GRC Stipulation O

Updated Decarbonization Study

December 22nd, 2023

PUGET SOUND ENERGY

Table of Contents

PUGET SOUND ENERGY

GRC Stipulation O – Updated decarbonization study

Executive Summary

PUGET SOUND ENERGY

Overview

- Scenario 1. Air Source Heat Pump (ASHP) - standard
- Scenario 2. Cold Climate Heat Pump (CCHP)
- Scenario 3. Hybrid heat pumps (HHP) for all gas customers
- Scenario 4. HHP for existing gas customers, new gas customer would become electric with CCHP

Per the requirements of the Decarbonization Study Compliance Filing Dockets UE-220066, UG-220067 and UG-210918, PSE conducted a decarbonization study that analyzed the impacts on both the gas and electric utility analyzing the infrastructure requirements, emissions and costs associated with each scenario. The analysis also evaluated the impacts to customers by translating the financials into customer rates, showing the annual customer cost for each scenario.

- All four scenarios leveraged equipment burn out as the point for transition as well as a technology adoption curve that the Cadmus Group (Cadmus) used based on market potential.

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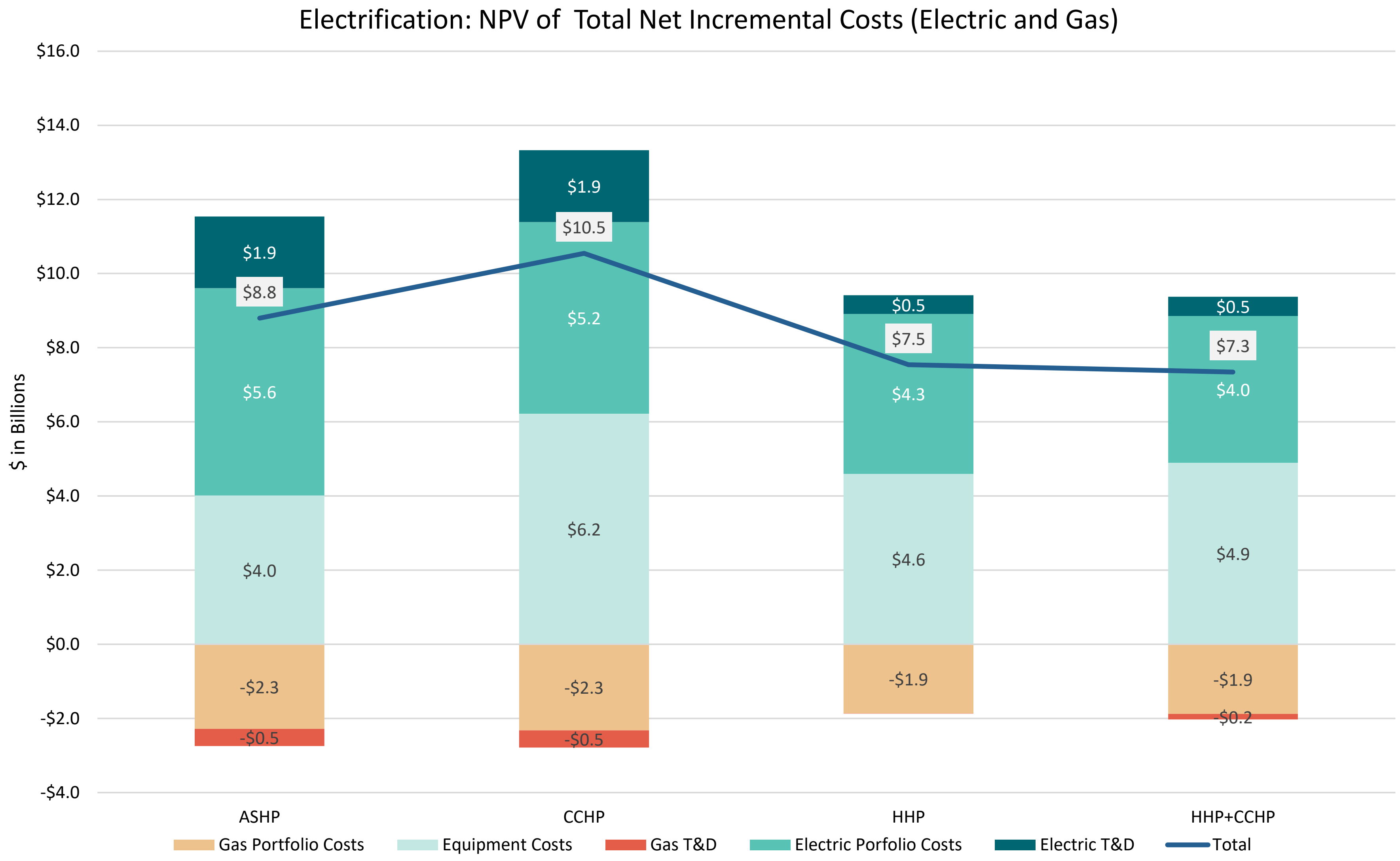
Total electric & gas portfolio, system and conversion net costs per scenario



Key:
ASHP = Air source heat pump
CCHP = Cold climate heat pump
HHP = Hybrid heat pump (dual fuel heat pump, gas furnace backs up heat pump)
T&D = Transmission and Distribution

Note: Costs on this slide are direct costs. Externality costs are included in a subsequent slide.

Gas system shows benefits from targeted electrification for constrained parts of the system

Element F - Study the impacts and benefits of electric heat pump technologies on PSE’s gas constrained delivery systems.

