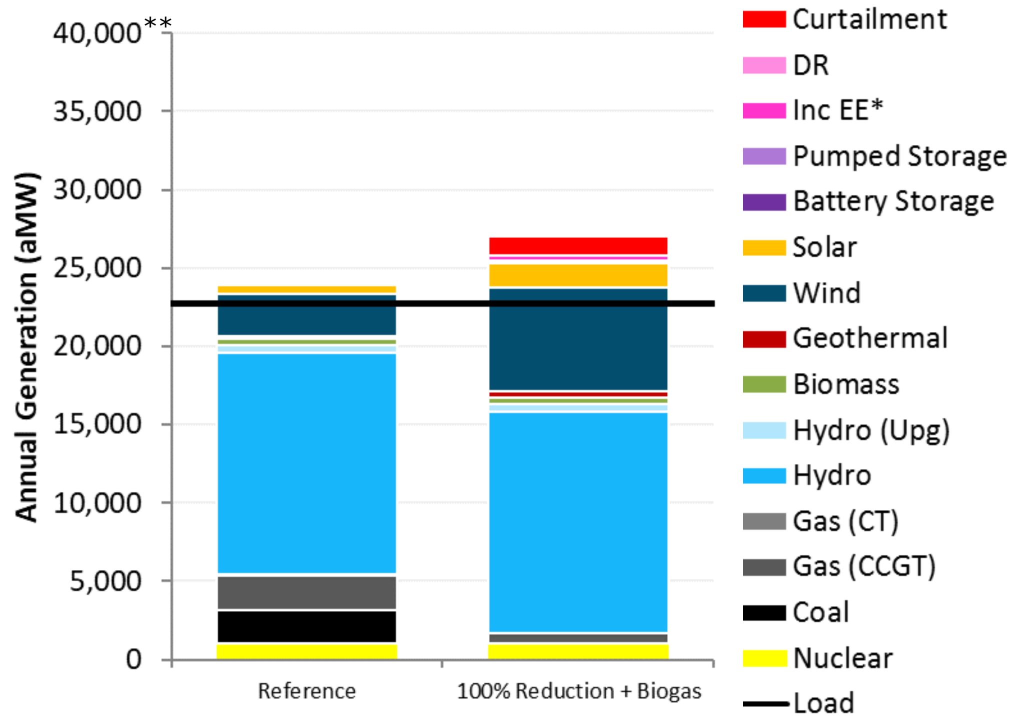
- 21 GW of new renewable capacity added by 2050
- 41 Tbtu of pipeline biogas used in gas generators in 2050
- Least cost option for meeting a 100% GHG reduction target

Scenario	Inc Cost ($MM/yr.)	GHG Reductions (MMT)	Effective RPS %	Zero CO2 %
Reference	-	-	20%	91%
100% Reduction + Biogas	+$3,264	27.6	44%	115%

Resources Added (MW)



Energy Balance (aMW)

