EXH. JJJ-5
DOCKETS UE-22___/UG-22___
2022 PSE GENERAL RATE CASE
WITNESS: JOSHUA J. JACOBS

BEFORE THE
WASHINGTON UTILITIES AND TRANSPORTATION COMMISSION

WASHINGTON UTILITIES AND TRANSPORTATION COMMISSION, Complainant, v. PUGET SOUND ENERGY, Respondent.	Docket UE-22____ Docket UG-22____

FOURTH EXHIBIT (NONCONFIDENTIAL) TO THE
PREFILED DIRECT TESTIMONY OF

JOSHUA J. JACOBS

ON BEHALF OF PUGET SOUND ENERGY

JANUARY 31, 2022

Energy+Environmental Economics

E3-PSE Gas LDC Decarbonization

Final Report

October 22, 2020

Dan Aas
Sharad Bharadwaj
Amber Mahone
Arne Olson
John Stevens
Greg Von Wald

PSE operates in a state committed to GHG emissions reductions

- **E3 has a long track-record supporting PSE's work to identify the implications of meeting WA's increasingly aggressive GHG reduction goals**
- **This phase of work is focused on PSE's gas LDC, key questions include:**
  - What are expected cost ranges in 2030 and 2045 for decarbonized gases (RNG and hydrogen)?
  - What are the electric system impacts of decarbonizing PSE's gas LDC?
  - What are the consumer costs associated with different gas LDC decarbonization strategies?
  - How can energy efficiency, electrification and RNG be utilized in concert to reduce the costs of achieving deep GHG reductions in PSE's gas LDC

Scenarios were designed to be consistent with the PSE 2030 effort

- ***Gradual Replacement:*** a scenario where PSE's gas LDC sees a moderate amount customer attrition and where RNG is blended in limited quantities.
- ***Peaky Electric:*** this scenario assumes large scale electrification of PSE's residential and commercial customers, RNG is blended in limited quantities.
- ***Carbon Out – Managed***: the same amount of electrification as the preceding scenario, but existing customers use hybrid heat pumps. RNG is blended in higher quantities.
- ***Carbon Out – Accelerated:*** like the preceding scenario, but on a more aggressive timeframe.

The geographic scope of this analysis is the PSE's gas LDC, including both its combined and gas only service territories

Four gas LDC decarbonization scenarios, aligned with BCG PSE 2030

	Gradual Replacement	Peaky Electric	Carbon Out Managed – Hybrids
GHG reduction	48% by 2045	73% by 2045	90% by 2045
PSE customer base	Slow decline	Rapid erosion	Growing (same as BAU)
Heat Pumps – Sales Share	25% by 2030 50% by 2040 ***All-electric***	50% 2030; 100% 2040 ***All-electric***	50% 2030; 100% 2040 ***Hybrid***
Industry electrification	10% by 2050	10% by 2050	30% by 2050
RNG and hydrogen	5% RNG 2030; 20% RNG 2040	5% RNG 2030; 20% RNG 2040	20% RNG in 2030; RNG, as needed to meet GHG target in 2045

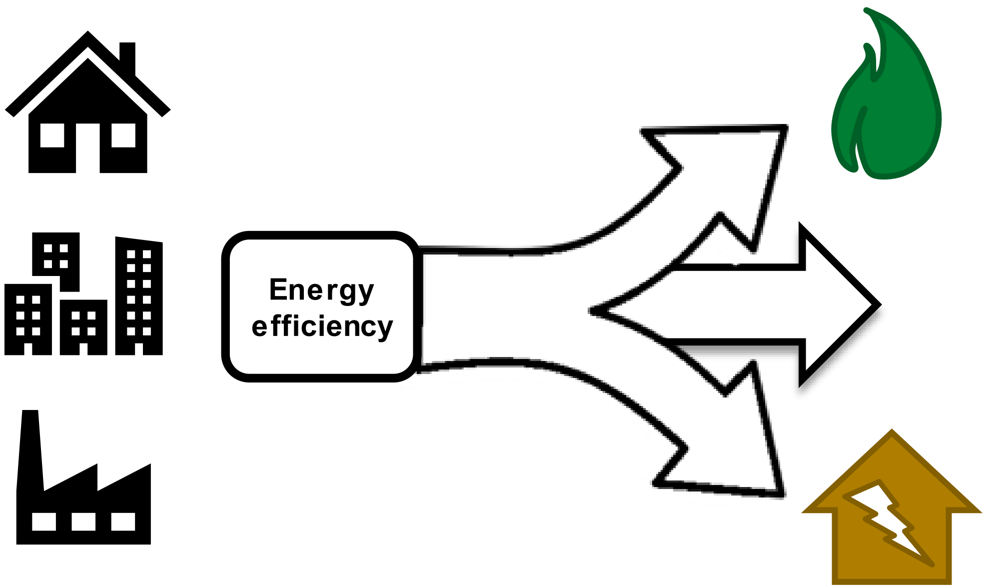
E3 modelled scenarios using the PATHWAYS model

Model functionality		Outputs
End-use Infrastructure and Demand	Stock-rollover accounting of changes in customer demands in each scenario	• Throughput • Electrification loads • Customers • Demand-side costs
Electric Infrastructure Module	Analysis of hourly electrification impacts & sector costs. Draws from CETA compliant cases from E3's RESOLVE model.	• Peak loads by end-use • Bulk system portfolio costs • T&D infrastructure costs
RNG Supply Module	Least-cost biofuels optimization model, hydrogen and SNG production costs	• Biofuels production by feedstock • Infrastructure builds and RNG production costs

+ Scenarios are summarized in terms of a Total Resource Cost Metric, that includes:

- **Consumer expenditures**: panel upgrades, furnaces, heat pumps, air conditioning ….
- **Electric infrastructure**: CETA compliant MWhs, peak capacity, T&D upgrades
- **Fuels**: RNG procurement, avoided natural gas

Options to decarbonize PSE's gas LDC



Decarbonized gas
Renewable natural gas or hydrogen

Hybrid
Heat pumps paired with gas

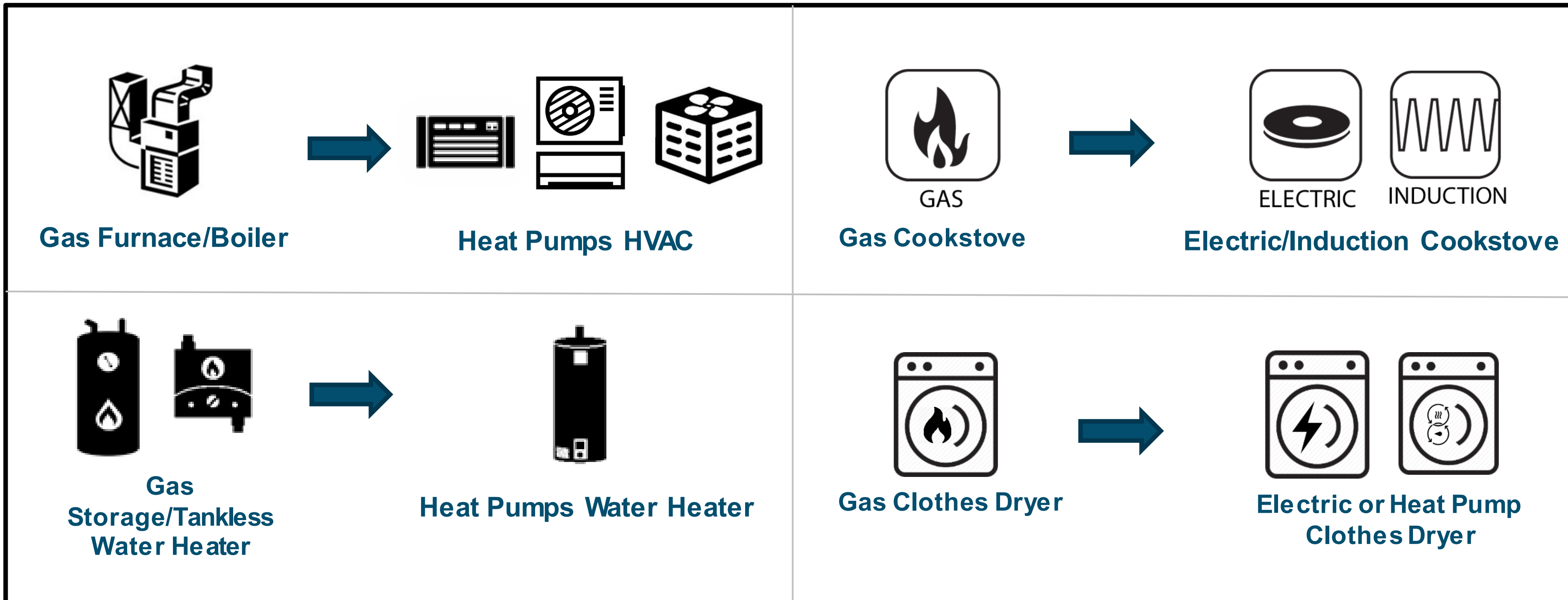
Electrification
Heat pumps, induction stoves

+ There are multiple different strategies to achieve deep emissions reductions in PSE's gas LDC. Each have advantages and drawbacks.

Types of electrification

- Electrification leverages a decarbonizing electricity system to displace gas combustion emissions
- Building electrification could sharply reduce demands on PSE's gas LDC and add substantial loads to PSE and neighboring utilities' electricity systems.

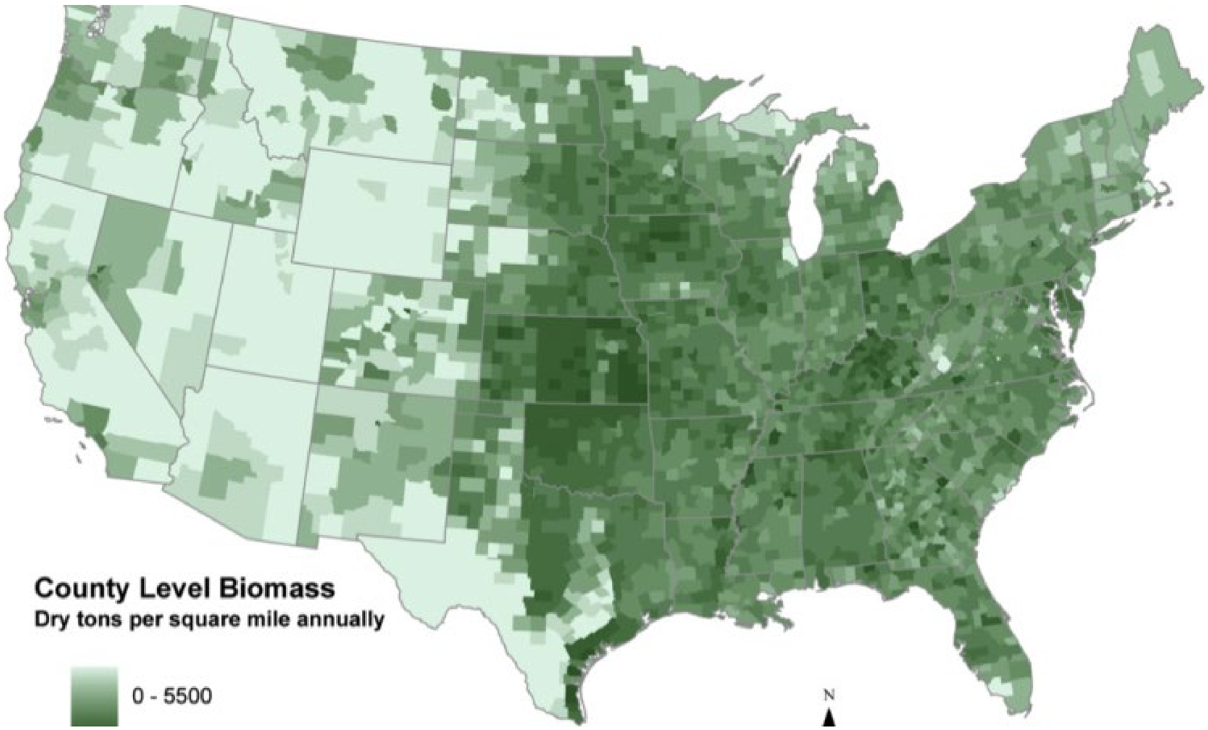
Building Electrification Technologies



Note: industry electrification is also possibly for (mostly) lower-temperature end-uses, such as electric boilers for steam supply, heat pumps can be for low/medium temperature heat applications and electric furnaces are possible for certain high heat industrial processes.

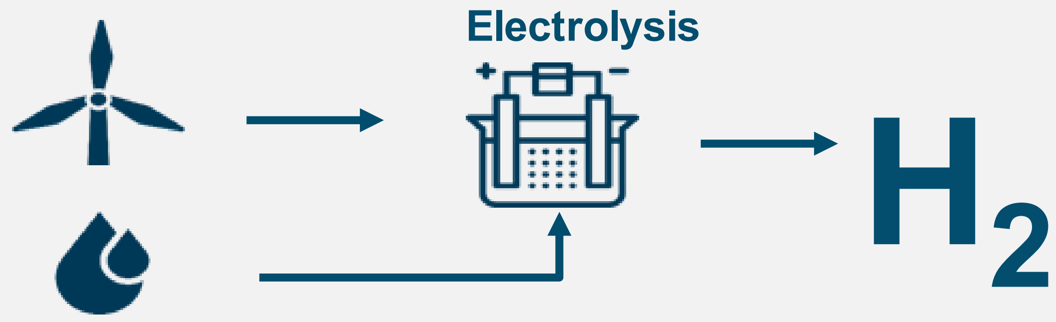
Biomethane is the lowest cost-form of decarbonized gas, but is limited in quantity

+ **E3 derives biomass estimates from a variety of sources:**
  - **National**: US Department of Energy *Billion Ton Report*
  - **Washington**: WSU Energy Program *Harnessing Renewable Natural Gas for Low-Carbon Fuel: A Roadmap for Washington State*
  - **Oregon:** OR Department of Energy *Biogas and Renewable Natural Gas Inventory*



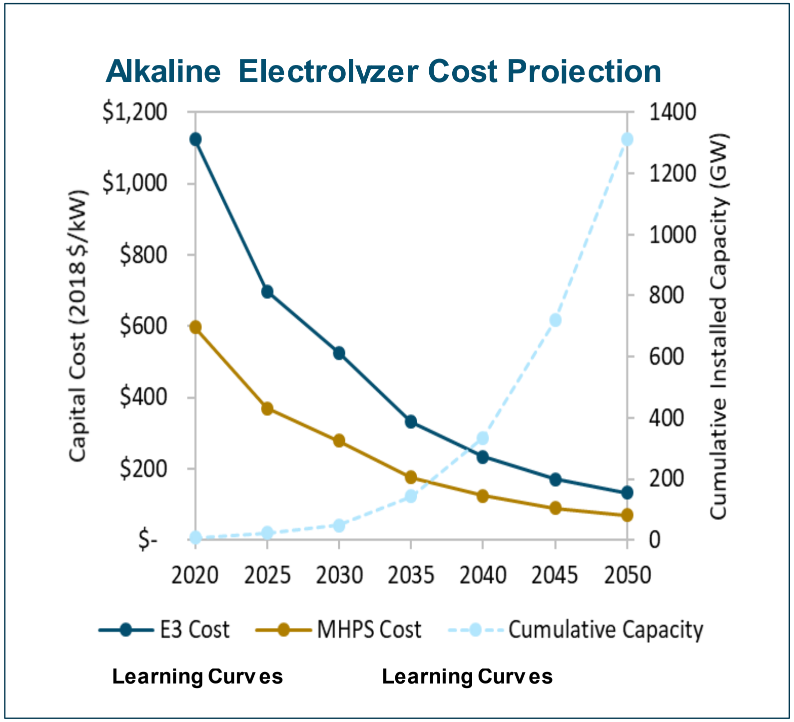
What about hydrogen?

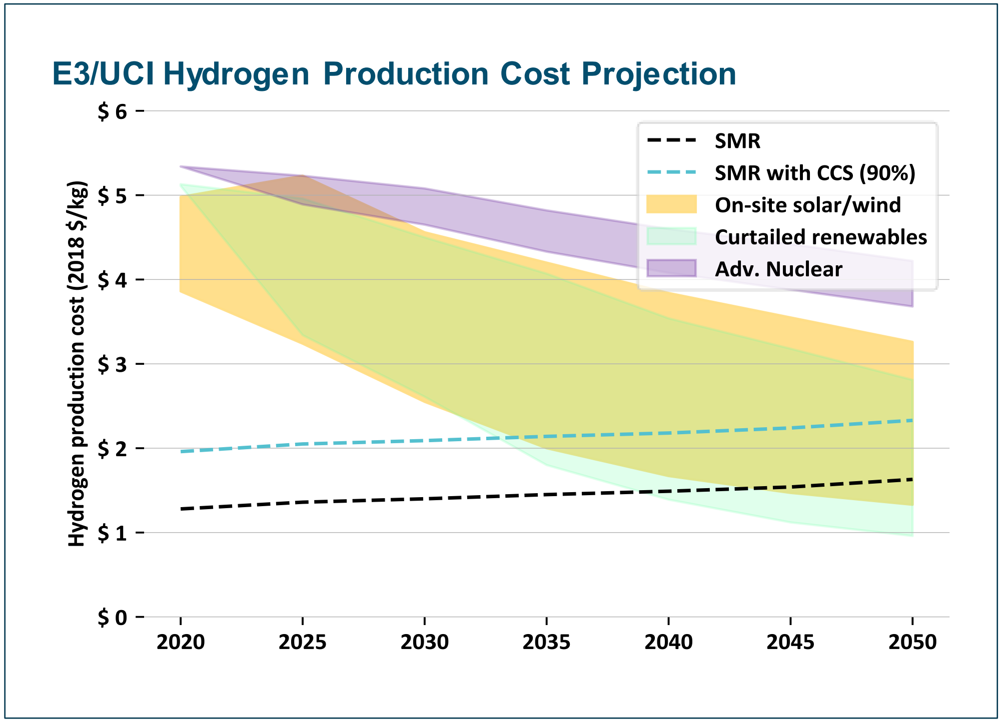
“Green” Hydrogen



“Blue” Hydrogen

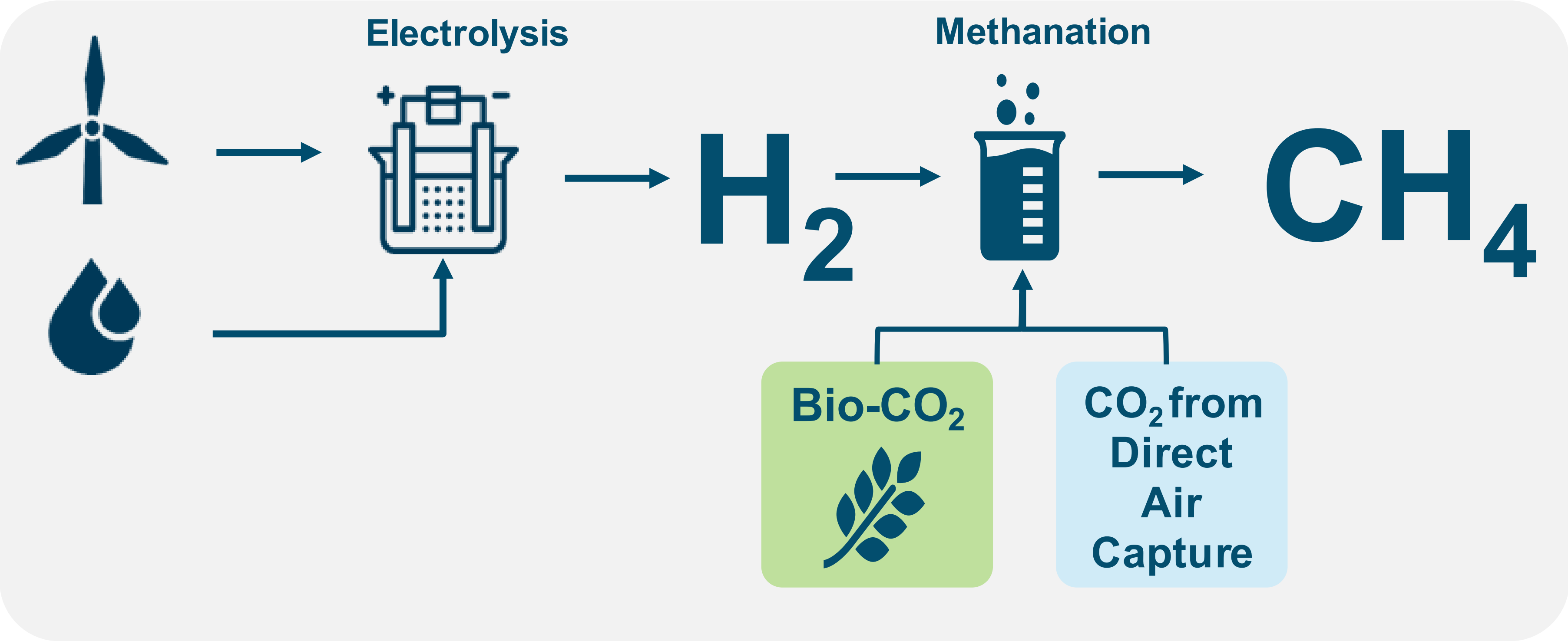
Hydrogen production costs are expected to decline