Scenario	Time period	Fuel blend	Total load constraint	# Conversions	Estimated cost to convert	Benefits/ opportunities
Base case – 100% NG	current	100% NG (1046 BTU)	472,000 scf/hr*	11,800	$177M	
Scenario 1 – ASHP Scenario 2 – CCHP	2032	100% RNG	322,000 scf/hr	6,600	$99M	Reduces constrained areas on system occurring with lower carbon fuel
Scenario 3 – HHP	2032	100% RNG	642,000 scf/hr	16,050	$240M	Reduces temperature where actions are needed
Scenario 4 – HHP + CCHP	2032	100% RNG	610,000 scf/hr	15,250	$228M	Reduces temperature where actions are needed

*scf/hr: standard cubic foot per hour

The study of the gas system impacts found the following impacts:
- Location and population matters
- Heat content changes over time with low carbon fuels, targeted electrification can offset impacts in most areas
- Electrification costs are greater than gas pipeline upgrades for largely constrained areas

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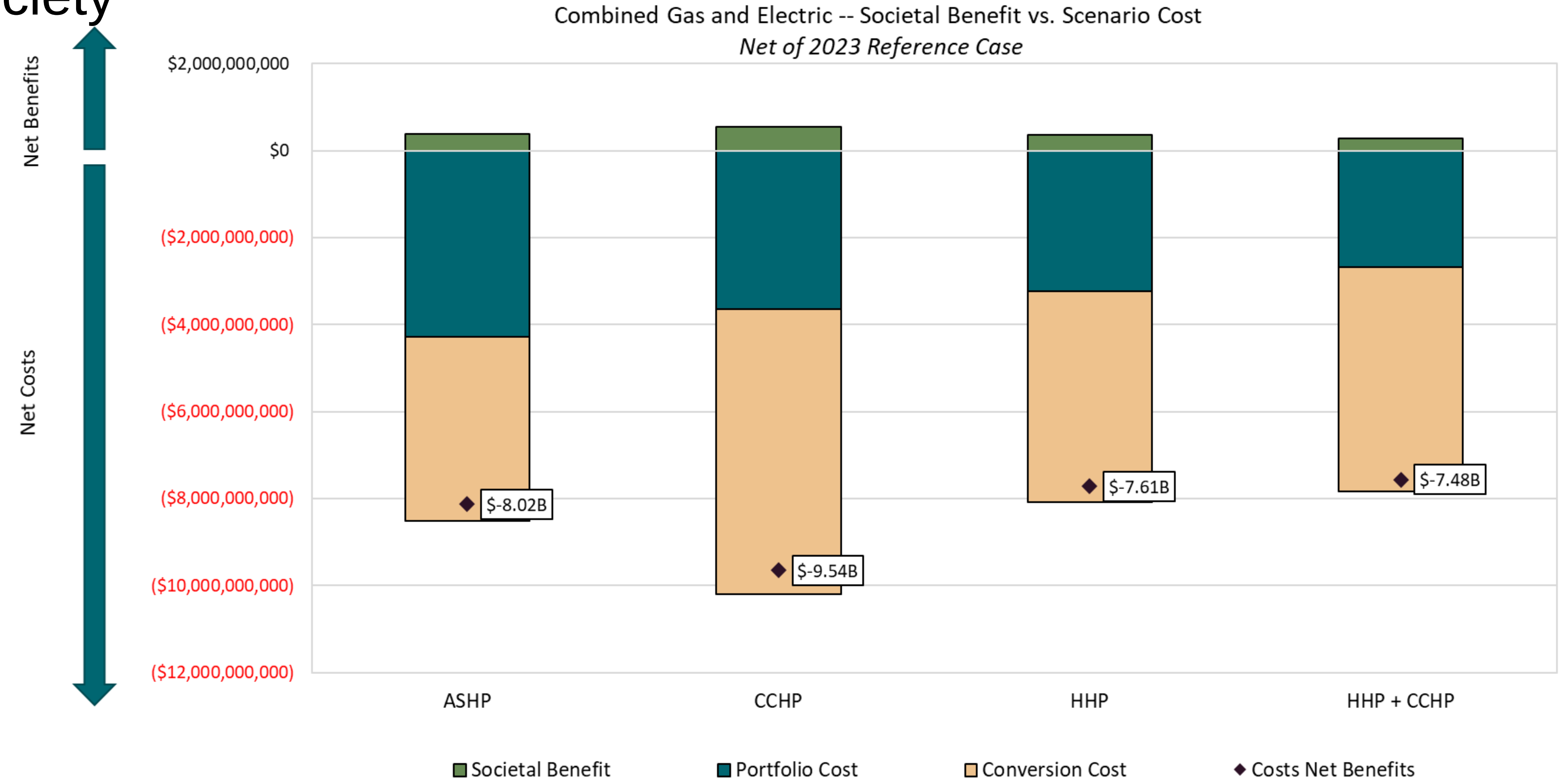
Portfolio and conversion costs outweigh the emission reduction benefit to society