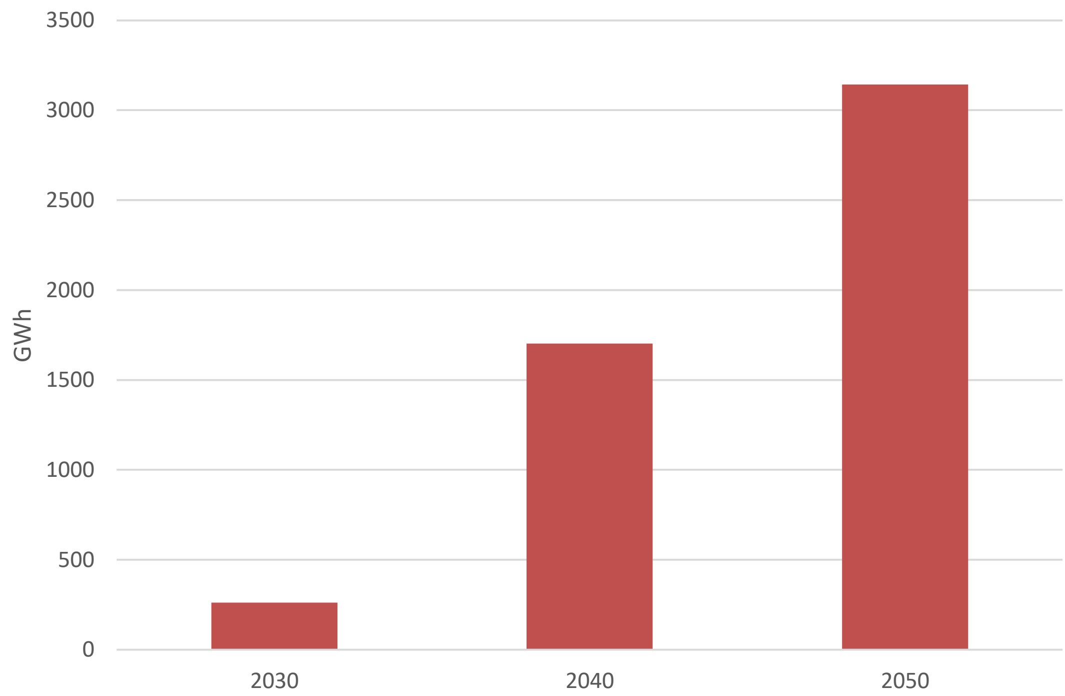


**Note the change in the Y-axis scale change

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

Efficiency Incremental to Projections

- Model relies on conservative EE supply curve from NWPCC without accounting for new technology or improved methods of measuring and valuing
- Represents a 7% increase over current projections



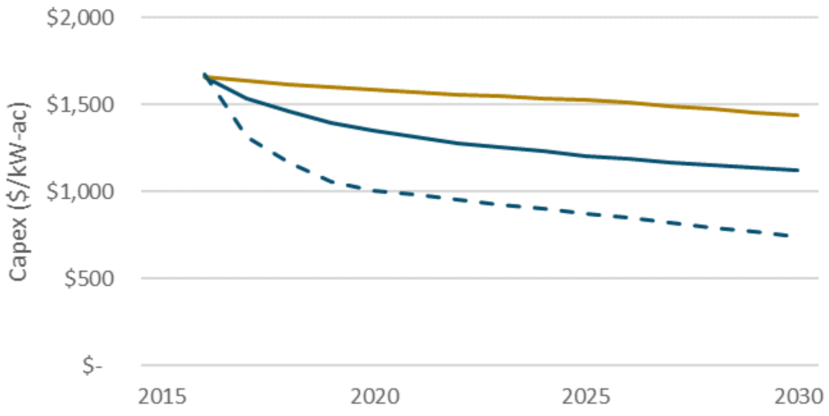
Alternative Technology Cost Sensitivity

+ **In the Alternative Technology Cost sensitivity, this study explores potential increased cost reductions for emerging technologies:**
  - **Solar PV :** capital costs updated using low cost projections for NREL 2017 Annual Technology Baseline (ATB)*
  - **Land based wind:** capital costs reduced by 20% relative to the Base Case
  - **Battery storage:** capital costs reduced by 70% relative to the Base Case. Derived using Lazard LCOS 3.0**
  - **Biogas:** fuel cost of biogas reduced by 20% relative to the Base Case
+ **Sensitivity captures the potential impact of technological breakthrough on the optimal renewable portfolio for the Northwest**

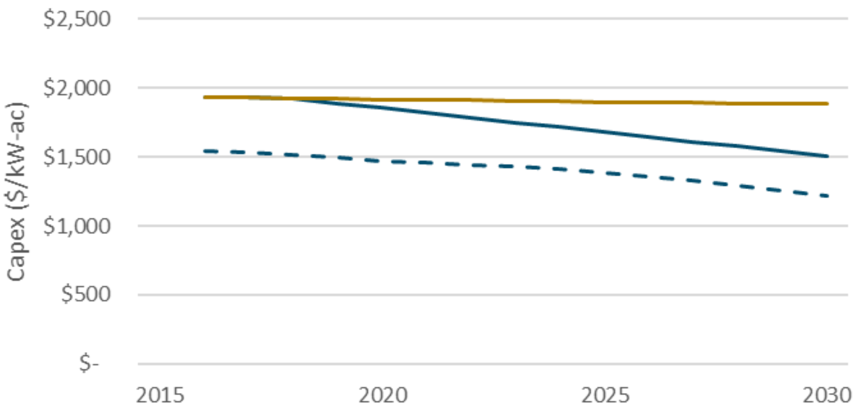
*NREL 2017 Annual Technology Baseline: https://atb.nrel.gov/electricity/2017/
**Lazard Levelized Cost of Storage 3.0: https://www.lazard.com/media/