- E3 recently published a report on potential opportunity for renewable hydrogen in a deeply decarbonized future with Mitsubishi Hitachi Power Systems (MHPS)
- Electrolysis with renewable power may be more economic than SMR with CCS if electrolyzer costs fall with an aggressive learning rate of 25% and curtailed renewables are available at close to zero cost

Synthetic natural gas (SNG) production



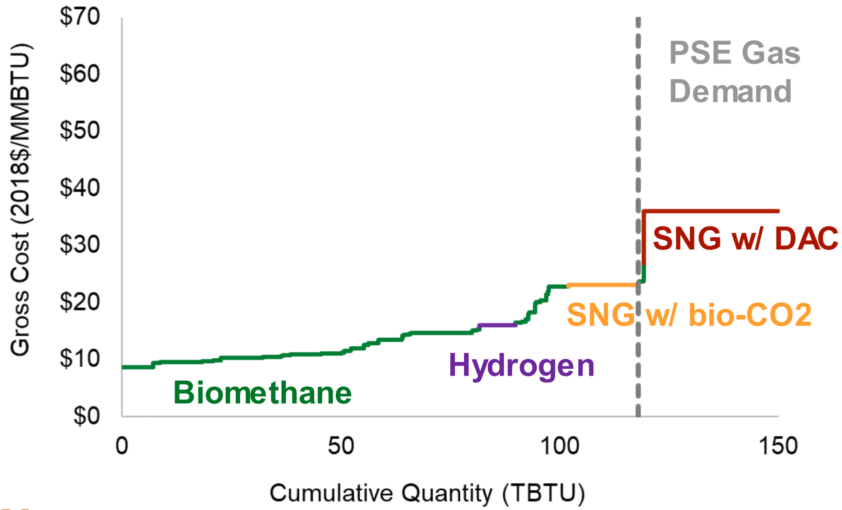
- SNG (also called Power-to-Methane) production requires a combination of climate neutral hydrogen and climate neutral CO2.
- E3 considers two sources of climate neutral CO2: 1) less costly bio-CO2 from biofuels production, 2) more costly CO2 from direct air capture.

Sources of decarbonized gas

Biomethane		Power-to-Gas (P2G)	
Waste biogas	**Gasification of biomass**	**Hydrogen**	**Synthetic Natural Gas (SNG)**
Sources: Municipal waste, manure	**Sources:** Agriculture and forest residues, and purpose grown crops, e.g. switchgrass;	**Sources:** Electrolysis + zero-carbon electricity or Steam Methane Reforming of natural gas with Carbon Capture and Sequestration	**Sources:** Renewable hydrogen + CO2 from biowaste (bi-product of biofuel production) and/or direct air capture (DAC)
Constraints: Very limited supply	**Constraints:** Limited supply and competing uses for biofuels	**Constraints:** Limited pipeline blends (7% by energy) without infrastructure upgrades, cost	**Constraints:** Limited commercialization, low round-trip efficiency, high cost

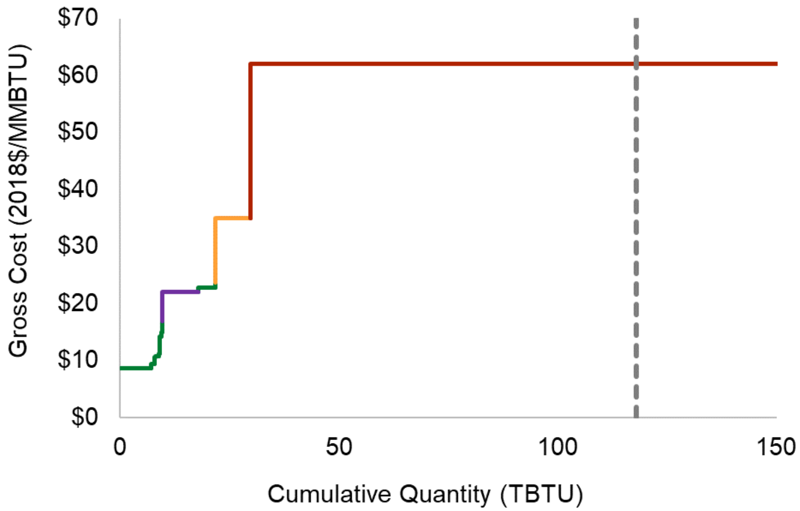
E3 examined a range of decarbonized gas scenarios

Best case



- National biofuels market
- All feedstocks to RNG
- Optimistic P2G capex
- National bio-CO2 availability
- Lower cost DAC

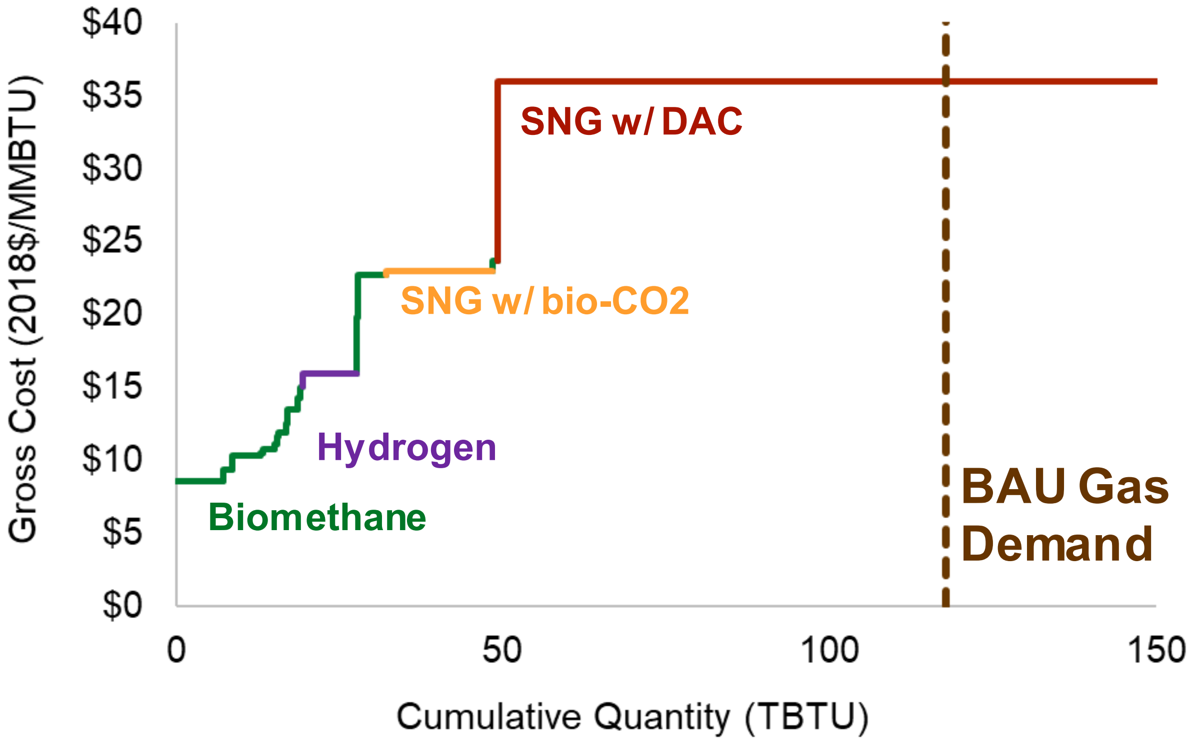
Worst case



- PNW only biofuels market
- Competing demands for feedstocks
- Conservative P2G capex
- PNW bio-CO2
- Higher cost DAC

E3 developed a PSE-specific view of decarbonized gas availability and cost

2050 Decarbonized Gas Supply Curve – E3 "Base Case"

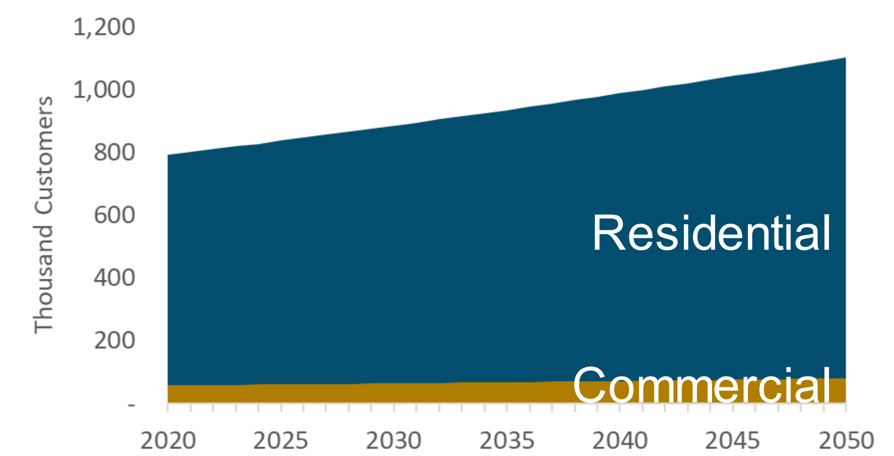


+ This supply curve assumes:

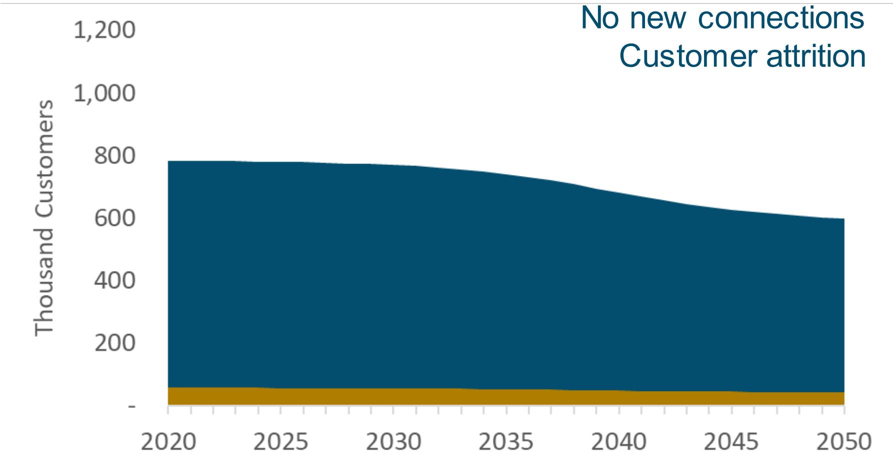
- A limited amount of biomass is available to produce RNG
- There is a competitive national market for biomass
- Steep cost declines in RNG and hydrogen production costs