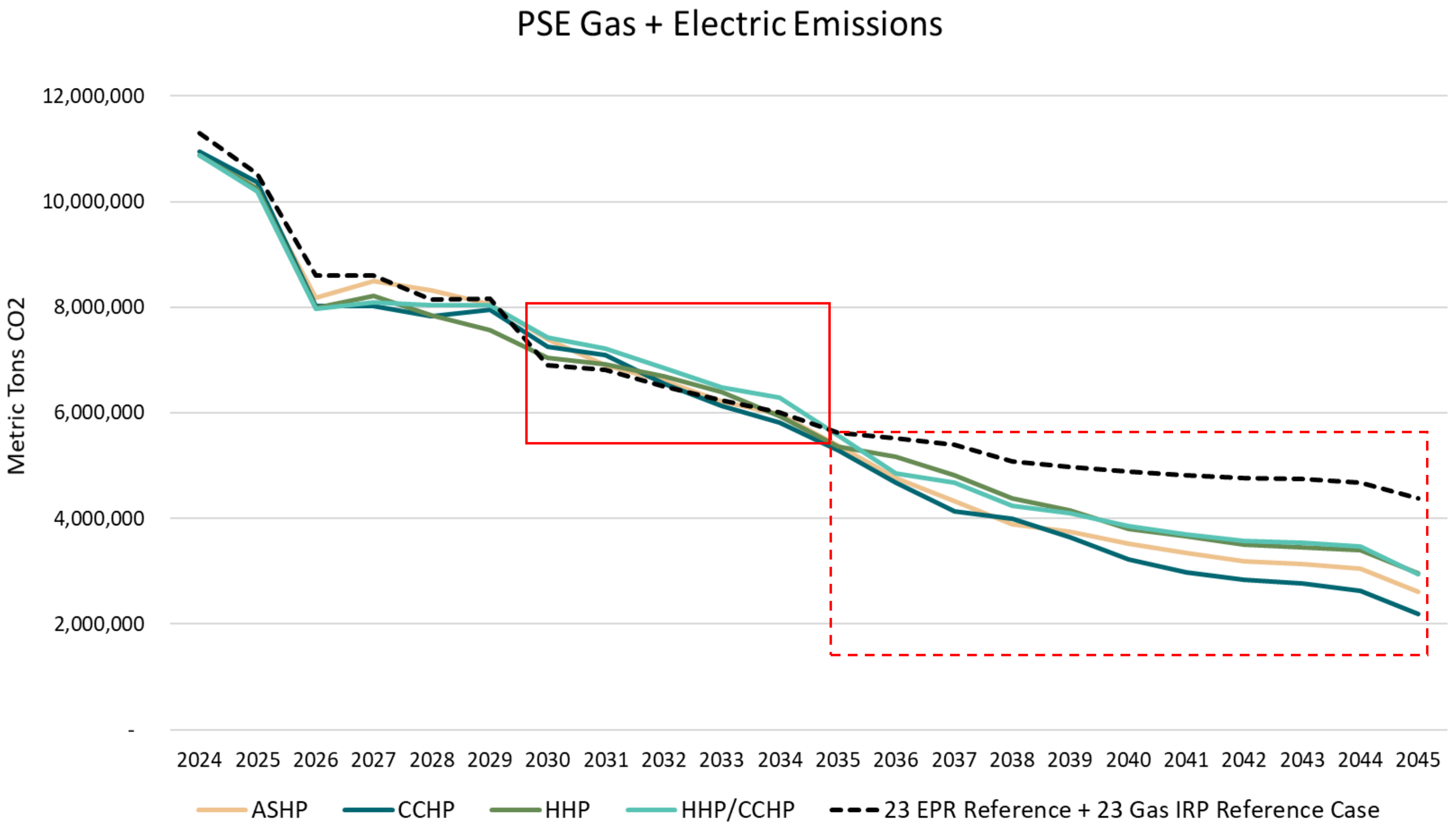
*Societal benefit is calculated using net emissions which use the WECC wide market emission rate which changes year to year.

PSE Gas + Electric utility operations emissions

Near term increase in total emissions while renewable energy on the system builds, followed by long-term emission reduction across all scenarios

Benchmarked to 23 IRP (Reference)

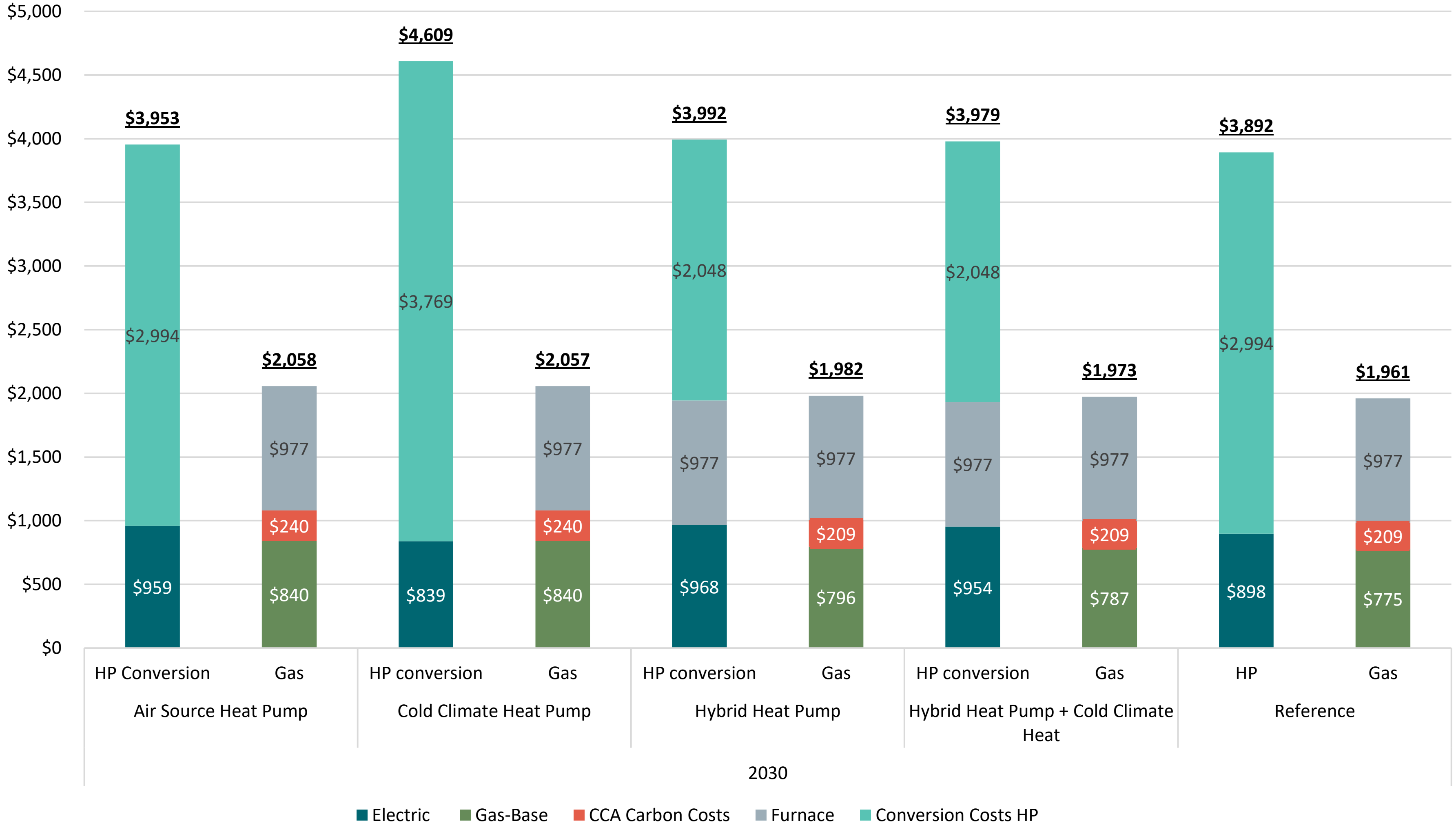
- **CCHP scenario** --
  - 2030: **5% above Reference**
  - 2045: **50% below Reference**
- **HHP scenario** --
  - 2030: **2% above Reference**
  - 2045: **32% below Reference**