Alternative Technology Cost Trajectories

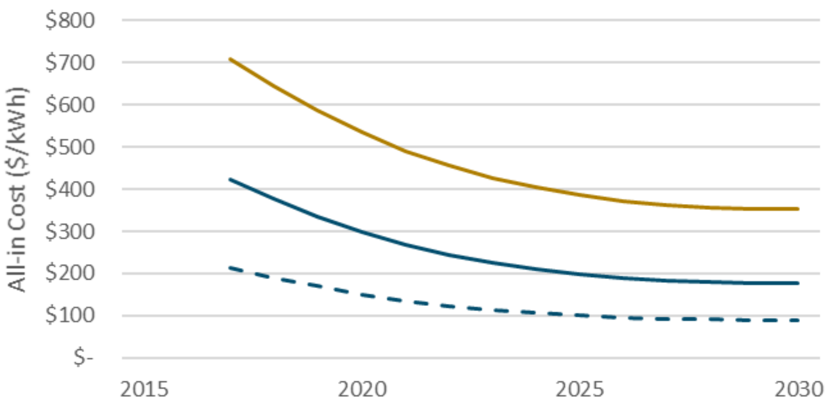
Solar PV – WA/OR



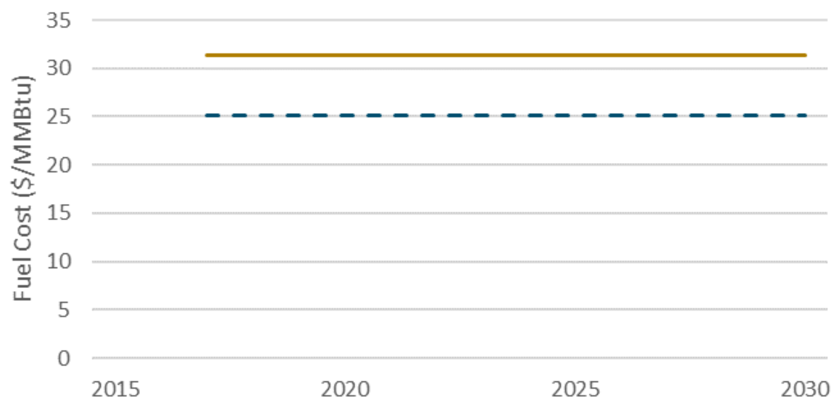
Land Based Wind – Columbia River Basin



Battery Storage – 4-hr Storage



Pipeline Biogas



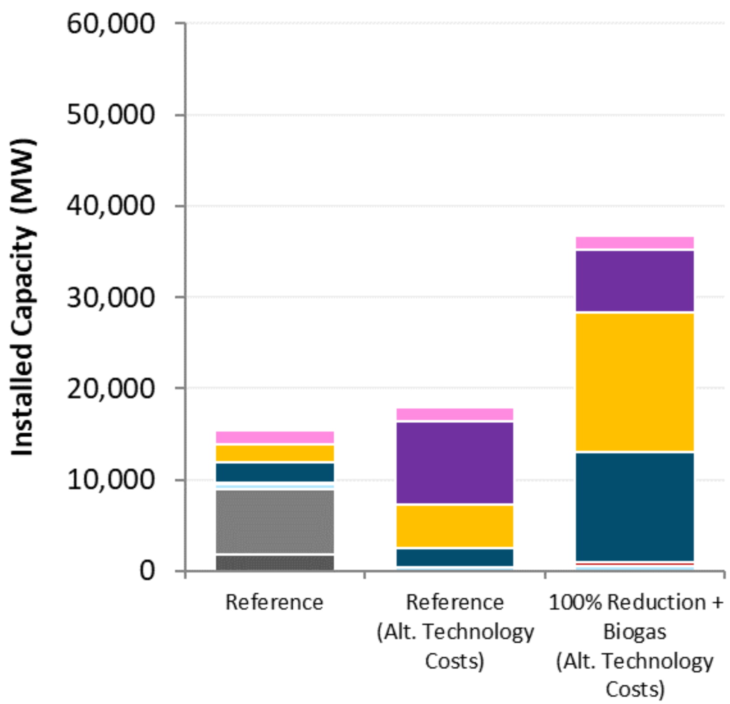
– Original PGP Study Base; – Original PGP Study Low Tech Costs; **- - - Climate Solutions Alt. Tech Costs**