PSE's customer base in scenarios

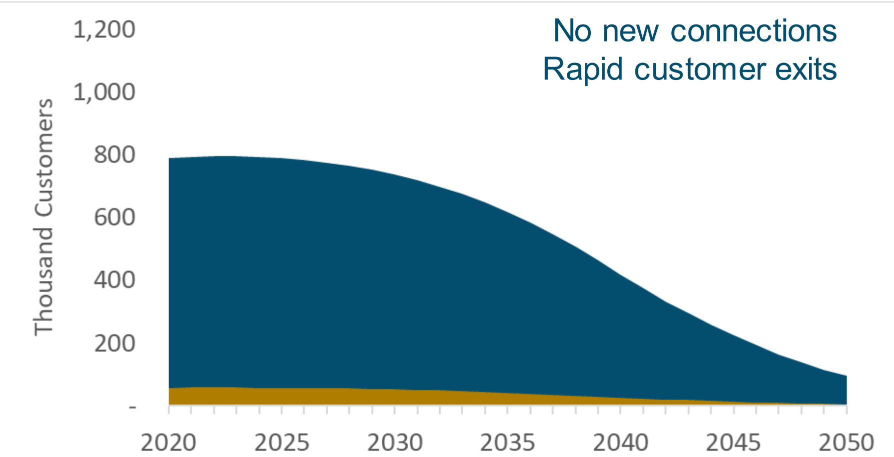
Business as Usual



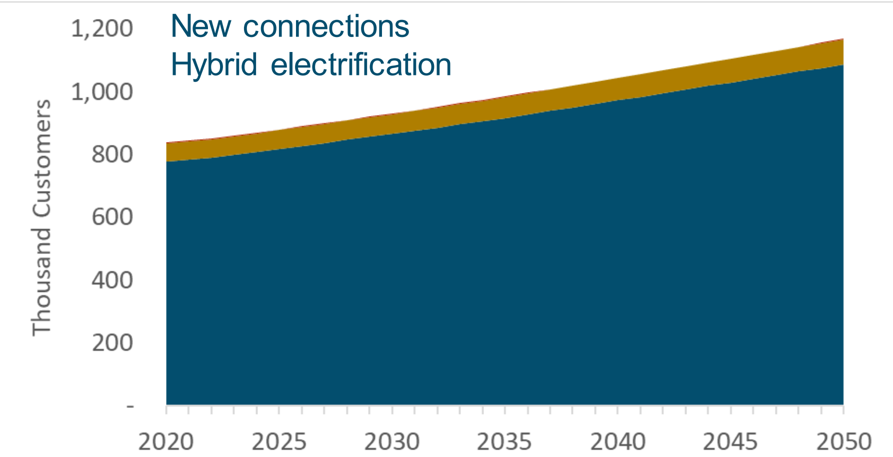
Gradual Transition



Peaky Electrification

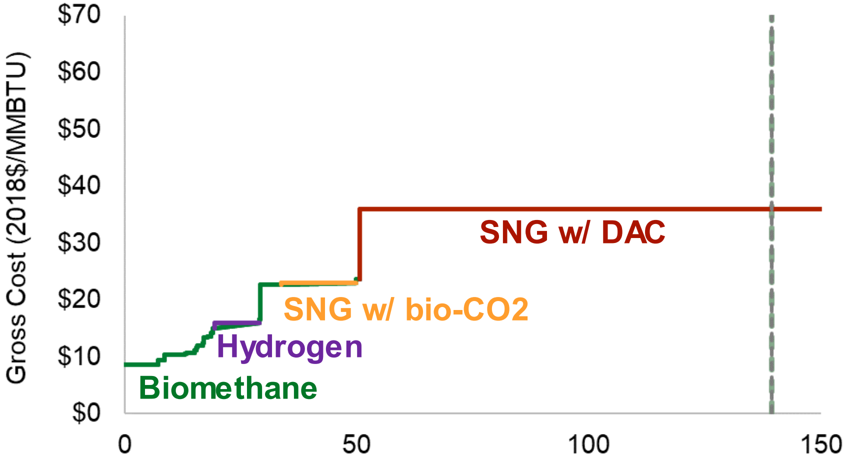


Carbon Out - Managed

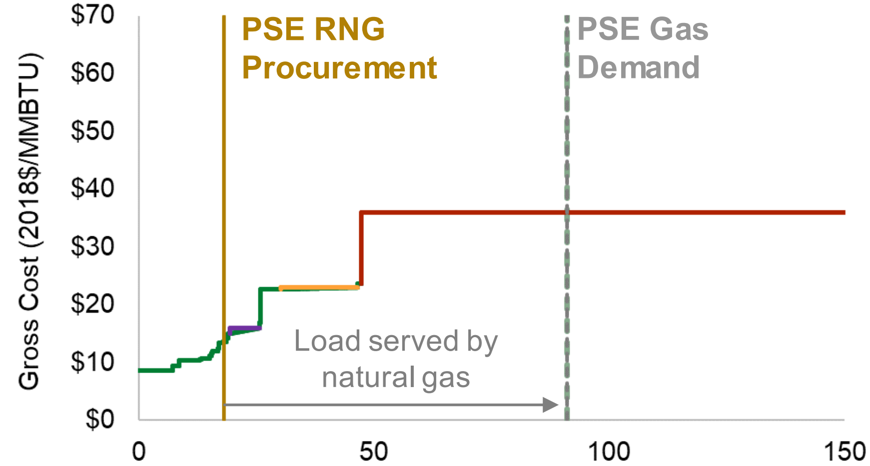


PSE RNG supply and demand by scenario

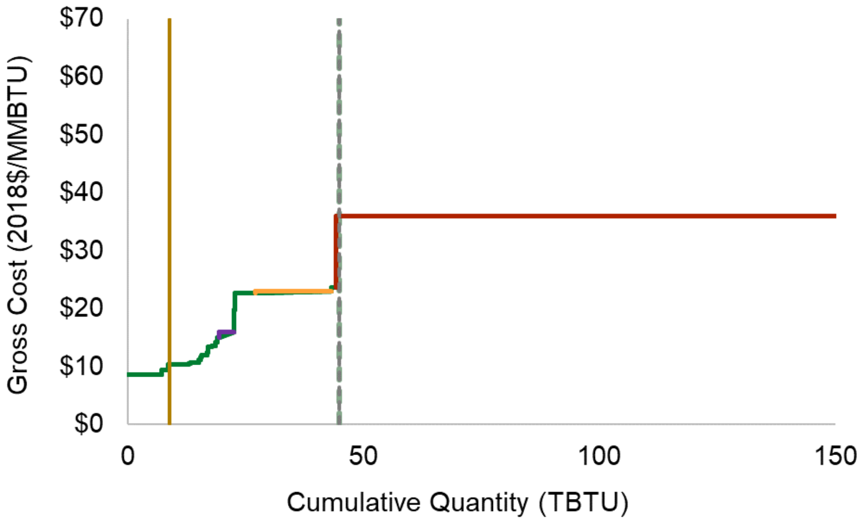
Business as Usual



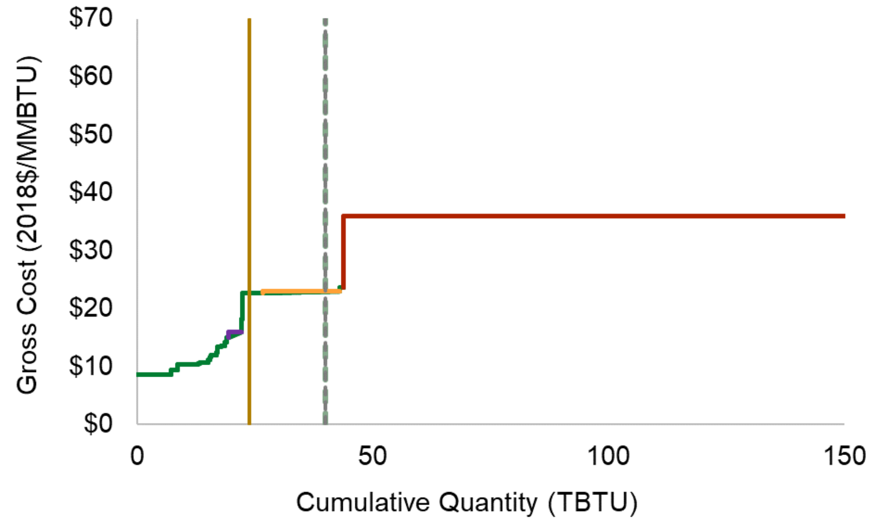
Gradual Transition



Peaky Electrification

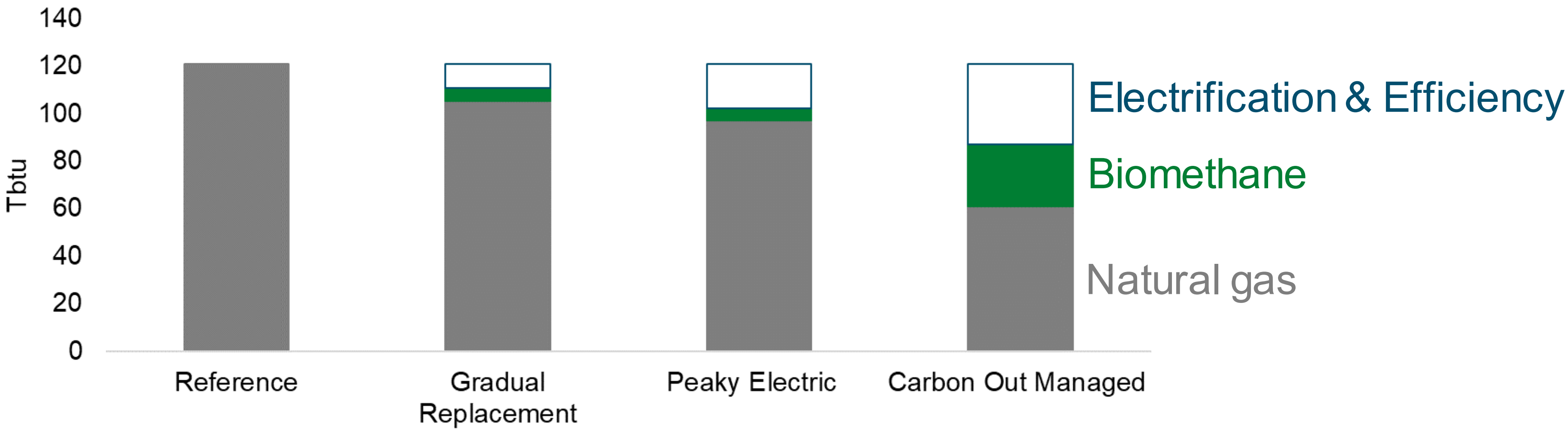


Carbon Out - Managed

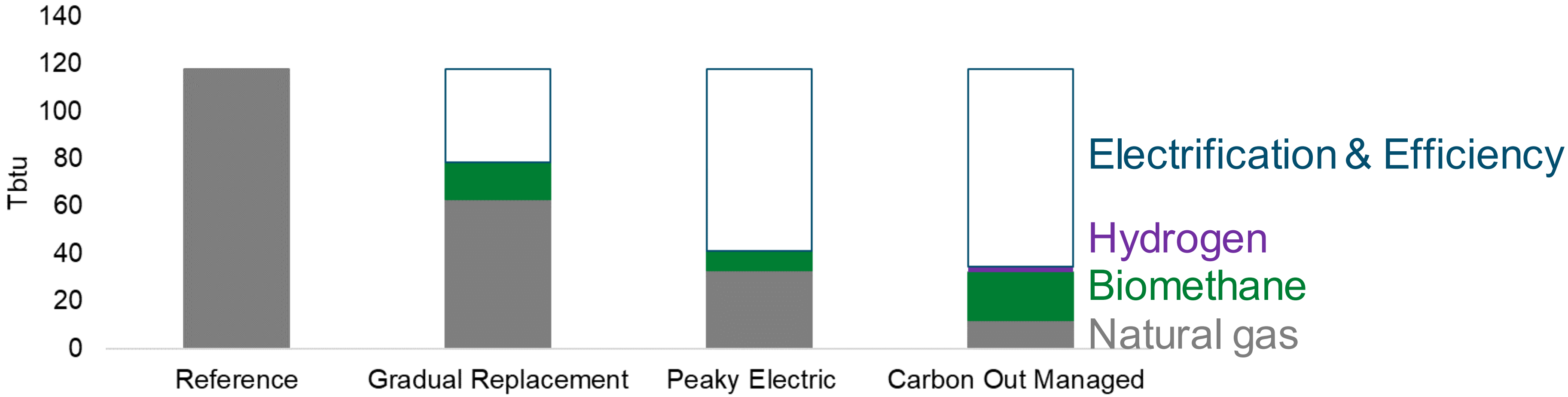


Gas demand and pipeline composition by scenario and year

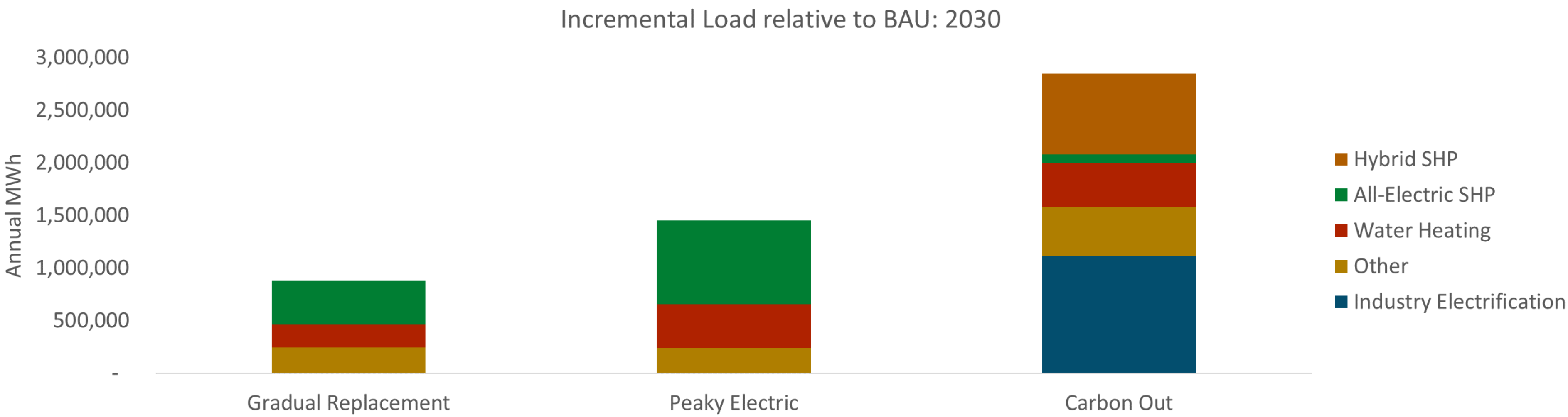
2030

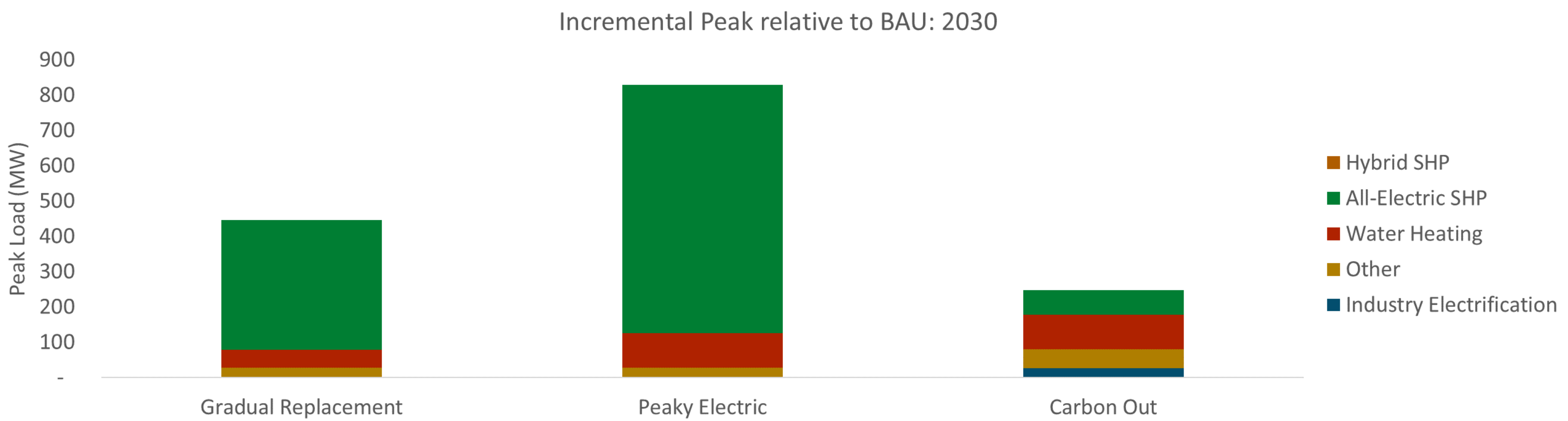


2045

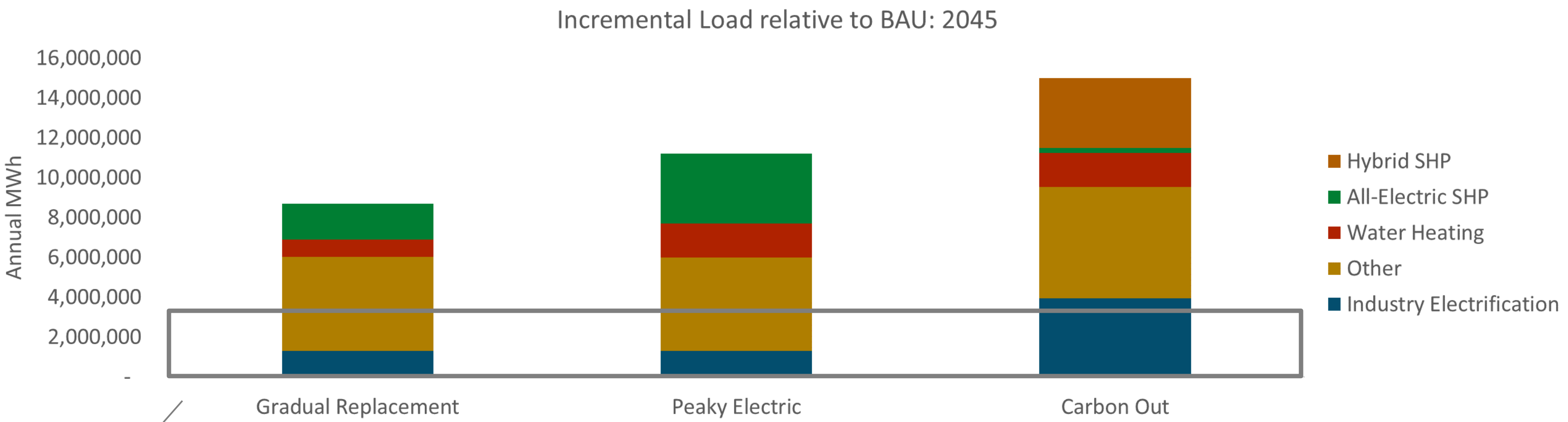


Incremental electricity demand and load: 2030

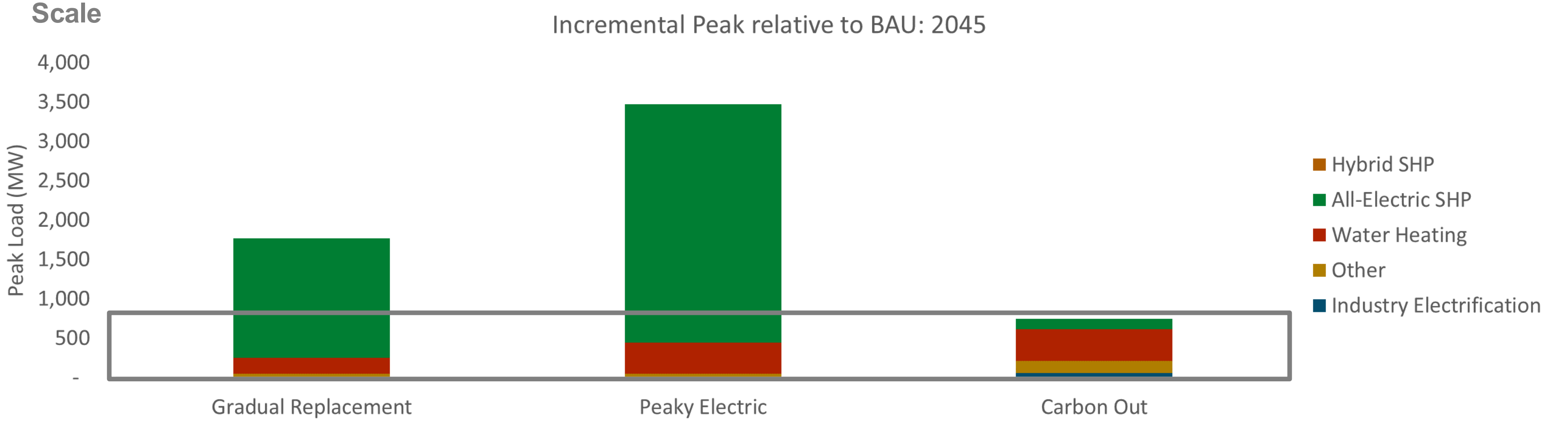




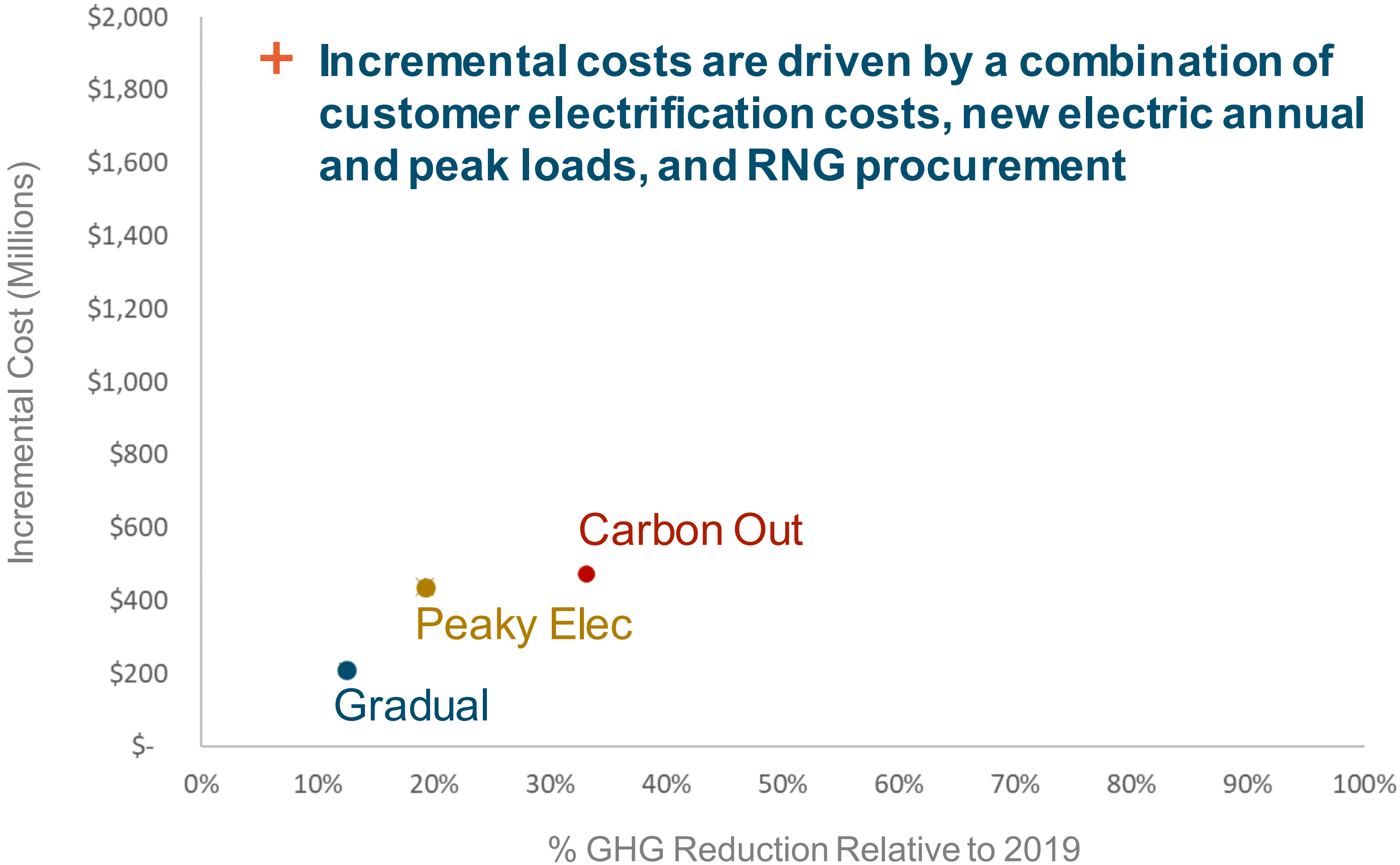
Incremental electricity demand and load: 2045