Annual residential costs for heat pump customers vs all gas customer in 2030, costs are similar across all scenarios

2030 residential bill impacts

- Billing impacts across all scenarios are very similar.
- A customer would likely not get a price signal to move if their equipment does not need replaced.



Note- the equipment costs are annualized over 10 years (refer to slide 22 for total equipment investment).

Dollars are shown in 2030 dollars

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Annual residential costs for heat pump customers vs all gas customer in 2045, costs are similar across all scenarios

2045 residential annual impacts

- Looking out 20 years, any of these scenarios could flex in either direction

Note- the equipment costs are annualized over 10 years (refer to slide 22 for total equipment investment).

Dollars are shown in 2045 dollars

Roadmap showing the magnitude of the infrastructure builds that would be required to meet the energy and capacity needs of Scenario 2 - cold climate heat pump

ILLUSTRATIVE

2025

- **13 Electrification Pilots** (16,000 CCHPs)
- **3.6 million MWh of utility-scale renewables**
- **6 utility-scale batteries** (570 MW capacity)
- **1 transformer per year** (2 total)

2030

- **100 Electrification Pilots** (122,000 CCHPs)
- **8.6 million MWh of utility-scale renewables**
- **28 utility-scale batteries** (2,800 MW capacity)
- **1,200 MW of Cross-Cascades transmission**
- **~1 transformer per year** (9 total)

2035

- **260 Electrification Pilots** (308,000 CCHPs)
- **12 million MWh of utility-scale renewables**
- **36 utility-scale batteries** (3,600 MW capacity)
- **1,800 MW of Cross-Cascades transmission**
- **~4 local transmission projects** (59 miles)
- **~4 transformers per year** (31 total)

2040

- **420 Electrification Pilots** (504,000 CCHPs)
- **22 million MWh of utility-scale renewables**
- **47 utility-scale batteries** (4,700 MW capacity)
- **3,600 MW of Cross-Cascades transmission**
- **~6 local transmission projects** (91 miles)
- **~3 transformers per year** (48 total)

2045

- **570 Electrification Pilots** (686,000 CCHPs)
- **26 million MWh of utility-scale renewables**
- **58 utility-scale batteries** (5,800 MW capacity)
- **4,600 MW of Cross-Cascades transmission**
- **~7 local transmission projects** (117 miles)
- **~3 transformers per year** (62 total)

Key

- Cold climate heat pumps adopted, as Electrification Pilot size (1,200 residential customers)
- MWh of utility-scale renewable generation built
- MW of capacity resources built, as generic utility-scale battery installation (100 MW)
- Miles of local 115kV transmission needed, as Energize Eastside projects (16 miles)
- MW of Cross-Cascades transmission needed
- New distribution substation transformers needed, assuming completed within previous 5 years

Decarbonization study key findings

Based on the assumptions of the Study;

- **Emissions increase in the near term**, until more renewable resources are built
- The **cost of reducing emissions is greater than the benefit to society**
- For an average residential customer, **costs increase similarly across all scenarios over time**
- **All scenarios increase energy costs for low-income customers in the near term**
  - Low-income energy bills for either fuel have small delta between them in the near term, it is unlikely to trigger a customer to switch without a need to do so
- **There are additional benefits to targeted electrification on certain parts of the gas system,** this will be further evaluated within the targeted electrification strategy

PSE PUGET SOUND ENERGY

GRC Stipulation O – Updated decarbonization study

Methodology Overview

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GRC stipulation O: study scenarios

Scenario 1. Air Source Heat Pump (ASHP) - standard

- Fully electrifying customers based on Cadmus burn out rate
- Leverages standard heat pumps
- Incorporates Climate Commitment Act (CCA)
- Incorporate Cadmus Inflation Reduction Act (IRA) est.

Scenario 2. Cold Climate Heat pump (CCHP)

- Full electrification with only Cold Climate Heat Pumps (CCHP)
- Based on CCHP performance research
- Incorporates CCA
- Incorporate Cadmus IRA est.

Scenario 3. Hybrid Heat Pump (HHP) for all gas customers

- Convert existing gas customers to Hybrid Heat Pump (HHP) based on Cadmus burn out rate
- Incorporates CCA
- Incorporate Cadmus IRA est.

Scenario 4. HHP for existing, new customers electric with CCHP

- HHP Existing gas customers & Electrify new customers with CCHP
- Leverages retrofit opportunities with HHP
- Incorporates CCA
- Incorporate Cadmus IRA est.