2050 Portfolio Summary – Climate Solutions
Alternative Technology Costs Sensitivity

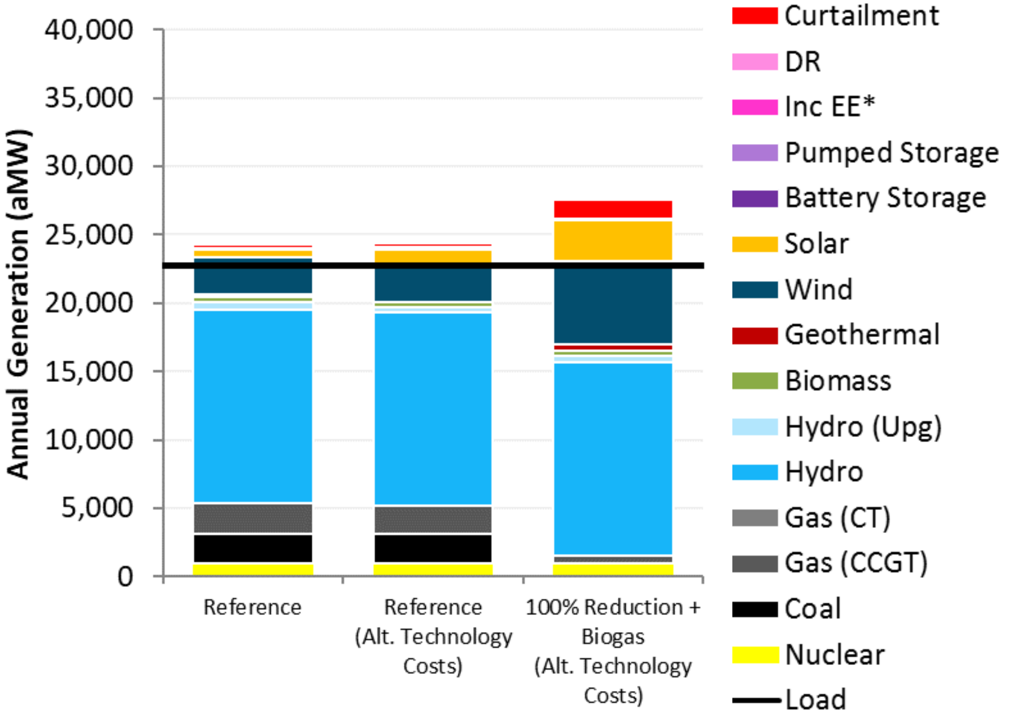
Summary
- 7 GW of renewable capacity and 9 GW of storage capacity are added by 2050 in the Reference Scenario
- 28 GW of renewable capacity and 7 GW of storage capacity are added by 2050 in the 100% Reduction WWGS + Biogas Scenario

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)



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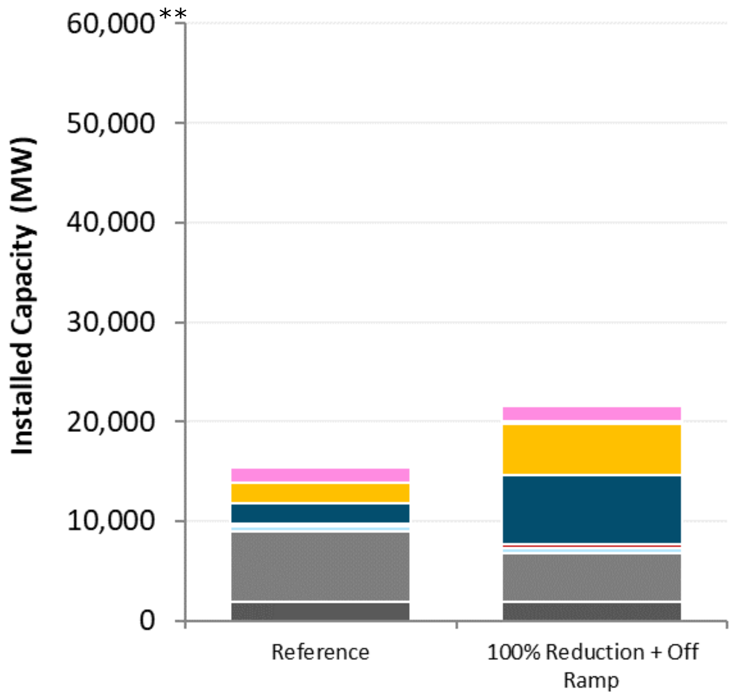
2050 Portfolio Summary
100% Reduction + Off-Ramp