Previous Scale

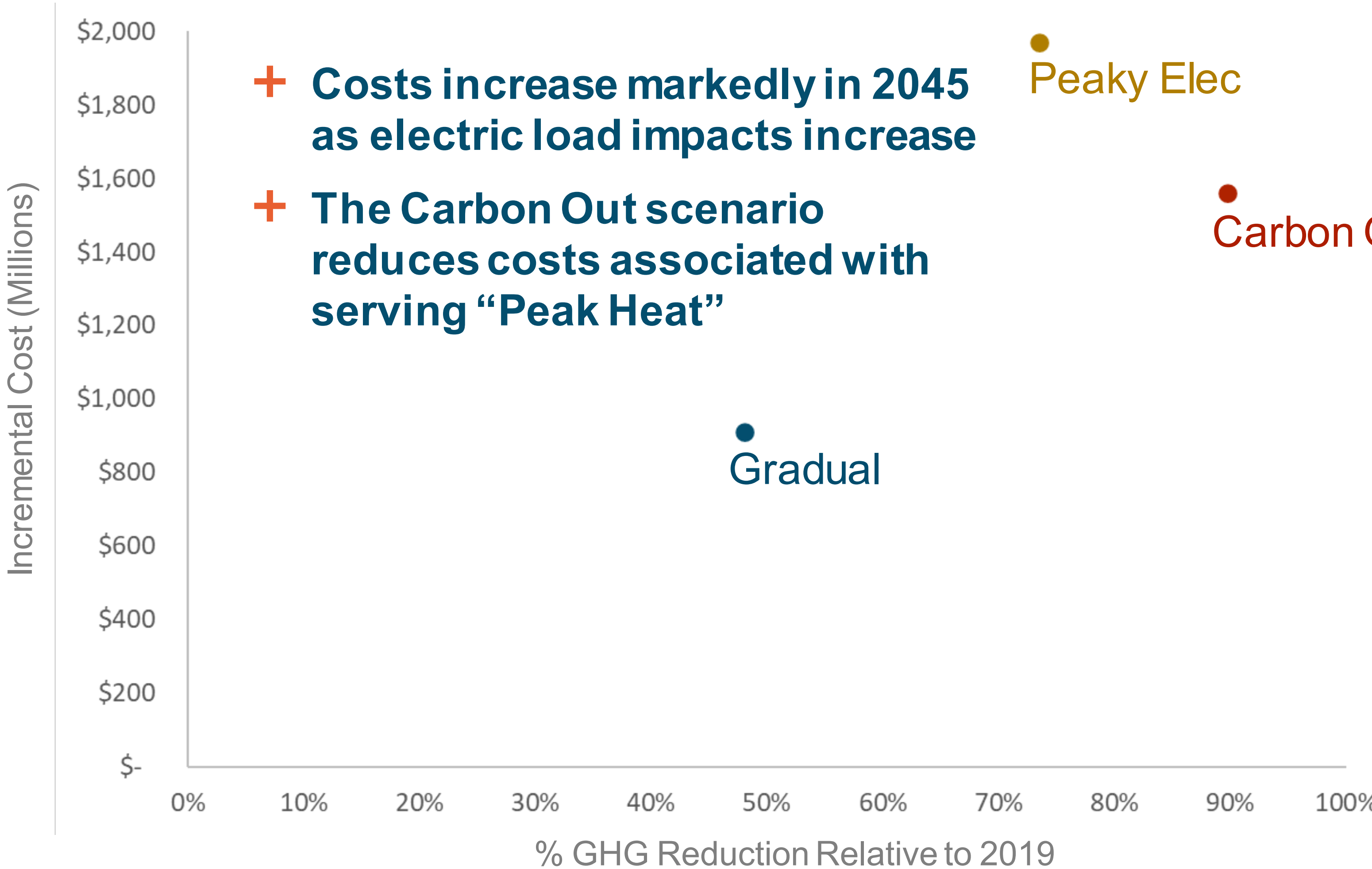


2030 scenario cost summary



+ Incremental costs are driven by a combination of customer electrification costs, new electric annual and peak loads, and RNG procurement

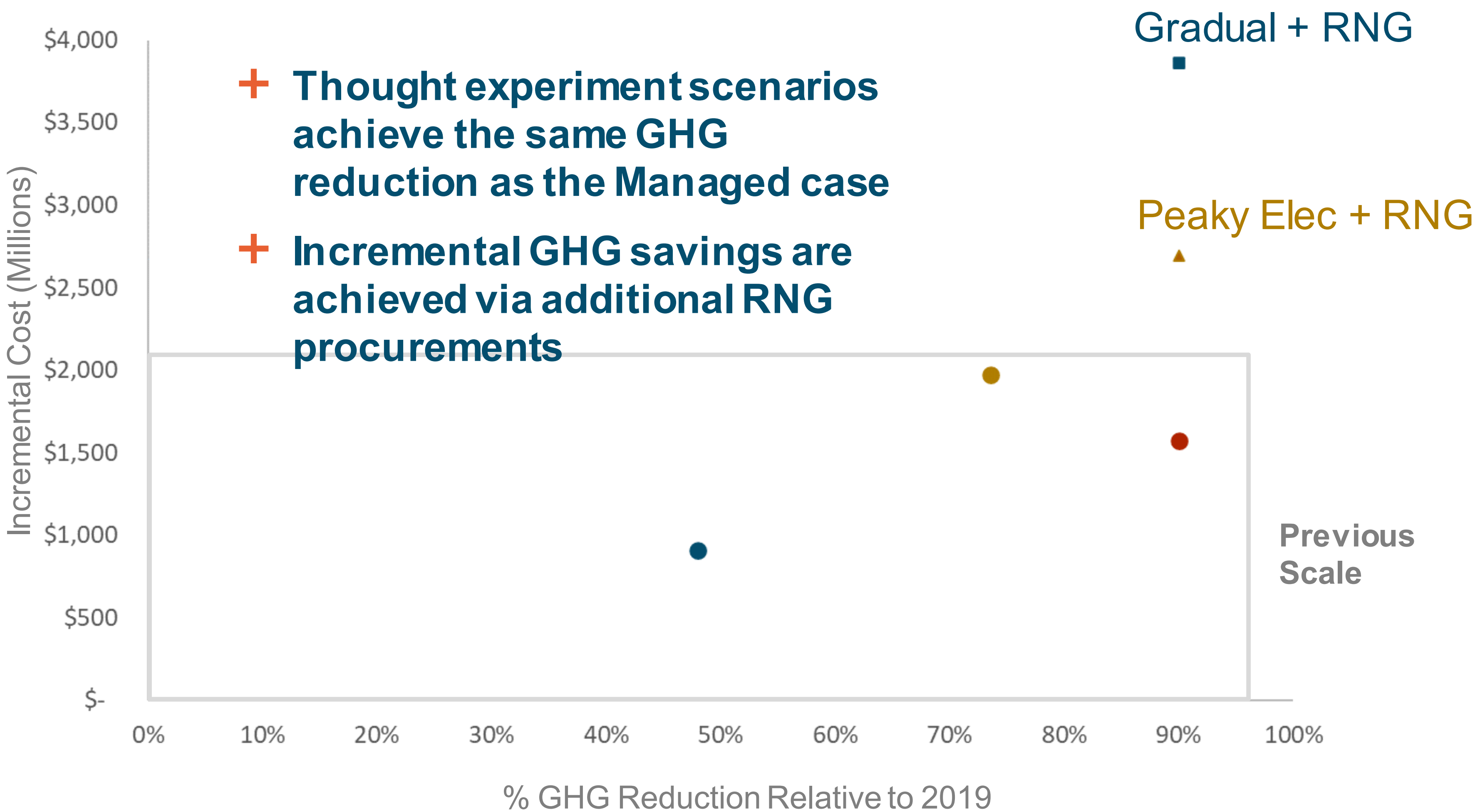
2045 scenario cost summary



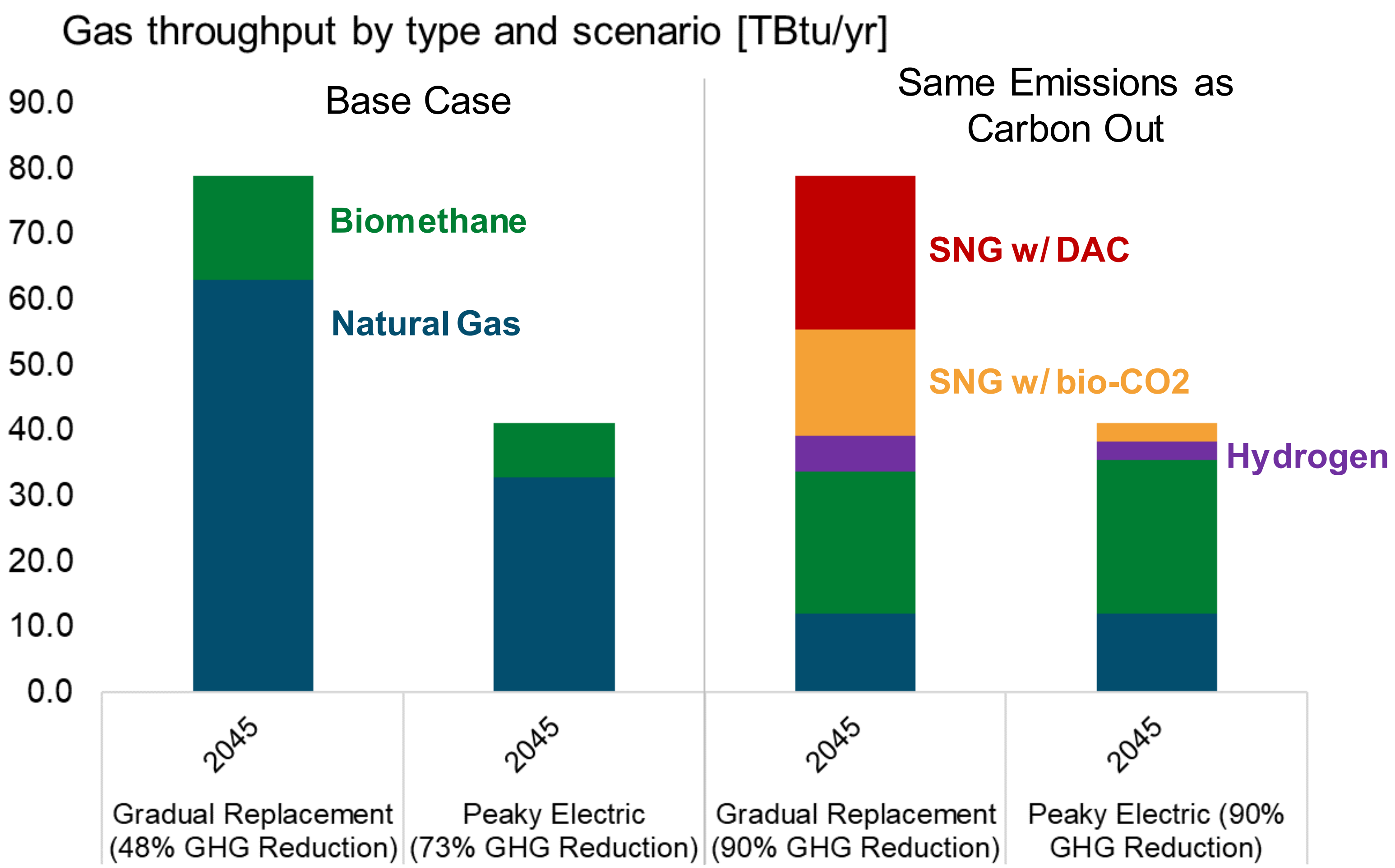
- Costs increase markedly in 2045 as electric load impacts increase
- The Carbon Out scenario reduces costs associated with serving "Peak Heat"

2045 "though experiment" scenario cost summary

- Thought experiment scenarios achieve the same GHG reduction as the Managed case
- Incremental GHG savings are achieved via additional RNG procurements



Costs increases in thought experiment scenarios are driven by costly SNG



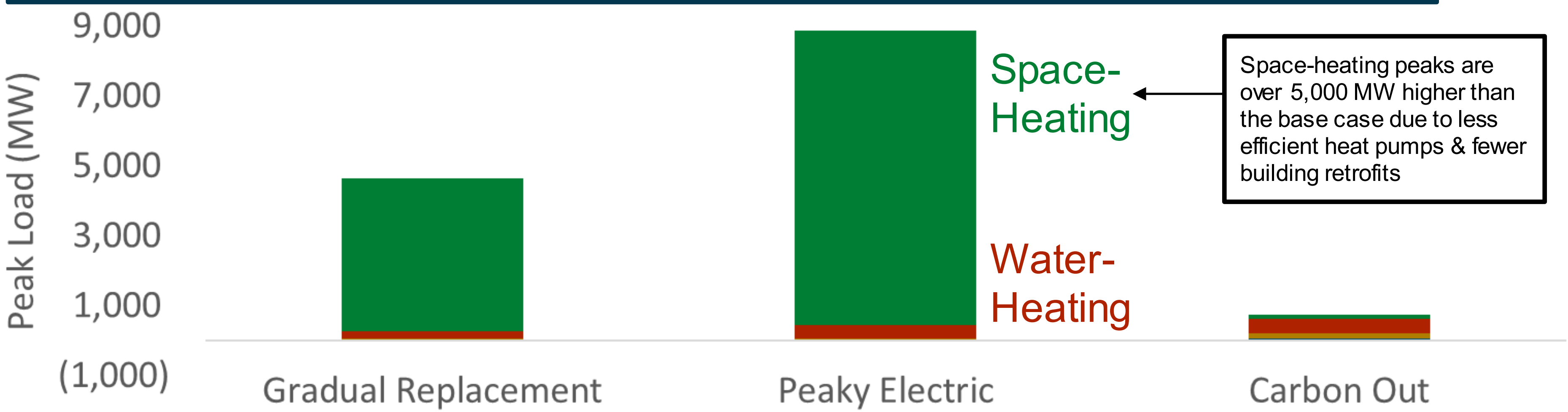
Sensitivity Analysis

Sensitivities

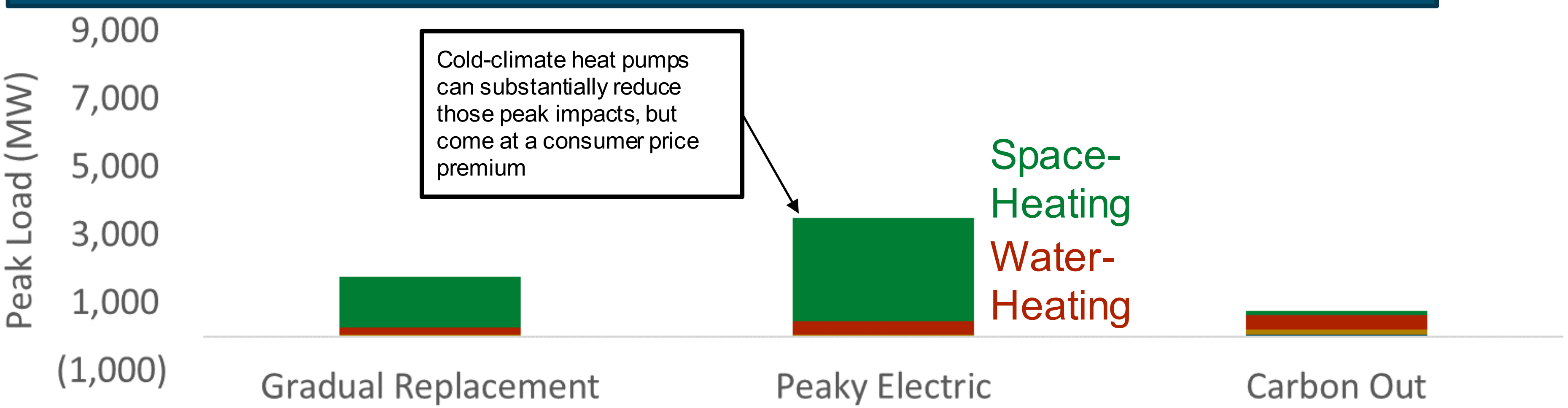
- **"Peakier Electric"**
  - Less efficient, but lower cost, heat pumps on an annual and peak basis. No retrofits of existing buildings.
- **"High Consumer Cost"**
  - Higher incremental costs for heat pumps
- **"Low Consumer Costs"**
  - Lower incremental costs for heat pumps
- **"High RNG Cost"**
  - PSE cannot leverage biomethane produced outside the Northwest, slower learning rate for hydrogen and SNG production costs.

"Peakier Electric" Sensitivity

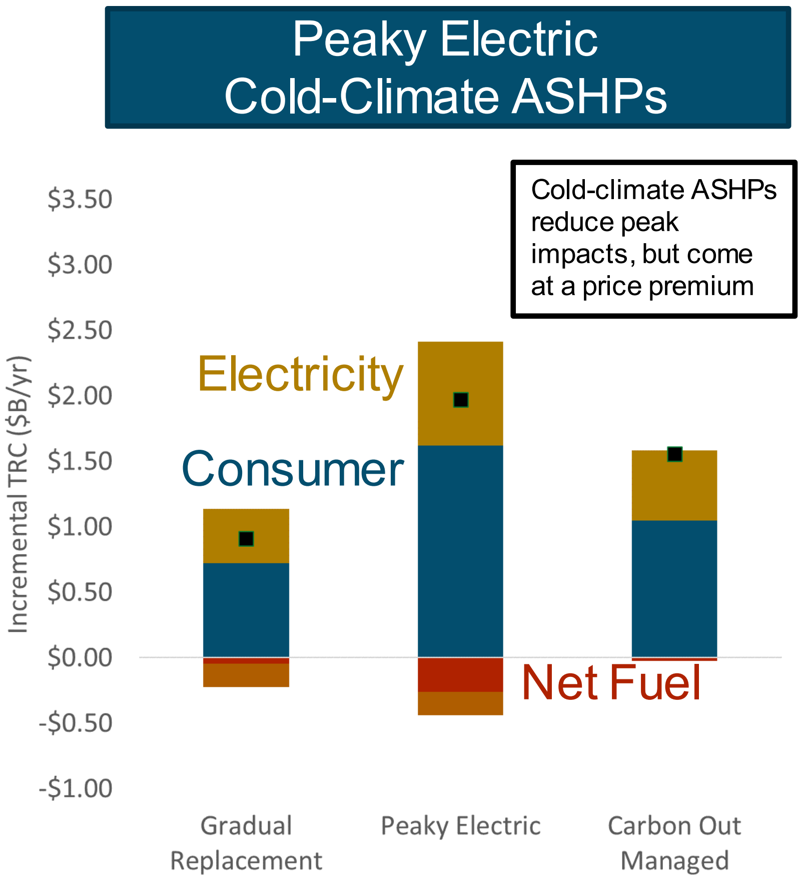
2045 Electric Peak Impacts – "Peakier" Sensitivity