Cadmus Scope

- High level IRA assumptions
- Updated load shapes for each scenario
- Conservation for each scenario
- Performance of CCHPs

E3 Scope

- Regional market assessments
- High level regional IRA Assumptions
- Resource costs and supply curves

PSE Scope

- Flows into PSE resource & system planning models
- Develop financial analysis to show rate impacts for both gas and electric

High-level modeling approach

Input

- Load profiles for each scenario with respective conservation bundles + est. IRA demand side (Cadmus)
- Regional impacts from electrification (E3)

Analysis

- Gas & Electric 23 IRP models
- Gas & Electric System Planning models
- Regional transmission impacts

Financial Analysis

- Utility costs
- Inclusion of IRA impacts
- Customer cost impacts

Output

- Integrate findings into targeted electrification strategy
- Electric & Gas customer rates
- Conservation numbers for various scenarios
- Study report

Modeling approach – details regarding input usage

INPUTS

PSE Service Territory

Cadmus:

- 4 scenarios
  - Load supply curves
  - Conservation bundles

PNW

E3:

Regional Electrification

- Resource Costs
- RNG, hydrogen supply curves

PSE MODELS

Electric T&D System Planning

Gas T&D System Planning

Gas Portfolio Model

Electric Portfolio Model

Gas Portfolio Model

Electric Portfolio Model

OUTPUTS

Electric T&D System Planning

Gas T&D System Planning

Gas Portfolio Model

Electric Portfolio Model

Per Scenario:

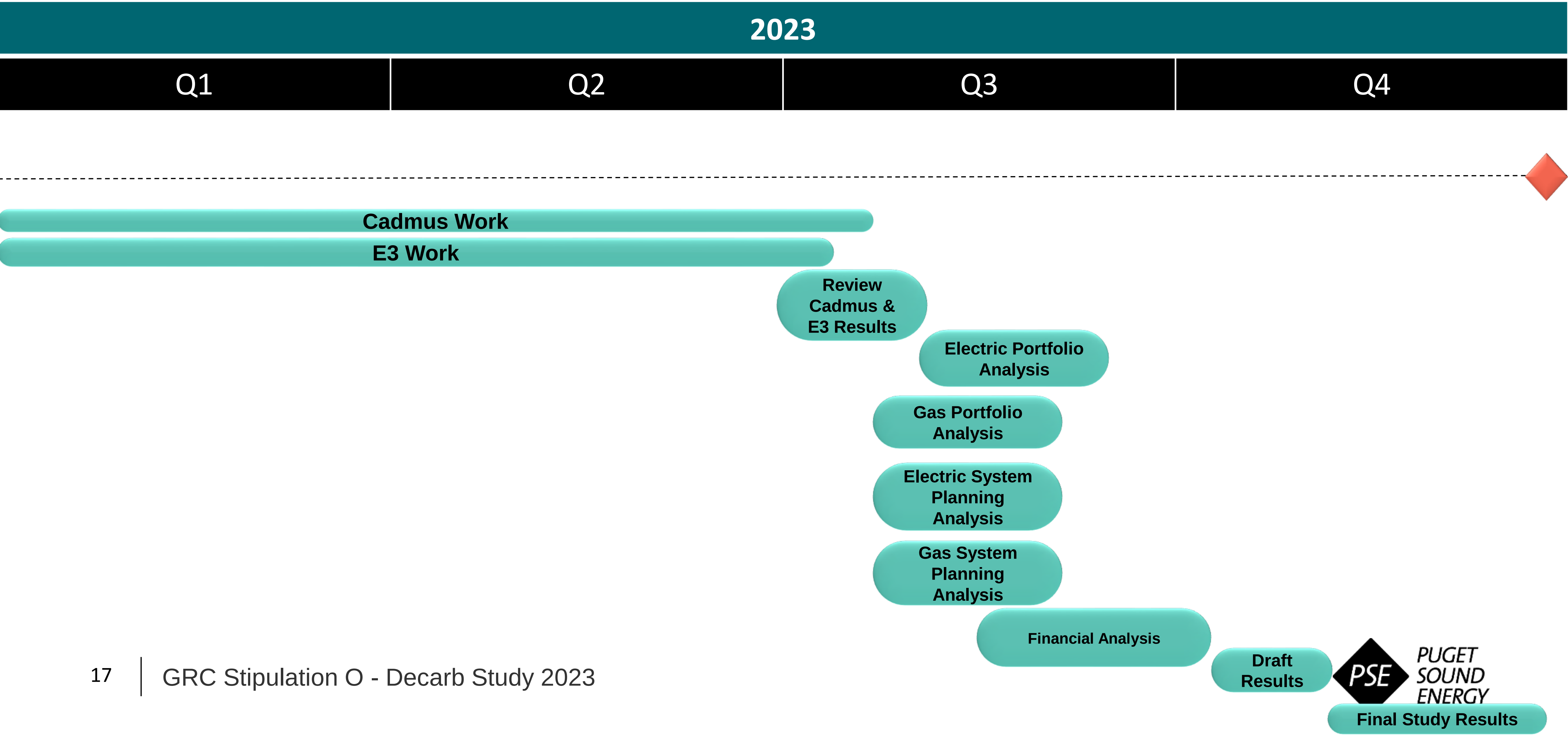
- Volume of infrastructure
- Fuel supply & emissions where applicable

Financial Analysis

Per Scenario:

- Total utility costs
- Total customer cost
- Est. customer rate impacts

GRC Stipulation O – updated decarbonization study timeline



PSE PUGET SOUND ENERGY

Scope update provided at final parties meeting on 12/8/23

Requirement	Status	Comments/Questions
(Pg. 35) PSE's final updated decarbonization study and the results of its electrification pilot will be made available to the public with no designations of confidentiality.	N/A	PSE plan to make the study, outputs and most of the inputs public (PSEs resource models, transmission models, and market prices are confidential).
a. A more up-to-date electrification scenario that takes into account recent performance trends of cold climate heat pumps (CCHPs)	✓	PSE generation & T&D system impact results shared on September 28, 2023. Cadmus reviewed load results in meeting on August 10, 2023.
b. An accounting of both near-term (3-5 years) and long-term costs and benefits of electrification, including carbon reductions and avoided gas system infrastructure costs due to fewer new customer connections.	✓	Shared near and long-term PSE generation & T&D system impact results on September 28, 2023. Updates provided in the December 8, 2023 meeting.
c. A segmentation of new and existing customers to separately evaluate the costs and benefits of electrifying new and existing customers and a scenario whereby PSE seeks to electrify all new customers and projected corresponding carbon emission reductions.	✓	PSE generation & T&D system impact results shared on September 28, 2023. Cadmus reviewed load results in meeting on August 10, 2023.
d. A review of the time to build out and the cost of incremental electric system costs based on recent cost trends in power and capacity, as well as sensitivity analysis around electric system assumptions to understand how these assumptions impact the viability of high electrification scenarios.	✓	PSE generation & T&D system impact results shared on September 28, 2023

Scope update provided at final parties meeting on 12/8/23

Requirement	Status	Comments/Questions
e. Updated unit costs, including the incentives provided by the Inflation Reduction Act (IRA).	✓	See Cadmus presentation from August 10, 2023.
f. Study the impacts and benefits of electric heat pump technologies on PSE's gas constrained delivery systems.	✓	See PSE presentation on September 28, 2023.
g. Collaborate with adjacent consumer-owned utility electric service providers to conduct coordinated electric delivery system and gas delivery system studies or pilots.	✓	This item is being met via the Targeted Pilot work with SCL.
h. Evaluate how to use the biennial conservation planning process to advance least-cost decarbonization strategies in PSE's gas utility service area, including by promoting fuel switching to electric utility service.	✓	Plan provided via email on August 31, 2023. Updates provided in the December 8, 2023 meeting.
i. Include regional forecasted load and market price sensitivities that reflect regional electrification.	✓	See E3 presentation from August 24, 2023.
j. An evaluation of the impact of electrification with and without hybrid heat pumps on gas and electric rates, to provide an update to the existing analysis in the E3 study referenced above.	✓	PSE presentation on September 28th for PSE generation & T&D system impact results, and Rate Impacts shared on November 8th & December 8th.
k. The results of the updated study will be incorporated into PSE's 2025 Natural Gas Integrated Resource Plan and a compliance filing in this docket by January 2025.	N/A	PSE will incorporate and expand on this study in the 2025 Natural Gas IRP.

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	Scenario 1: ASHP	Scenario 2: CCHP	Scenario 3: HHP	Scenario 4: HHP + CCHP
Based on	2023 Gas IRP & Electric Progress Report Loads	2023 Gas IRP & Electric Progress Report Loads	2023 Gas IRP & Electric Progress Report Loads	2023 Gas IRP & Electric Progress Report Loads
New Residential Customers	Full Electrification with air source heat pump (ASHP)	Full Electrification with cold climate heat pump (CCHP)	Hybrid Heat Pump (HHP)	HHP Existing & Electrify new customers with CCHP
Existing Gas Residential Customers	100% of gas furnaces converted to ASHP, starting in 2024 and the annual stock turnover reaches to 100% heat pump adoption in 2045. 74.2% (~591,000) ASHP and 25.8 (~206,000) ductless heat pump (DHP) in 2050	100% of gas furnaces converted to CCHP, starts in 2024 and the annual stock turnover reaches to 100% heat pump adoption in 2045 100% (~797,000) CCHP in 2050	100% of gas furnaces converted to hybrid heat pumps (std ASHP), starts in 2024 and the annual stock turnover reaches to 100% heat pump adoption in 2045 74.2% (~591,000) HHP and 25.8% (~206,000) DHP in 2050	100% of gas furnaces converted to hybrid heat pumps (std ASHP), starts in 2024 and the annual stock turnover reaches to 100% heat pump adoption in 2045 58.2% (~464,000) HHP, 20.2% (~161,000) DHP, and 21.6% (~172,000) CCHP in 2050
	100% of gas water heaters converted to market average water heaters, starts in 2024 and the annual stock turnover reaches to 100% electric water heater adoption in 2050	100% of gas water heaters converted to market average water heaters, starts in 2024 and the annual stock turnover reaches to 100% electric water heater adoption in 2050	100% of gas water heaters converted to market average water heaters, starts in 2024 and the annual stock turnover reaches to 100% electric water heater adoption in 2050	100% of gas water heaters converted to market average water heaters, starts in 2024 and the annual stock turnover reaches to 100% electric water heater adoption in 2050
	75% of gas dryers are converted to electric dryers, starts in 2024 and the annual stock turnover reaches to 75% electric dryer adoption in 2050	75% of gas dryers are converted to electric dryers, starts in 2024 and the annual stock turnover reaches to 75% electric dryer adoption in 2050	75% of gas dryers are converted to electric dryers, starts in 2024 and the annual stock turnover reaches to 75% electric dryer adoption in 2050	75% of gas dryers are converted to electric dryers, starts in 2024 and the annual stock turnover reaches to 75% electric dryer adoption in 2050
	29% of gas ovens and ranges are converted to electric ovens and ranges, starts in 2024 and the annual stock turnover reaches to 29% adoption in 2050	29% of gas ovens and ranges are converted to electric ovens and ranges, starts in 2024 and the annual stock turnover reaches to 29% adoption in 2050	29% of gas ovens and ranges are converted to electric ovens and ranges, starts in 2024 and the annual stock turnover reaches to 29% adoption in 2050	29% of gas ovens and ranges are converted to electric ovens and ranges, starts in 2024 and the annual stock turnover reaches to 29% adoption in 2050
Existing Electric Residential customers	Some homes converted from electric resistance heating to heat pump, if DSR is cost effective, starting in 2024	Some homes converted from electric resistance heating to heat pump, if DSR is cost effective, starting in 2024	Some homes converted from electric resistance heating to heat pump, if DSR is cost effective, starting in 2024	Some homes converted from electric resistance heating to heat pump, if DSR is cost effective, starting in 2024
Commercial New and Existing customers	70% of gas furnaces converted to ASHP, starting in 2024	70% of gas furnaces converted to ASHP, starting in 2024	70% of gas furnaces converted to ASHP, starting in 2024	70% of gas furnaces converted to ASHP, starting in 2024
	70% of gas water heaters converted to market average water heaters, starting in 2024	70% of gas water heaters converted to market average water heaters, starting in 2024	70% of gas water heaters converted to market average water heaters, starting in 2024	70% of gas water heaters converted to market average water heaters, starting in 2024
	50% of gas cooking equipment converted to electric cooking equipment, starting in 2024	50% of gas cooking equipment converted to electric cooking equipment, starting in 2024	50% of gas cooking equipment converted to electric cooking equipment, starting in 2024	50% of gas cooking equipment converted to electric cooking equipment, starting in 2024
Industrial customers	30% of industrial loads electrified, starting in 2024 and reaching 30% of industrial load by 2050	30% of industrial loads electrified, starting in 2024 and reaching 30% of industrial load by 2050	30% of industrial loads electrified, starting in 2024 and reaching 30% of industrial load by 2050	30% of industrial loads electrified, starting in 2024 and reaching 30% of industrial load by 2050
Transport customers	Small transport customers emissions were included per the CCA in the emission results.	Small transport customers emissions were included per the CCA in the emission results	Small transport customers emissions were included per the CCA in the emission results	Small transport customers emissions were included per the CCA in the emission results
Service Area	Includes combination customers (gas and electric), customers converting from non-PSE gas service to PSE electric service, and PSE gas service converting to non-PSE electric service	Includes combination customers (gas and electric), customers converting from non-PSE gas service to PSE electric service, and PSE gas service converting to non-PSE electric service	Includes combination customers (gas and electric), customers converting from non-PSE gas service to PSE electric service, and PSE gas service converting to non-PSE electric service	Includes combination customers (gas and electric), customers converting from non-PSE gas service to PSE electric service, and PSE gas service converting to non-PSE electric service
Climate Change	Includes climate change	Includes climate change	Includes climate change	Includes climate change
Demand Side Resources	Updated DSR for new load	Updated DSR for new load	Updated DSR for new load	Updated DSR for new load