Highlights

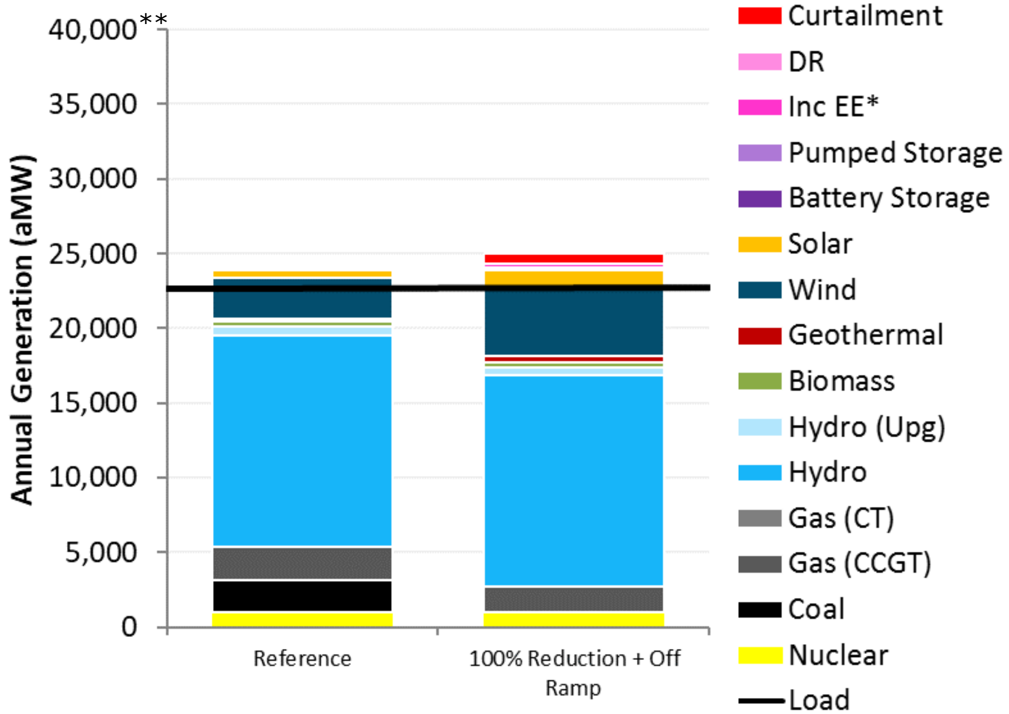
- 7 GW of gas capacity added by 2050
- 13 GW of new renewable capacity added by 2050
- Results in over 80% GHG reductions relative to 1990 levels

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%

Resources Added (MW)



Energy Balance (aMW)