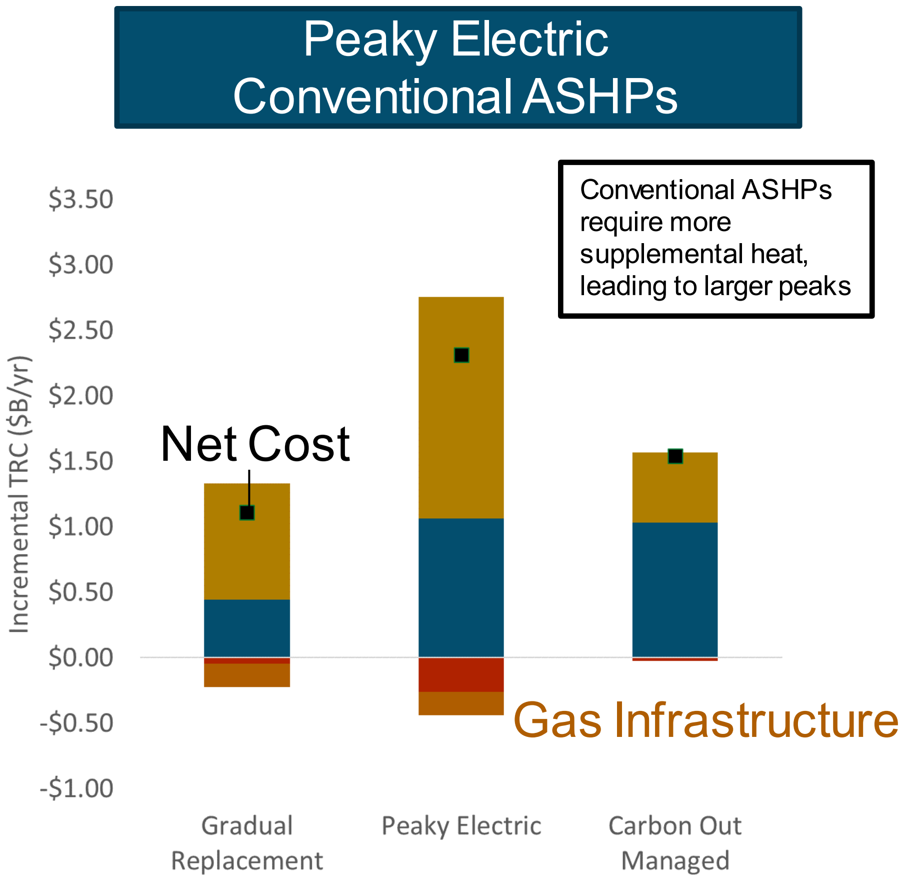


2045 Electric Peak Impacts – Base Case



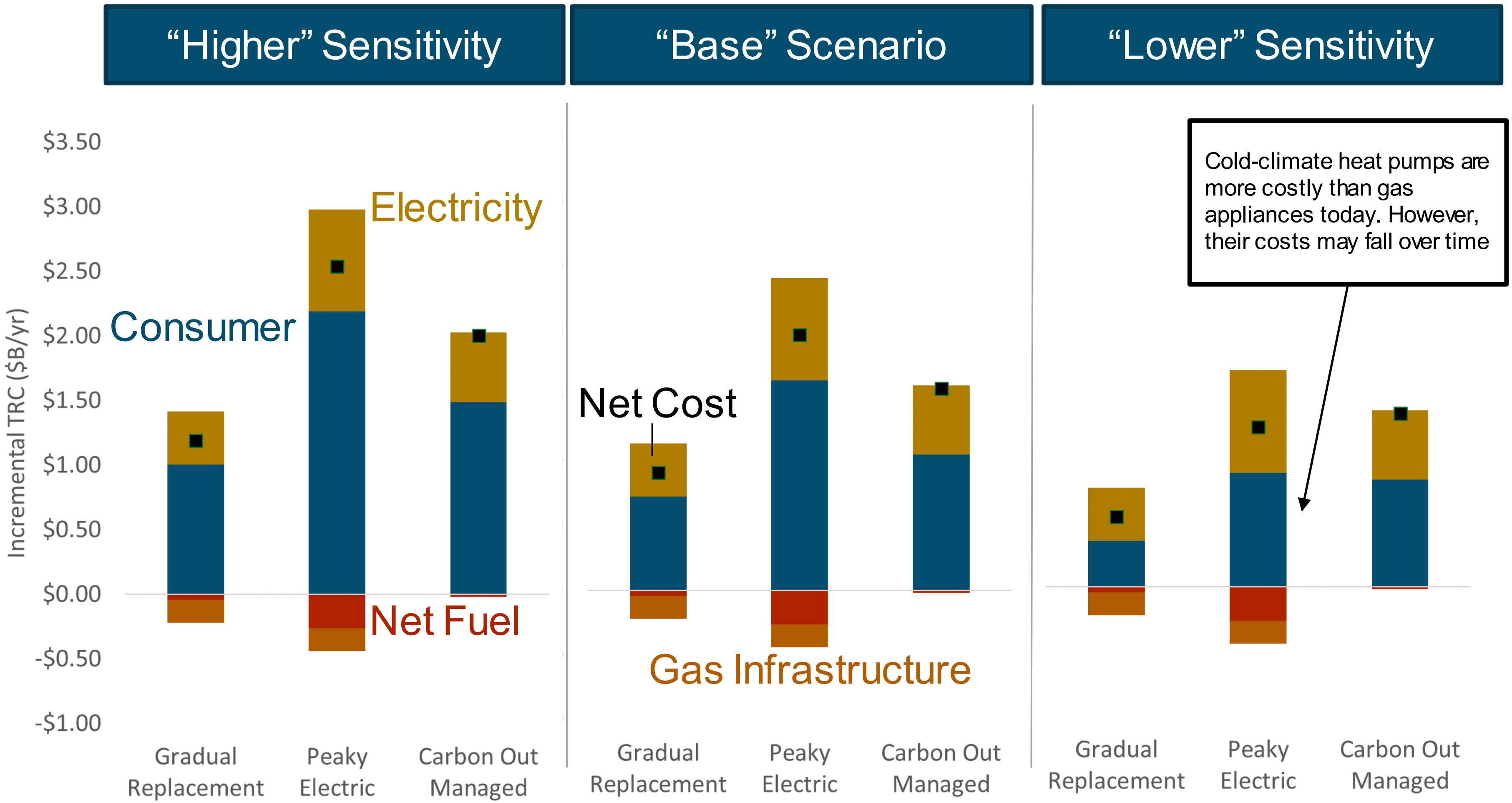
"Peakier Electric" Sensitivity





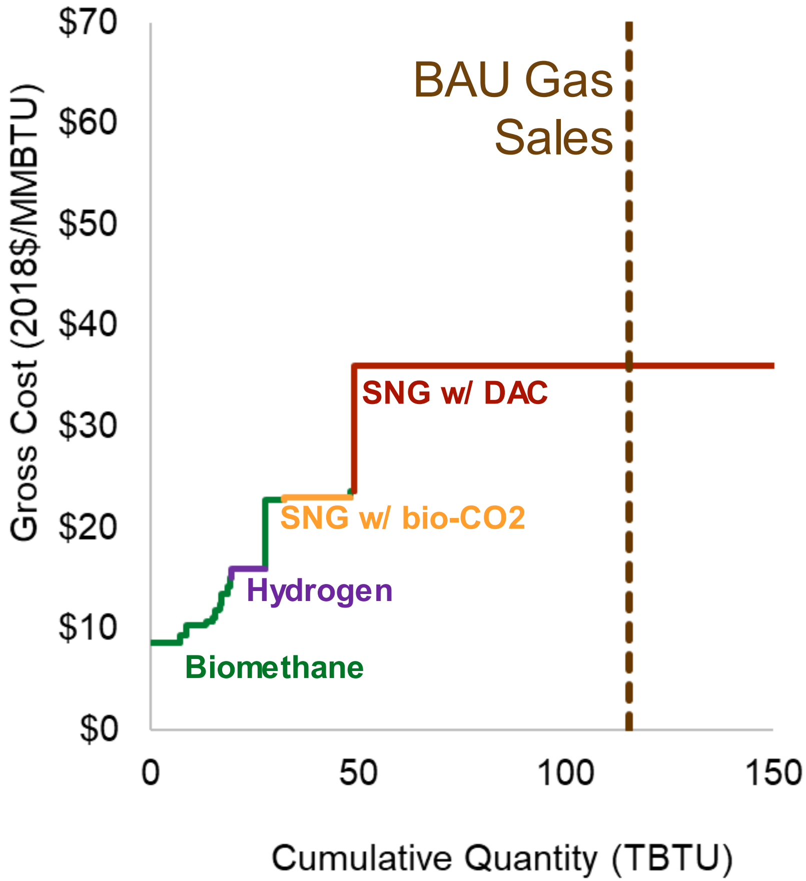
- **The societal cost of electrification depends heavily on what types of end-use equipment are installed**
- **It is not clear that consumers will opt for the societally optimal technology choice, particularly if there are not cost reflective rates**

"Higher/Lower" Consumer Cost Sensitivities

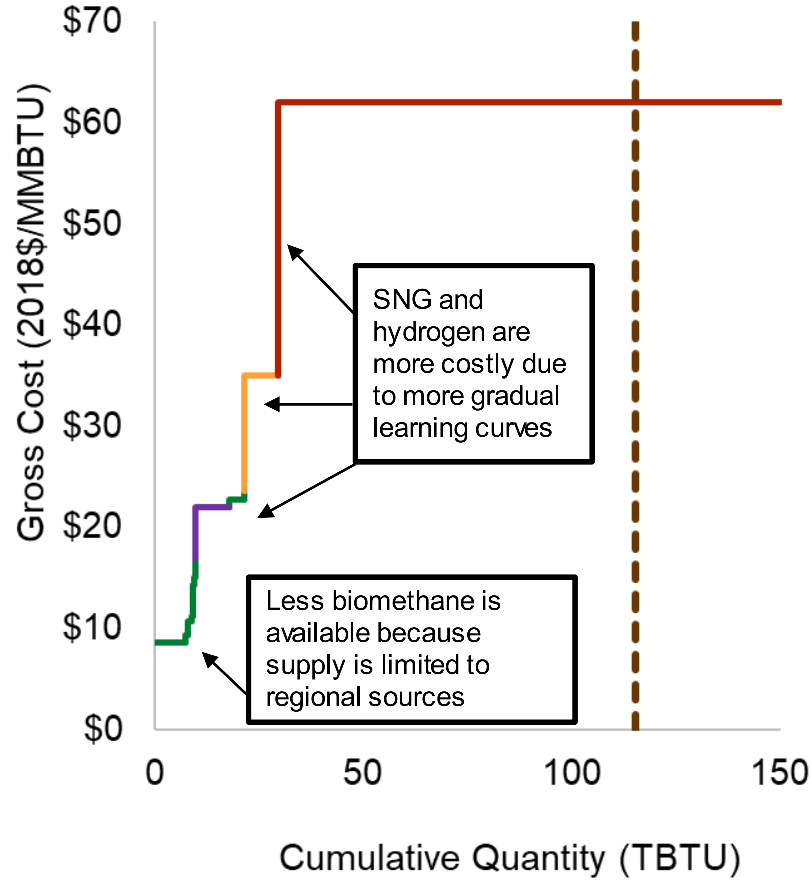


RNG Cost Sensitivity

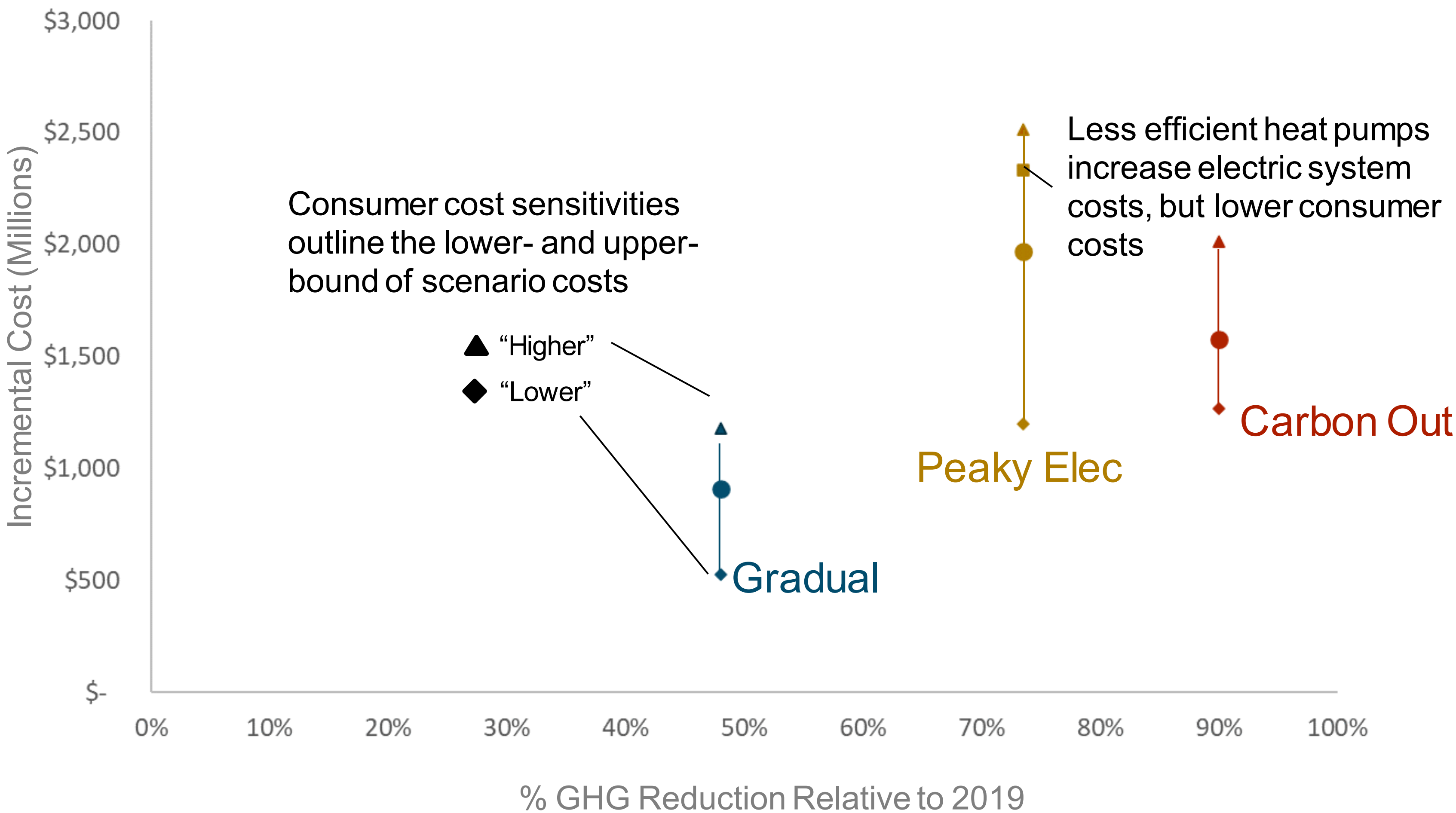
Base Scenario 2050 RNG Supply Curve



"High RNG" 2050 Cost Sensitivity



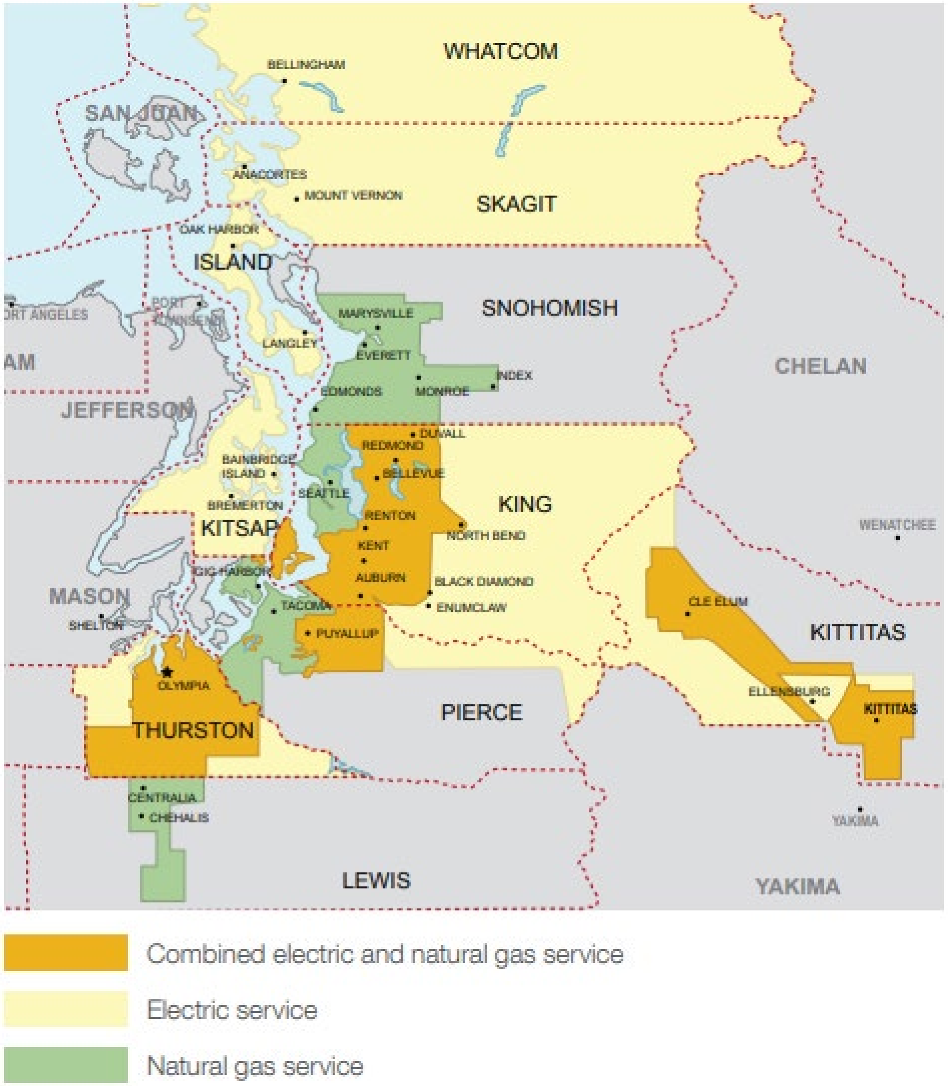
Scenario cost sensitivity ranges



Scenarios by Geography

PSE gas and electric territories only partially overlap

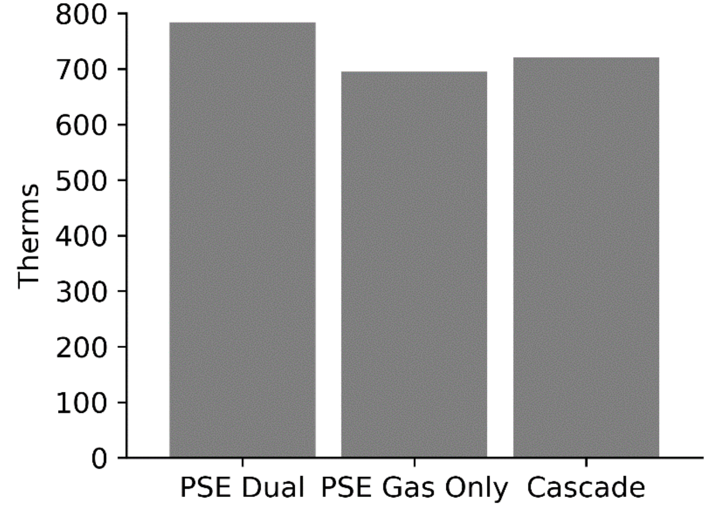
- **Key geographies**
  - **PSE Gas Only**
    - Seattle, Tacoma and Snohomish
  - **PSE Dual Fuel**
    - Suburbs, Olympia and Kittitas
  - **Cascade**
    - Parts of Whatcom, Skagit & Kitsap counties
  - **PSE Combined**
    - PSE Gas + Dual Fuel
  - **PSE Electric**
    - PSE Dual Fuel + Cascade
- **An important question for PSE is how each scenario will affect the company's loads and customer counts?**
- **An important question for society is how the cost of gas decarbonization may vary depending on the unique features of the geographies?**



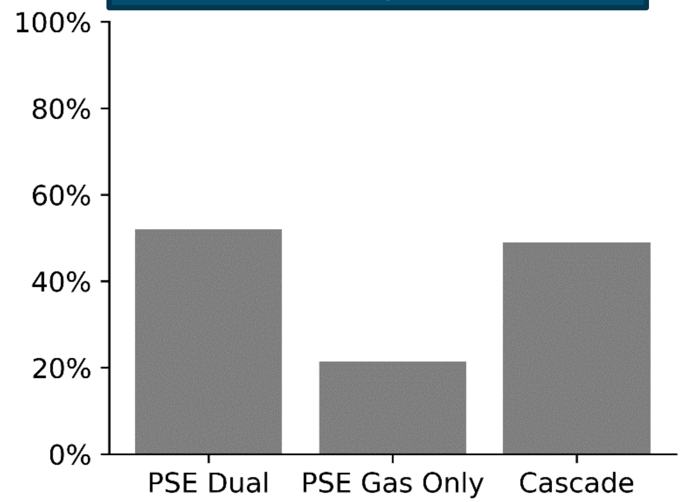
Key differences between service territories