GRC Stipulation O – updated decarbonization study

Cadmus's Outputs: CCHP Memo, Supply curves for various scenarios

Shared with Parties to the Settlement on August 10th, 2023

PUGET SOUND ENERGY

CADMUS

Puget Sound Energy Comprehensive Decarbonization Study

August 10, 2023

Meeting Agenda

1. Study Scope
2. Cold Climate Heat Pump Research
3. Inflation Reduction Act Research
4. Decarbonization Scenarios & Electric and Natural Gas Baseline Sales Impact

Study Scope

An **updated comprehensive decarbonization study** after 2023 CPA gas-to-electric conversion assessment, as part of Section O of Settlement Stipulation and Agreement between PSE and Settling Parties

Comprehensive **review of ASHP and CCHP technologies**, recent performance trends of CCHPs as well as equipment costs

Review of **Inflation Reduction Act** (IRA) for its impact on electrification

Evaluation of the **impacts of Cold Climate Heat Pumps (CCHPs) and hybrid systems** for new and existing customers within the residential sector

Electrification end uses assessed in this study includes **space heating, water heating, cooking and clothes dryers**.

Cold Climate Heat Pump Research

Cold Climate Heat Pumps (CCHPs): Definition

- The Northeast Energy Efficiency Partnerships (NEEP), a U.S. Department of Energy (DOE) Regional Energy Efficiency Organization, established the CCHP Specification in 2014.
  - The NEEP specification adds a requirement for efficiency at 5°F as AHRI standard test protocols for determining the Heating Seasonal Performance Factor (HSPF) do not include testing at temperatures below 17°F.
- The Northwest Energy Efficiency Alliance (NEEA) has adopted the NEEP standard for its own specification for ductless CCHPs while including an additional capacity requirement.
- Further, in 2022, ENERGY STAR adopted a cold-climate designation for residential ASHPs.

Heating Seasonal Performance Factor (HSPF) is a standard metric of efficiency used by the Air Conditioning, Heating, and Refrigeration Institute (ARHI) to estimate the seasonal heating efficiency of an ASHP. HSPF is the ratio of heating output (in Btus) over the course of the heating season divided by the electricity used (in watt-hours).

HSPF2 to replace HSPF (effective January 1, 2023), which attempts to better align measured efficiency with actual efficiency through a modified testing procedure. HSPF2 ratings are approximately 15% below previous HSPF ratings for ducted systems.

Coefficient of Performance (COP) is an instantaneous, unitless metric of efficiency (energy out divided by energy in) that is frequently used to characterize heat pump performance either at a particular temperature condition or as a seasonal measure of efficiency.

Seasonal COP (sCOP) is typically reported within field studies of heat pump performance**.**

Measuring CCHP Performance

- Actual performance of heat pumps typically been lower than rated efficiencies as measured by HSPF.
- A small field study in MA and NY including 23 homes of sole source cold climate heat pump heating found an average **sCOP of 2.38** (equivalent to HSPF 8.1).
  - Approximately 29% lower than the sCOP predicted by the rated HSPF of the equipment installed.
- As the climate of most of PSE's territory is milder than the climate in the Northeast, higher sCOPs may be expected in PSE service area.