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

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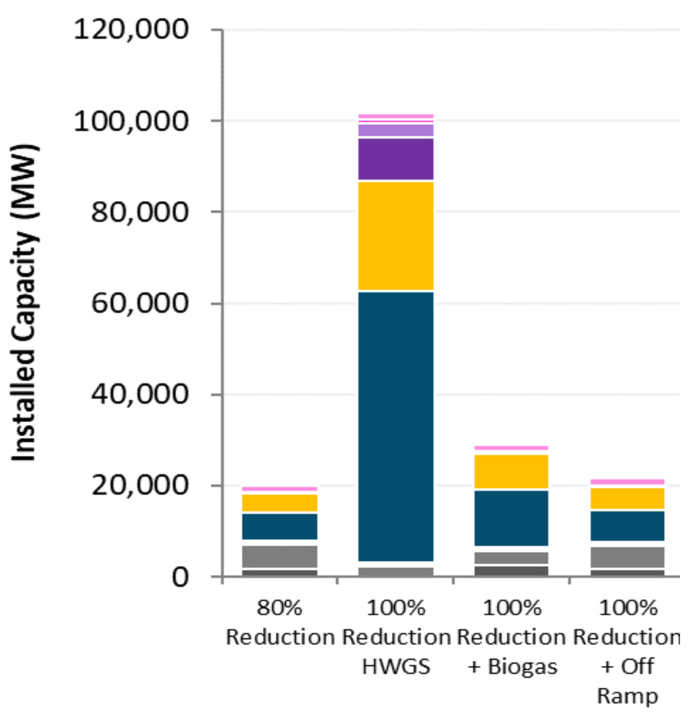
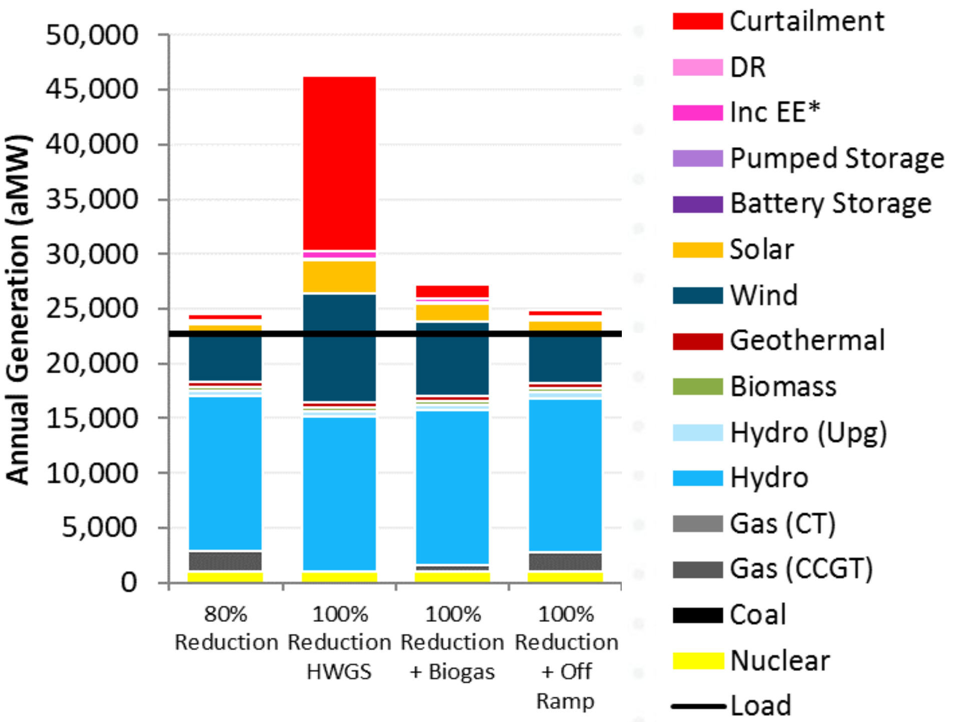
Comparison of Additional Scenarios

Resources Added (MW)



Energy Balance (aMW)



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

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2050 Scenario Summary
All Scenarios and Sensitivities

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 HWGS	+$18,377	27.6	$665	62%	135%	14,901
100% Reduction + Biogas	+$3,264	27.6	$118	45%	116%	1,082
100% Reduction + Off-Ramp	+$1,148	21.8	$53	33%	104%	591
100% Reduction + SMR	+$6,574	27.6	$238	37%	130%	852
Alternative Technology Costs Sensitivity						
Reference (Base Case)	+$818	-0.3	—	21%	91%	201
Reference	—	—	—	21%	92%	277
100% Reduction + Biogas	+$2,165	27.3	$79	47%	119%	1,354

Key Takeaways

- We can achieve 100% fossil-free energy with existing technologies
- Using renewable natural gas for integration presents the least-cost pathway for eliminating fossil fuels from the electricity sector
- 100% fossil-free electricity in WA and OR will reduce over 27MMTCO2e beyond BAU