- **PSE Gas Only**
  - **Residential**: low usage per customer (UPC), low (~20%) AC penetration makes heat pump customer conversions more costly on average
  - **Commercial**: higher UPC, higher proportion of commercial customers
  - **Industrial:** very high share of total W WA industrial loads served by gas LDCs
- **PSE Dual Fuel**
  - **Residential**: higher UPC, ~50% of homes have AC
  - **Commercial**: lower UPC, lower customer counts
  - **Industrial:** low share of W WA industrial loads
- **Cascade**
  - **Residential**: mid UPC, ~50% of homes have AC
  - **Commercial/ Industrial**: very low share of customer base, ~1/3 of throughput

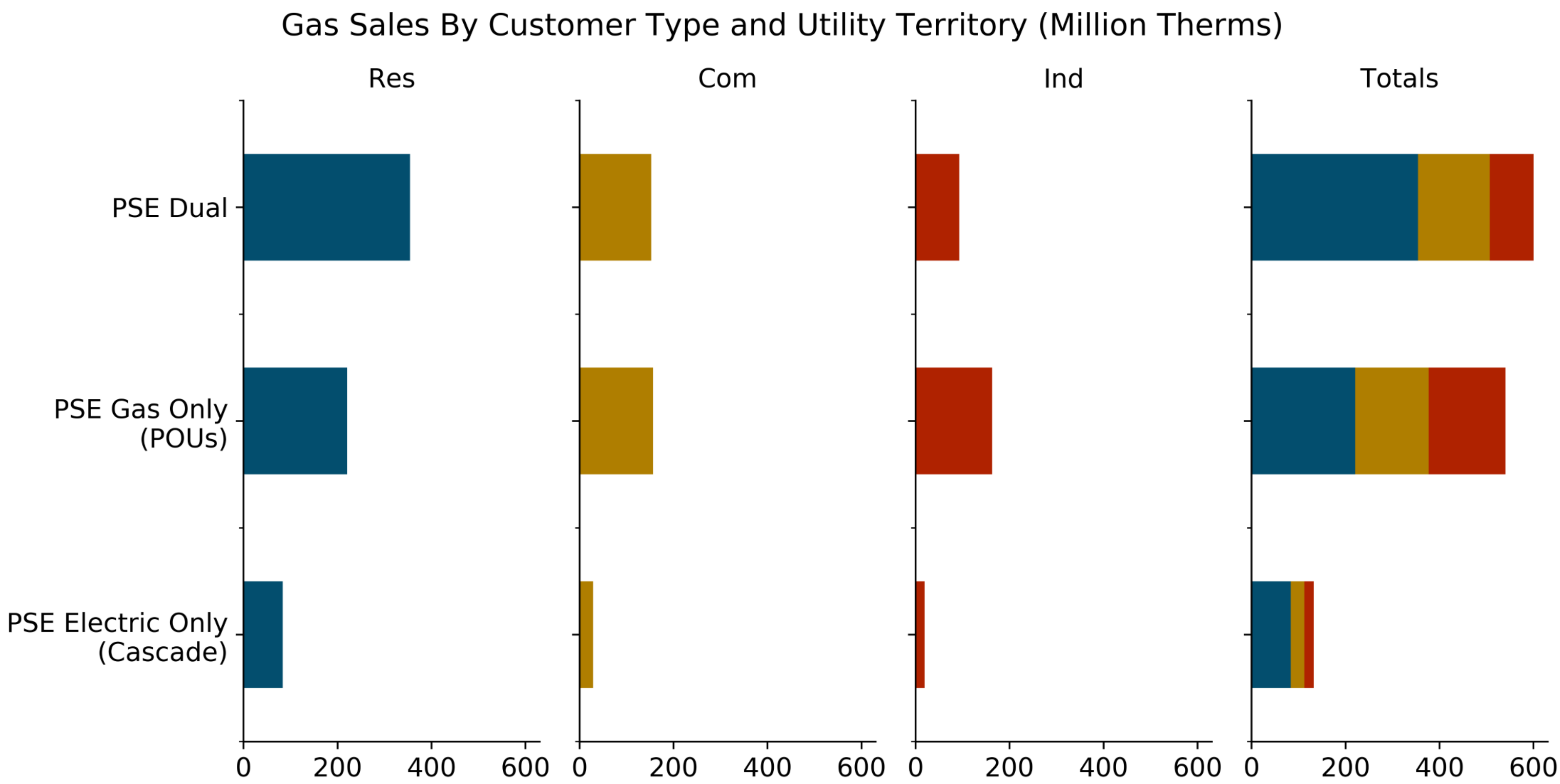
Residential Annual UPC



Residential AC penetration



PSE's service territory has distinct levels and sectoral distributions of loads



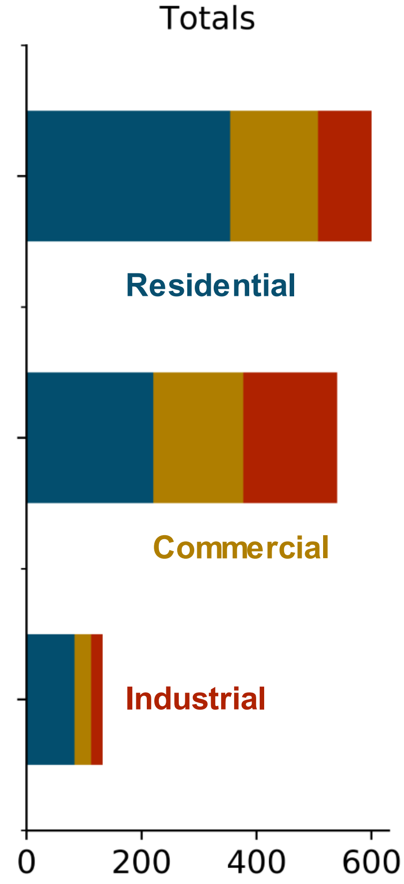
Implications of the distribution of loads across PSE's service territories

Implications by service territory

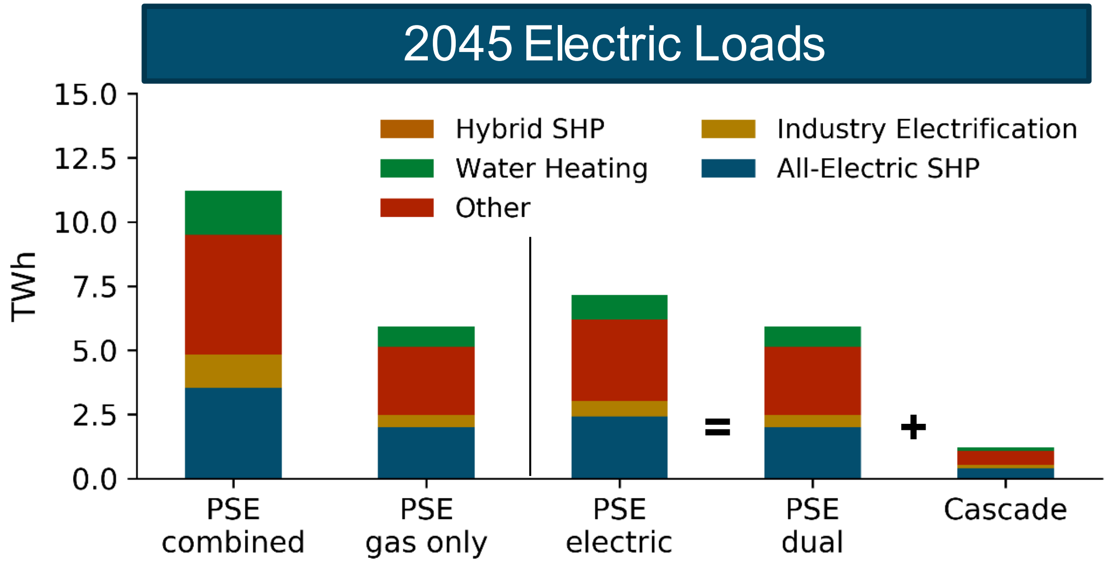
PSE continues to serve all dual fuel customer loads

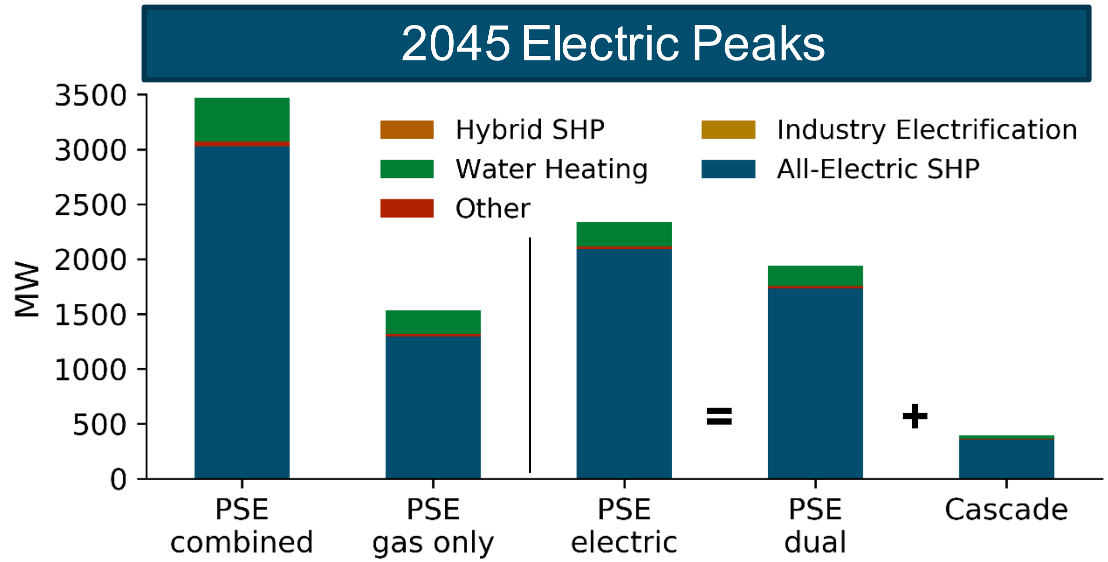
PSE could lose building loads and a share of industry in POU electric service territories

PSE could pick up building loads and a share of industry in portions of its electric only territory that overlap with Cascade



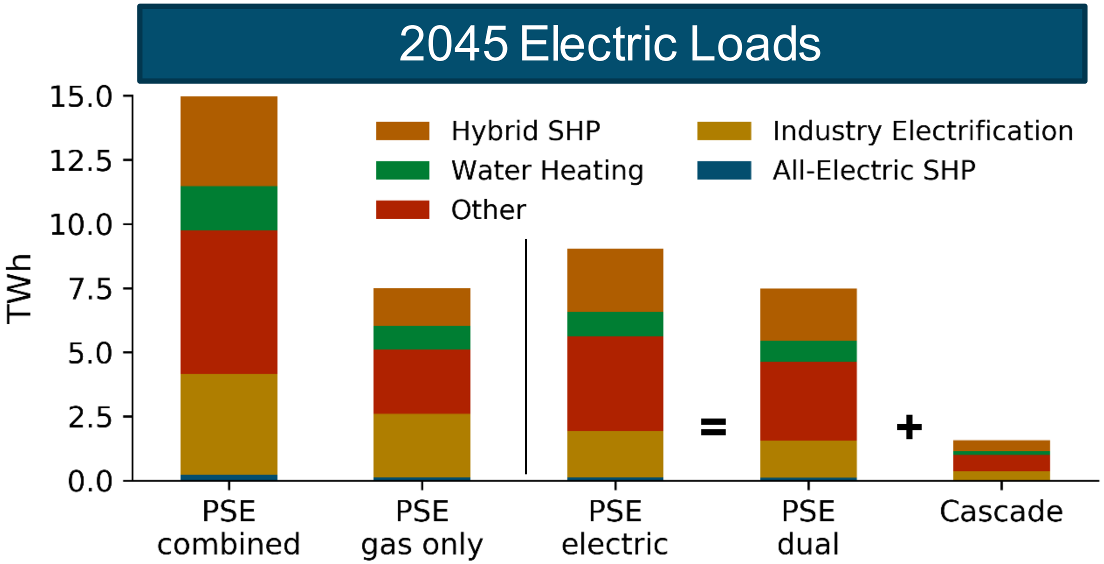
Peaky Electric

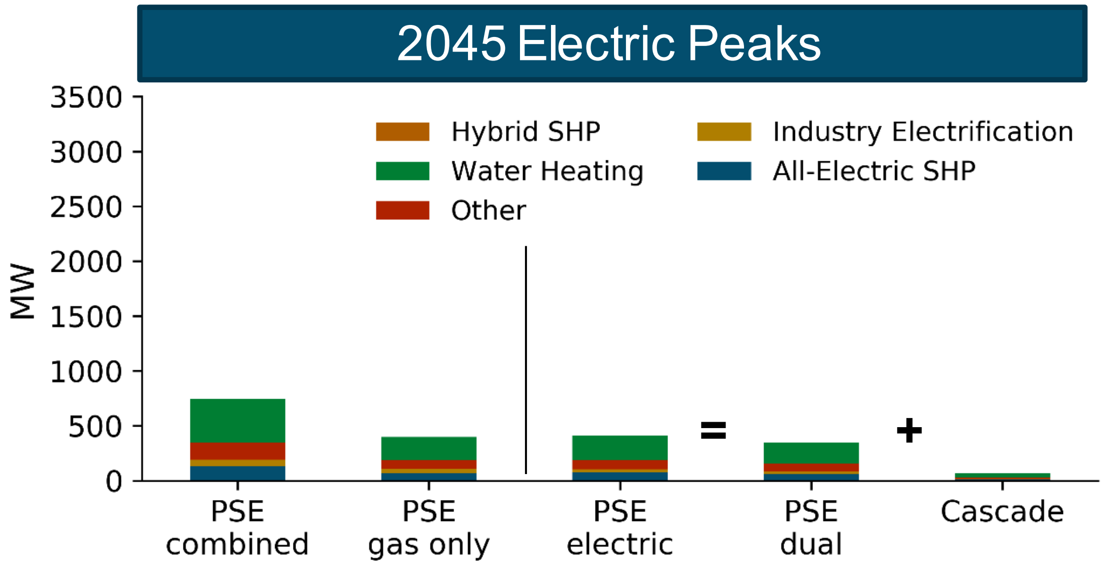




- **The primary source of geographic differentiation in annual electrification loads stems from levels of residential vs non-residential loads**
- **Loads are large in non-residential sectors (“Other”, “Industry Electrification”) because electric resistance is assumed to be the primary technology utilized**
- **Peaks are driven by space-heating loads in residential & commercial buildings**

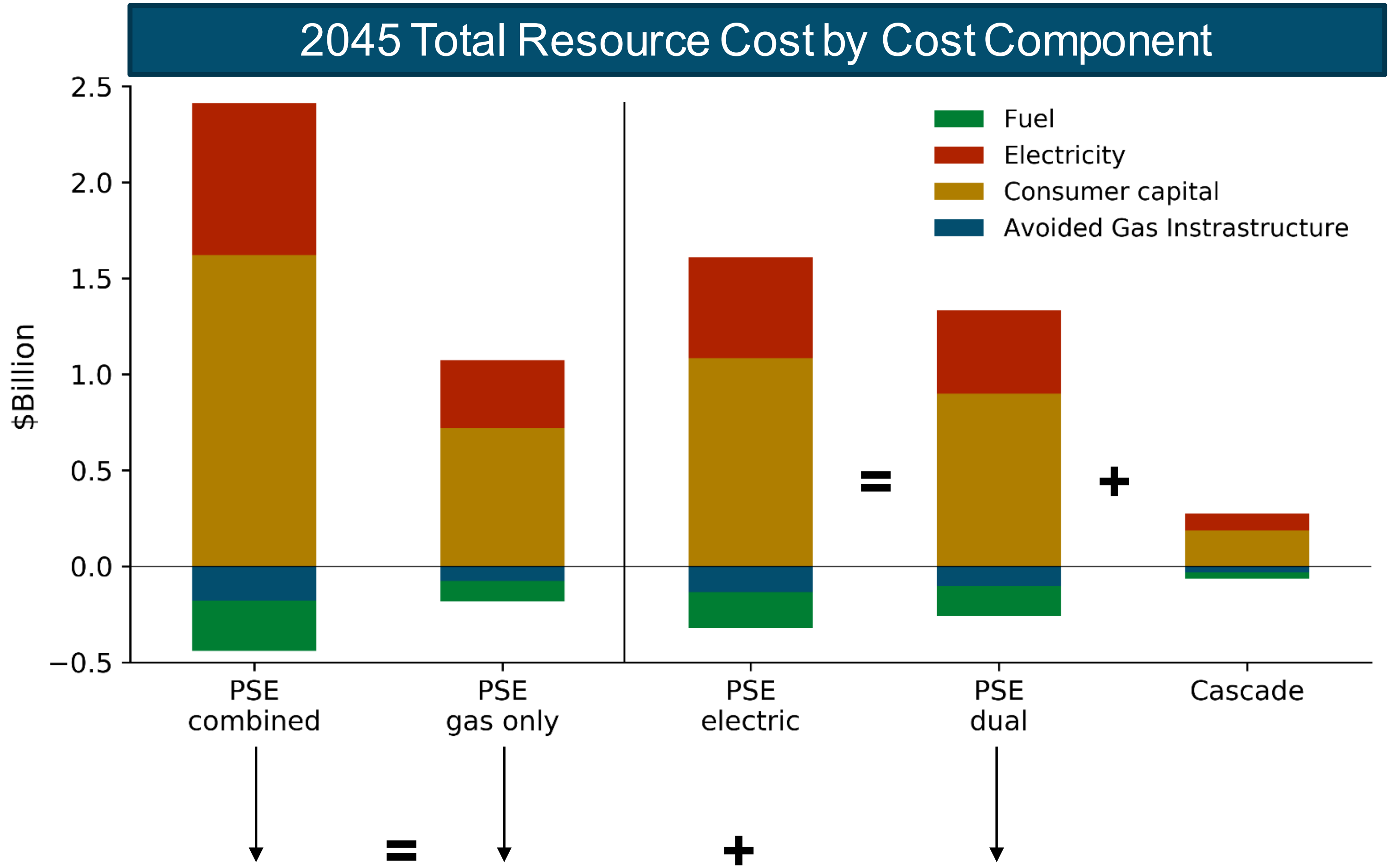
Carbon Out



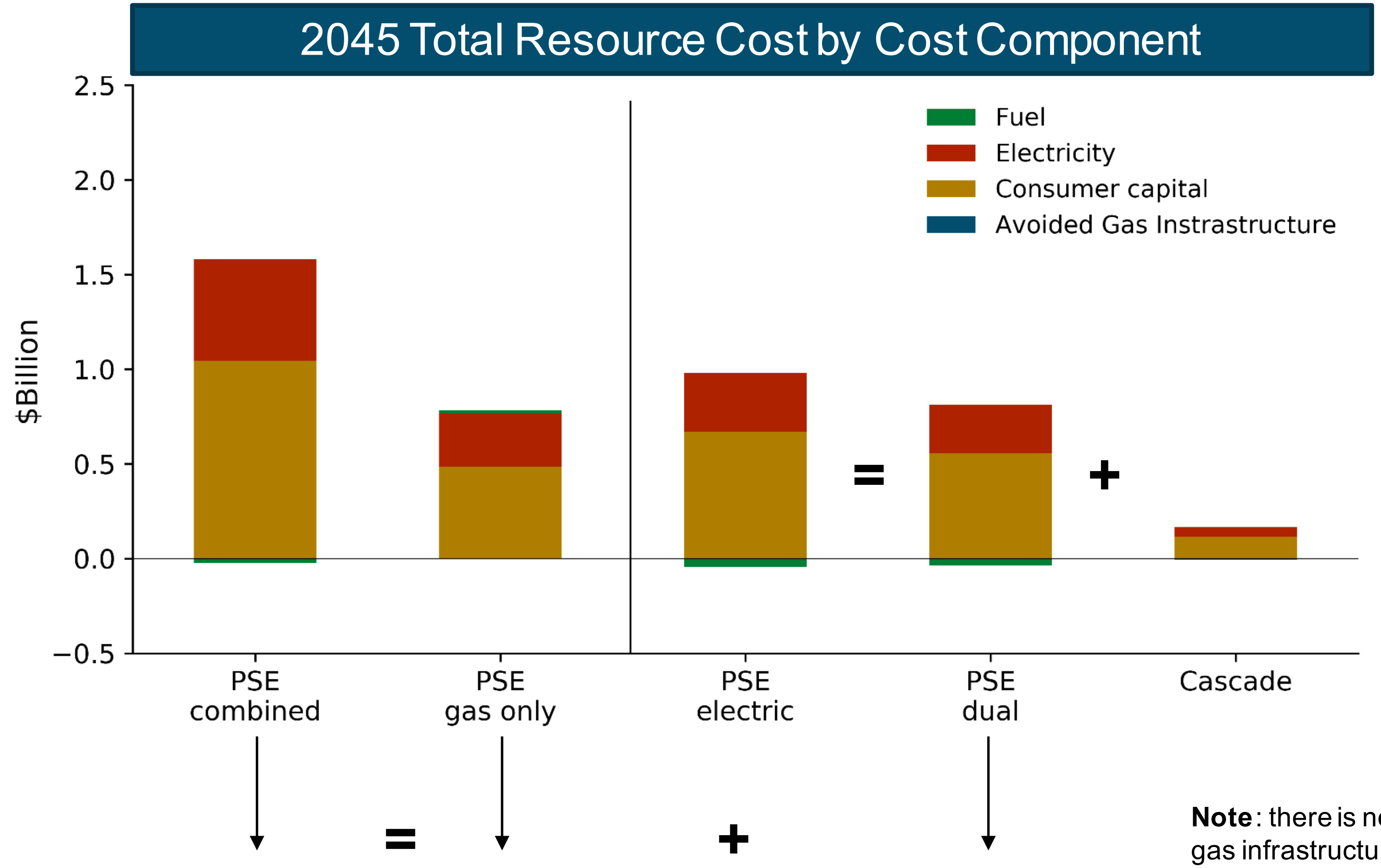


- **Carbon out scenarios see higher overall electric loads, but much lower peak loads due to the presence of hybrid heat pumps**
- **Peak load impacts are largely proportional to the amount of space-heating loads in each region**
- **Publicly owned utilities in the "PSE gas only" region see the largest peak load impacts**

Peaky Electric - TRC

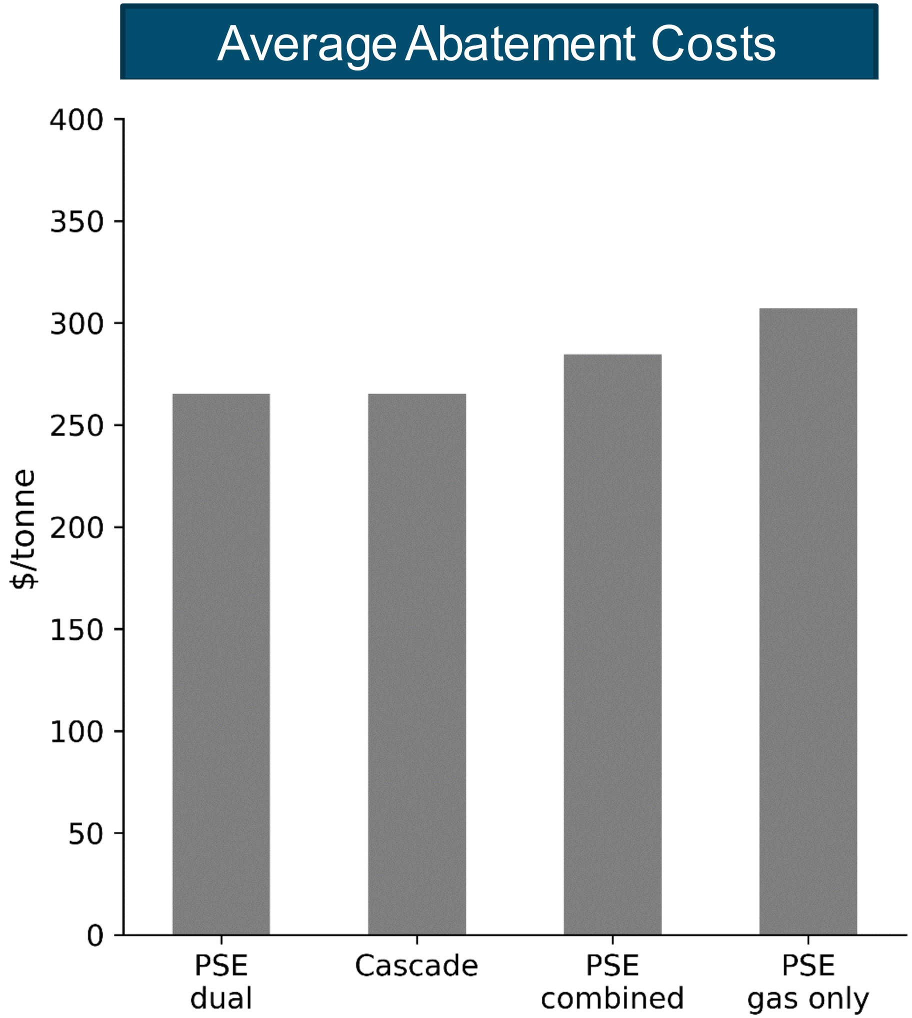


Carbon Out - TRC



Note: there is no avoided gas infrastructure in this scenario because of new customer connections

Average GHG Abatement Costs
Carbon Out, 90% GHG reduction



- **The average cost of abatement is highest in the PSE Gas Only territory for two reasons:**
  - Buildings are generally older and do not have AC, this leads to **higher customer conversion costs**
  - There is **more industry gas demand** that must be decarbonized via relatively costly electrification measures or RNG
- **The average cost of abatement is lowest in the PSE Dual Fuel territory because:**
  - Homes are newer and are more likely to have AC, leading to **lower customer conversion costs**
  - There is **less industry gas demand**

Net Zero

E3 evaluated 3 strategies to achieve net zero

Carbon Out Scenario
(90% GHG Reduction by 2045, 0.6 MMtCO2 remaining)

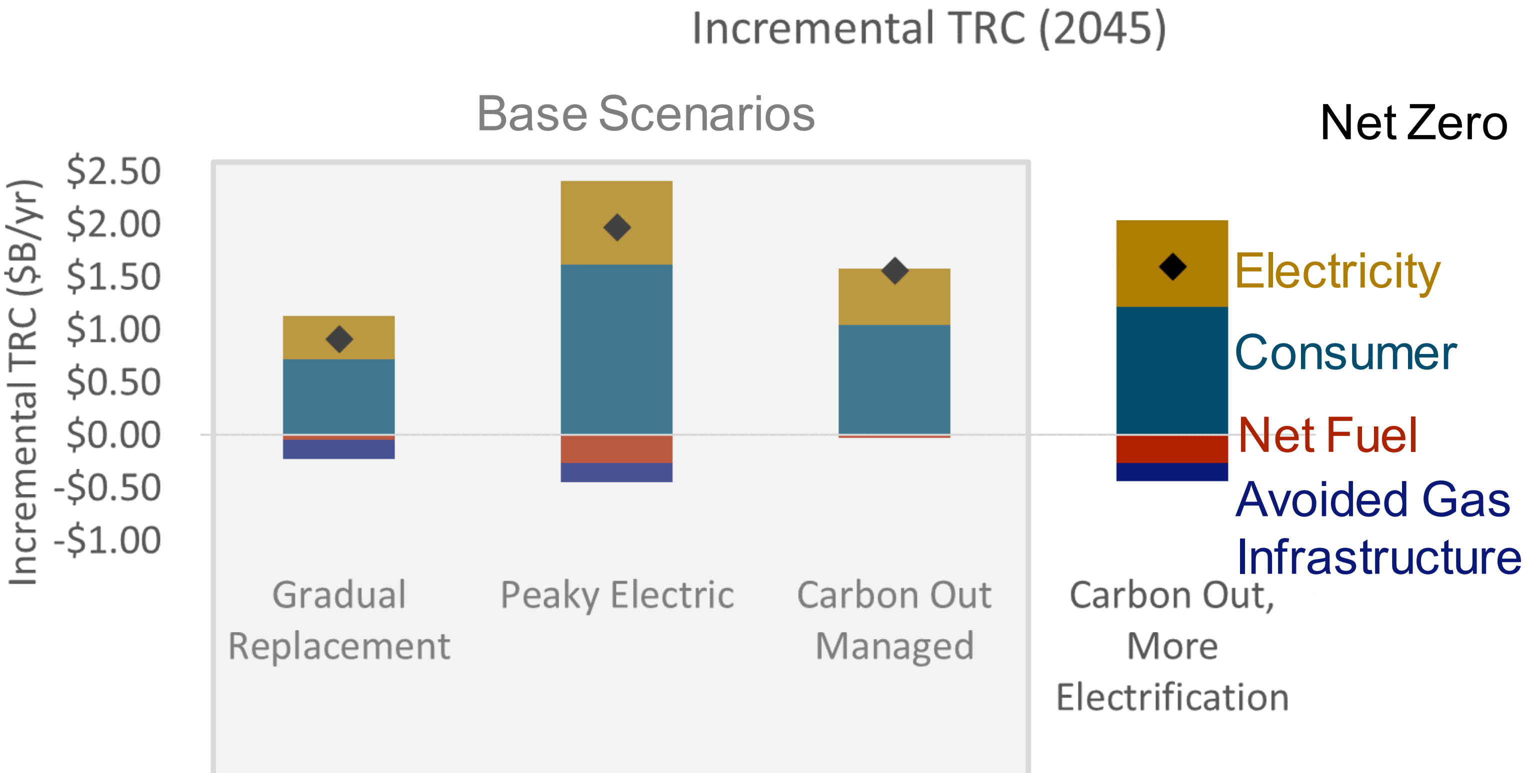
More Electrification
+ Electrification of industry and commercial loads
– Reliance on RNG

More RNG
+ RNG blend up to 100% of delivered gas

Negative Emissions
+ Negative emissions technologies (NETs)

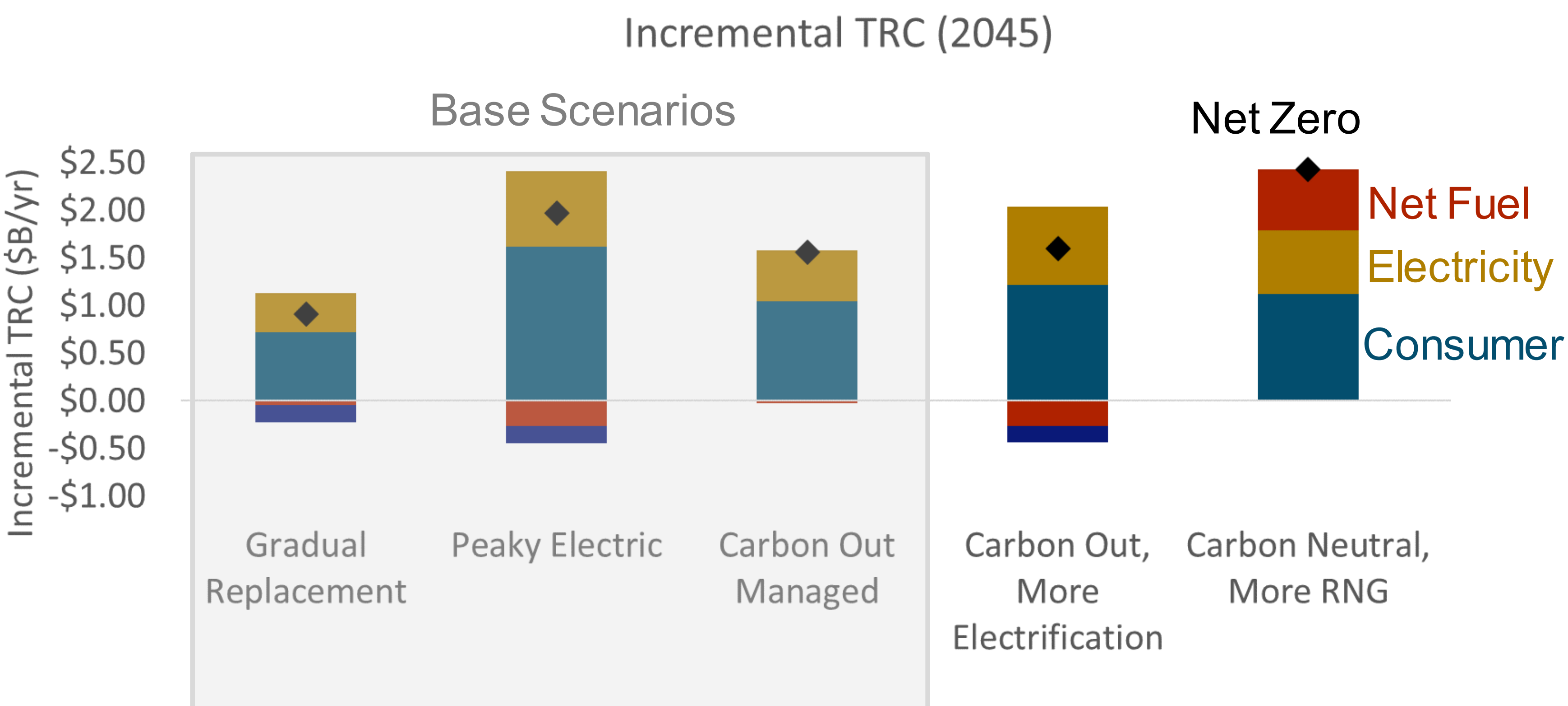
+ **An important caveat to these scenarios is that costs and technical feasibility of measures to achieve net-zero are uncertain**
+ **These scenarios help illustrate potential pathways to net-zero, but cannot by themselves determine an optimal strategy**

Net Zero: More Electrification



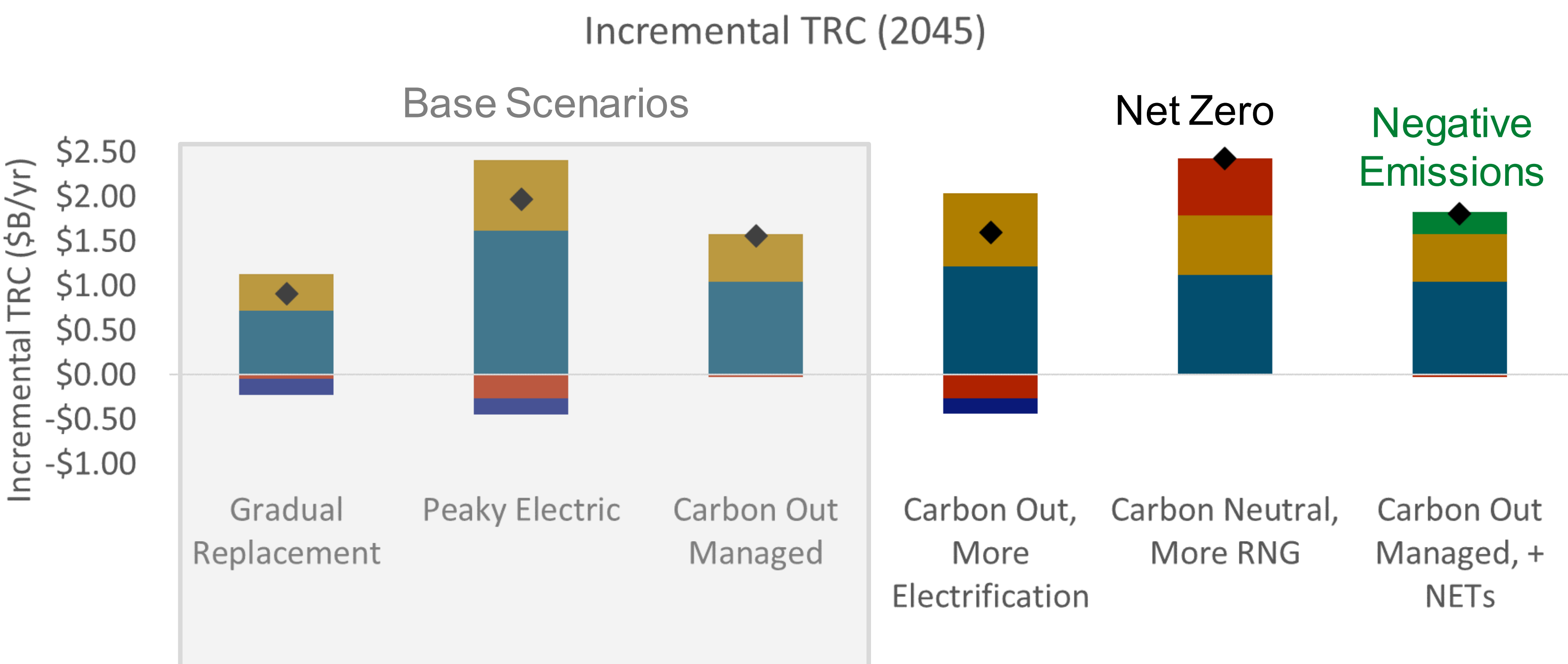
- This scenario assumes additional electrification, primarily in the industrial and energy intensive commercial loads
- There is a large amount of uncertainty about the cost of electrification for those loads.

Net Zero: More RNG



- Blending additional RNG into the pipeline substantially increases scenario costs because lower-cost biomethane resources are exhausted
- This scenario requires 7 Tbtu of SNG in order to achieve a 100% decarbonized gas supply

Net Zero: Negative Emissions



- E3 used a conservative assumption of $400/MMtCO2 for direct air capture of CO2
- Even at that cost, DAC has lower incremental costs than the next tranche of the RNG supply curve

Key conclusions

- Electrification of PSE's gas loads can drive deep GHG reductions, but has the potential to spur large electric system investments and puts stress on the LDC business model given customer attrition.
- Renewable natural gas can provide relatively low cost GHG abatement at low volumes, but its costs rise rapidly at higher volumes.
- A managed strategy that relies on hybrid heat pumps and RNG is a more cost-effective approach to reduce GHG emissions than either of the preceding options alone.
- Decarbonization is likely lower cost in PSE's dual fuel territory due to lower customer conversion costs and lower industrial loads

Energy+Environmental Economics

Thank You

Dan Aas

dan@ethree.com

High Level Consumer Economics Screen

+ **E3 developed a first-order estimate of the Residential consumer economics in 2045 for the gas decarbonization scenarios described above**
+ **This analysis is meant to provide an initial sense of the economic incentives PSE customers may face**
+ **Key areas where refinement is needed:**
  - Segmentation of PSE customer type, retrofit costs
  - Additional, intermediate time-steps
  - Gas and electric revenue requirement and rate build-up; including geographic differentiation based on electric utility
  - Consideration of alternative rate designs that better reflect costs
  - Account for changes in relative cost of heat pumps to gas equipment over time

Two customer types

+ E3 considered two types of single-family residential customers who might consider switching from gas service to some form of electrification.

Existing home w/o AC, Requires a Panel Upgrade

Higher incremental cost compared to gas service

- **ccASHP** – Higher consumer cost; Lower Grid Impacts
- **ASHP** – Lower consumer cost; Higher Grid Impacts
- **Hybrid** – Lower consumer cost; Lower Grid Impacts

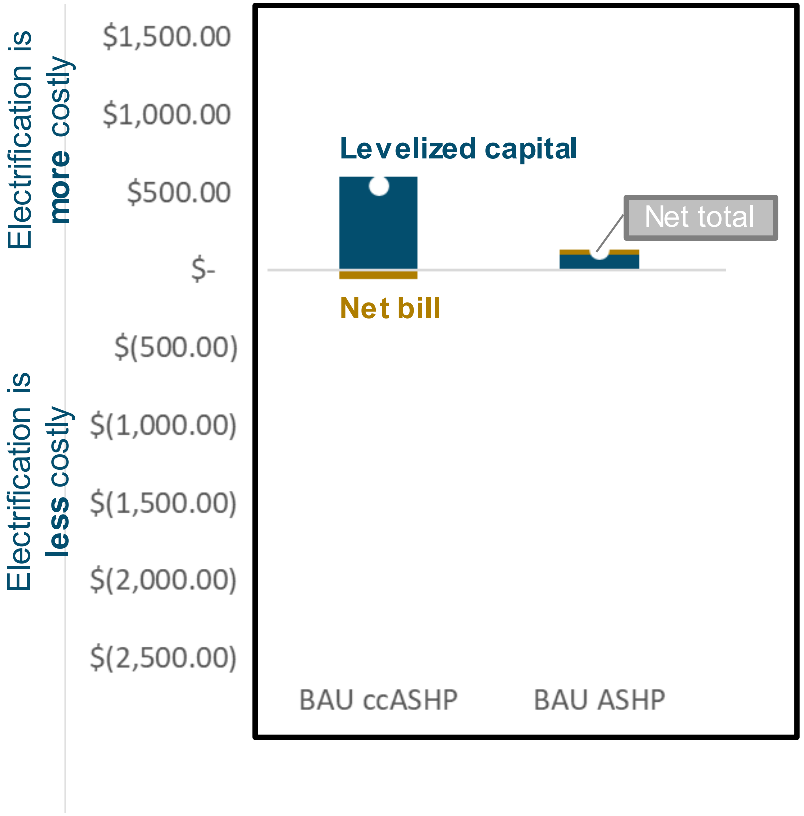
Home w/ AC that has a 200-amp panel

Lower incremental cost compared to gas service

- **ccASHP** – Higher consumer cost; Lower Grid Impacts
- **ASHP** – Lower consumer cost; Higher Grid Impacts
- **Hybrid** – Lower consumer cost; Lower Grid Impacts

BAU
Home with AC & 200 amp panel

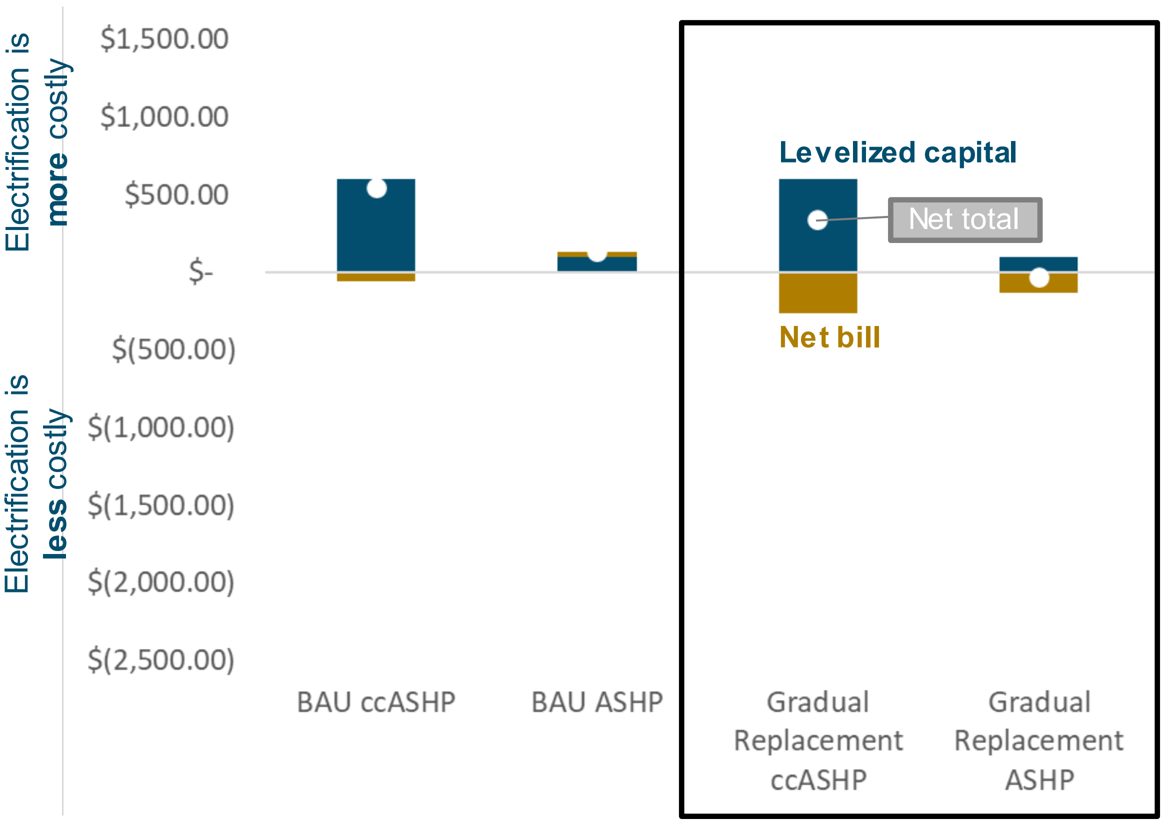
2045 Annualized Incremental Cost to the Consumer



+ **The BAU scenario assumes flat gas and electric rates.**
  - At those rates, heat pumps and gas appliances have similar annual operating costs
  - Heat pumps come at a cost premium, particularly cold climate heat pumps
  - Gas service remains lower cost for these homes
+ **This scenario does not achieve substantial GHG reductions**
+ **Cost components**
  - Levelized capital: annualized incremental cost of heat pumps
  - Net bill: difference in operating costs

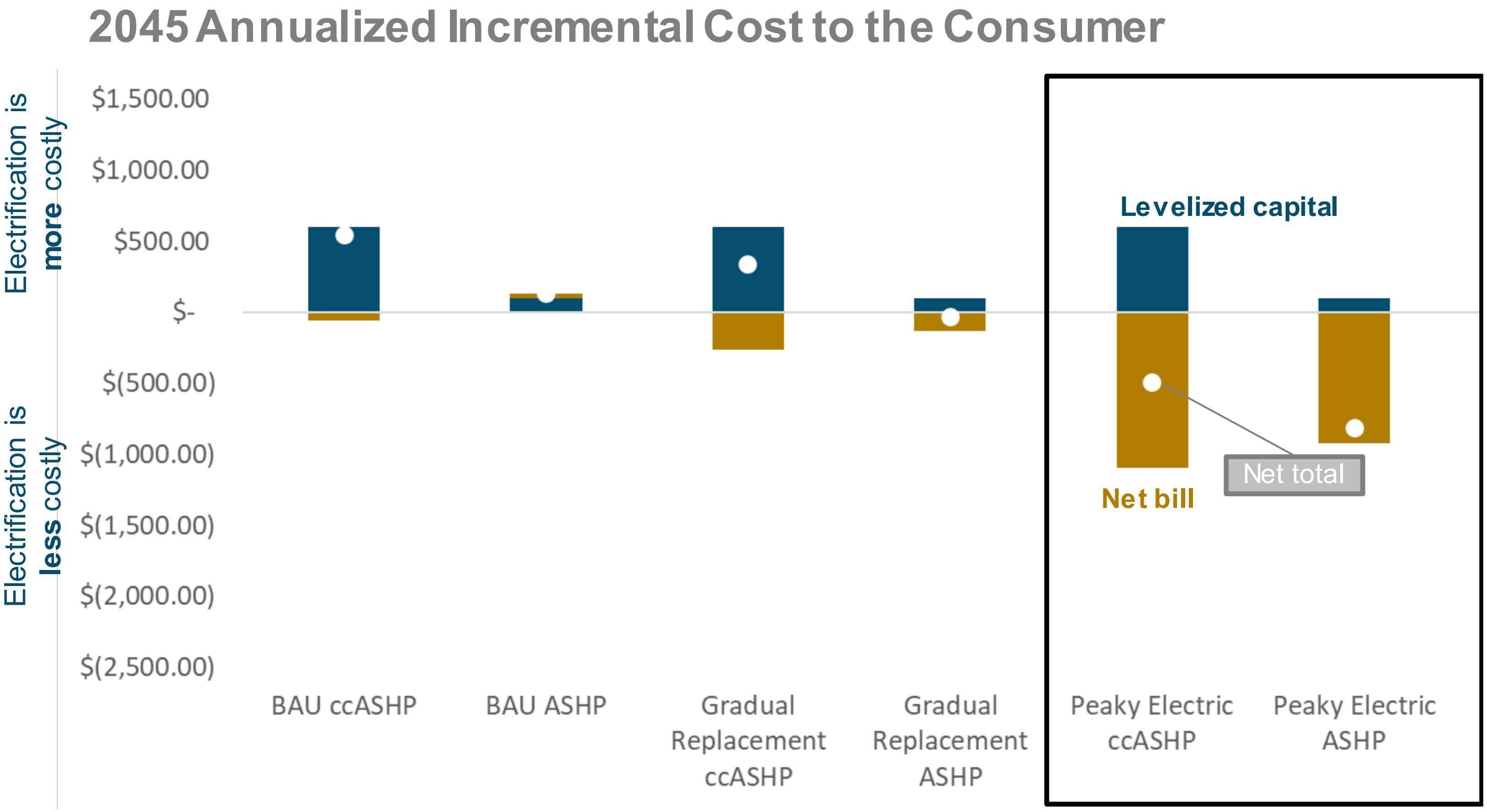
Gradual Replacement
Home with AC & 200 amp panel

2045 Annualized Incremental Cost to the Consumer



- Gas rates increase in this scenario due to customer departures increasing PSE's delivery rate

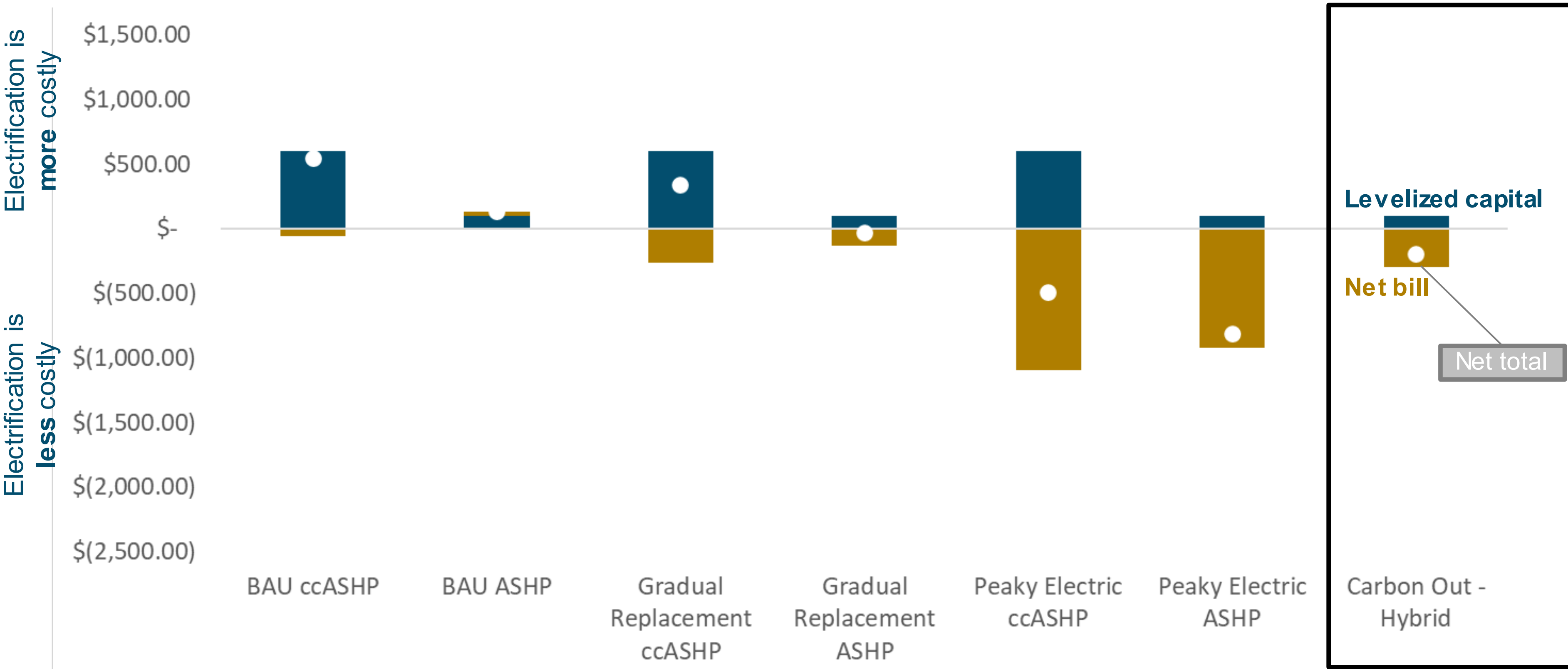
Peaky Electric
Home with AC & 200 amp panel



+ **Customer departures further improve the customer economics of electrification in the "Peaky Electric" scenario as a feedback effect takes hold**

Carbon Out
Home with AC & 200 amp panel

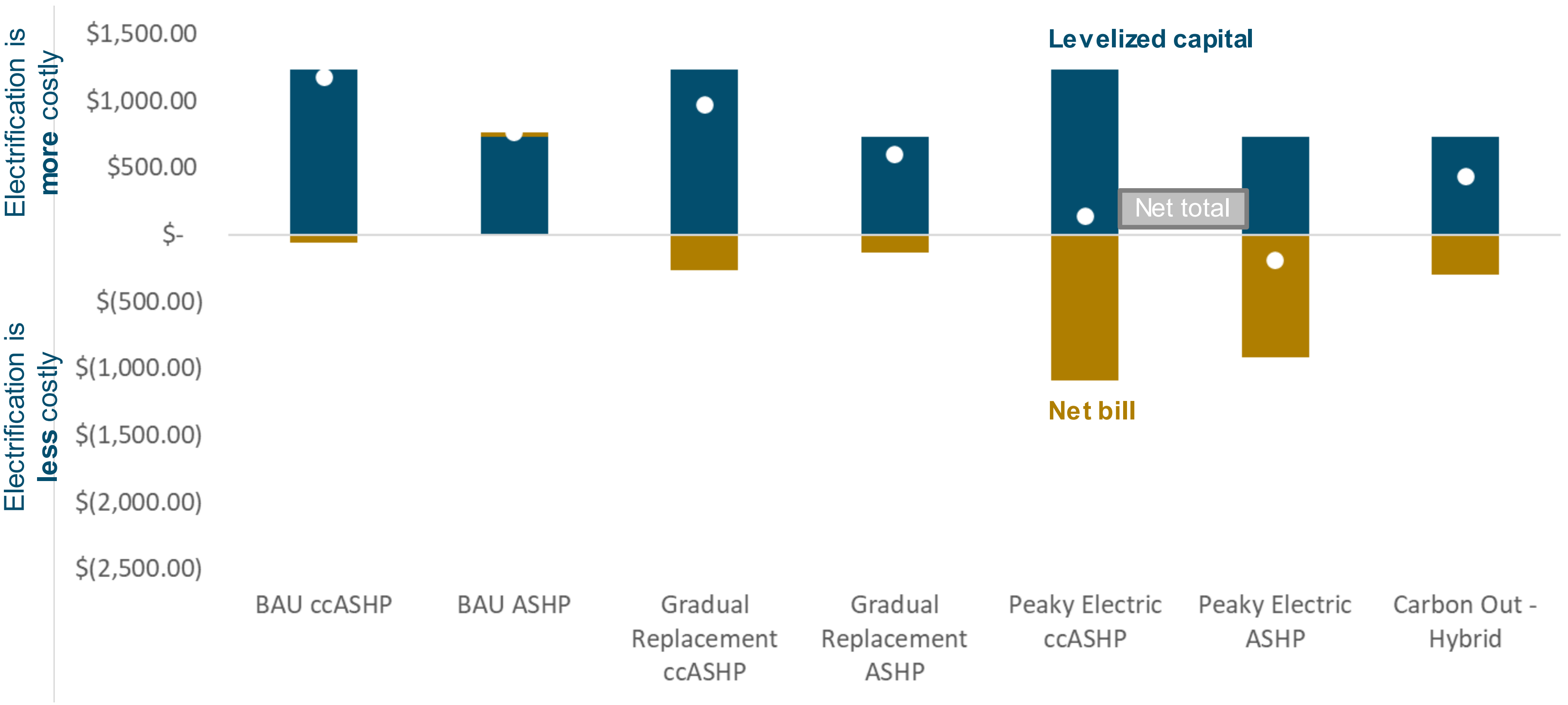
2045 Annualized Incremental Cost to the Consumer



- E3 assumes that customers with hybrid heat pumps pay a similar gas delivery bill as they do today, but save on gas operating costs
- Savings for those customers could be higher under volumetric rates

Customers without AC or who require a panel upgrade face higher retrofit costs

2045 Annualized Incremental Cost to the Consumer



Base Single-Family Residential cost assumptions

Parameter	Incremental Cost	Source
Incremental cost of **ASHP** (HSPF 10) over efficient gas furnace + AC	$0	AECOM / E3
Incremental cost of **cold-climate ASHP (HSPF 14+)** over efficient gas furnace + AC	$5000	Above + Energy Trust of Oregon data
Incremental cost of **cold-climate ASHP (HSPF 14+)** over efficient gas furnace, no AC	$7800	Above, assuming $2800 avoided AC cost
Incremental cost of **hybrid gas-electric heat pump** over efficient gas furnace + AC	$0	NRECA 2020
Cost of **panel upgrades** in homes installing heat pump space heater for first time	$3500	TRC Palo Alto study
Incremental cost of **heat pump water heater** over efficient gas storage	$1000	AECOM / E3
Incremental cost of **commercial** technologies	Proportional to incremental costs in the residential sector	E3 project experience, Brattle Group 2020