CCHPs: Benefits and Challenges

Benefits of CCHPs

- CCHPs offer **improved efficiency at lower temperatures**, with many CCHPs continuing to operate at temperatures at or below -13°F.
- Many CCHPs, though not all models, can be sized to provide the sole source of heating without backup.
- Variable capacity output provides **improved comfort and efficiency** through reduced cycling at mild temperatures and partial loads for both heating and cooling.

Challenges of CCHPs

- While it is not expected to be a constraint in PSE's territory, most centrally ducted CCHPs still rely on **backup electric resistance or other supplemental heat** at colder temperatures (due to only having limited models that are able to meet 80% to 100% of rated capacity at 5°F).
- Since ductless CCHPs do not use an existing central distribution system, they may face challenges with **adequately distributing conditioned air** throughout a home.
- It is common to use electric resistance baseboards in small rooms where placing an indoor unit is and this adds to **installation and operating costs**.
- The added systems are typically not installed with an integrated controls package in PSE's market and will **require separate thermostats or controls** for each system.
- Some cold climate models may only be able to modulate down to 50% of the rated capacity, which can still lead to **cycling during mild temperature conditions** (e.g. 45-50°F+)
- CCHPs have a **significant cost premium** and despite their widespread availability, **awareness** at both the customer and contractor levels remains low.

Winter Peak Loads from Electrification: CCHP Impacts

CCHPs are expected to have lower peak demand impacts at all temperatures relative to non-CCHPs due to improved efficiency, however actual peak demand impacts may depend on a few factors:

- **COP during peak conditions**
  - Many non-CCHPs and CCHPs may have similar COPs at more modest temperatures (around 30°F)
  - As a result, during typical PSE winter peak conditions **demand reductions from CCHPs compared to non-CCHPs may be modest**
- **Use of supplemental electric resistance**
  - The use of **supplemental electric resistance** will be a primary driver of **added electrical demand** from converting natural gas heating to heat pumps.
  - Ductless heat pumps are not installed with supplemental electric resistance (including CCHPs)
  - Central heat pumps typically use supplemental electric resistance (including CCHPs) when not installed in a dual-fuel configuration with a backup furnace.
- **Heat pump balance point**
  - **Temperatures below the balance point will require the use of backup heating to maintain indoor comfort**. For heat pumps with electric resistance backup, auxiliary resistance heat will be used in conjunction with the heat pump's declining capacity to maintain the indoor thermostat setpoint.

Winter Peak Loads from Electrification: CCHP Impacts

Average Winter Peak Demand from **Ductless** CCHP Compared to **Ductless** Non-CCHP (Single Family, Existing)

Average kW	Percent Savings in Winter Peak Demand with CCHP vs non-CCHP
Peak Period	14%
Peak Period (≤35°F)	19%
Peak Period (≤27°F)	29%

Average Winter Peak Demand from **Ducted** CCHP Compared to **Ducted** Non-CCHP (Single Family, Existing)

Average kW	Percent Savings in Winter Peak Demand with CCHP vs non-CCHP
Peak Period	12%
Peak Period (≤35°F)	16%
Peak Period (≤27°F)	14%

Percent Difference in Energy Consumption from **Ductless** CCHP, **Ducted** CCHP, and **Standard** ASHP (Single Family, Existing)

Equipment Type	Percent Consumption Difference in Energy with CCHP vs non-CCHP
Standard ASHP	NA
Ducted CCHP	18%
Ductless CCHP	19%

Study Assumptions:

- **Ductless CCHPs** are not installed with integrated electric resistance backup
- **Ducted CCHPs** are installed with electric backup
- **Dual-fuel systems**, the heat pump will switch off when below the balance point (35°F) and eliminates electrical demand (outside of the furnace fan and air handler operation) during those periods.

Heat Pump Costs

Equipment	Avg. Cost per Unit
Baseline Technologies	
Gas Furnace	$5,380
Gas Boiler	$9,500
Gas Wall Furnace	$3,513
Central AC - Replace on failure	$8,450
Centrally Ducted ASHPs	
Centrally Ducted ASHP – Base	$14,800
Centrally Ducted ASHP – Dual Stage	$17,175
Centrally Ducted ASHP – ENERGY STAR	$17,800
Centrally Ducted ASHP – Cold Climate	$19,425
Centrally Ducted ASHP – Dual Fuel	$11,277
Centrally Ducted ASHP + Furnace – Dual Fuel	$16,250
Ductless Heat Pumps	
Ductless Heat Pump – Base	$13,174
Ductless Heat Pump – ENERGY STAR	$14,588
Ductless Heat Pump – Cold Climate	$14,941

Cost data is based on the contractor interviews conducted as part of 2023 IRP CPA.

Additional gas-to-electric conversion costs were panel upgrade, wiring and duct/pad costs and included in the analysis.

Cost Type	Cost
Panel Upgrade (average range)	$1,668
Duct configuration (when existing system does not have AC ducts)	$1,400
Wiring	$250

**Avg Central AC and Dual Fuel Heat Pump capacities were reported at 2.79 tons*
***Avg Ductless and Ducted Heat Pump capacities were reported at 2.94 tons*

Inflation Reduction Act Research

CADMUS

Inflation Reduction Act

- High Efficiency Electric Homes Rebates Act (HEEHRA) is largely focused on providing rebates to income-eligible consumers for electric equipment and electrification projects.
  → Both HEEHRA and the 25C tax credit include **specific incentives for electrification improvements** and electrical upgrades needed to switch to heat pumps and other electric appliances.

- The Home Energy Performance-Based, Whole House Rebates program (HOMES) provides rebates for homeowners based on whole-house energy retrofits.
  → The HOMES Rebate program and 179D tax deduction **indirectly encourages electrification** through incentivizing site energy use or energy cost reduction.

- States will apply to the U.S. DOE for funding to implement their HEEHRA and HOMES programs through their respective state agencies.

- Washington State Department of Commerce expected to handle funding for the state and run programs sometime in 2024

- Expanded tax credits (25C) are available as of January 2023 through the IRA.

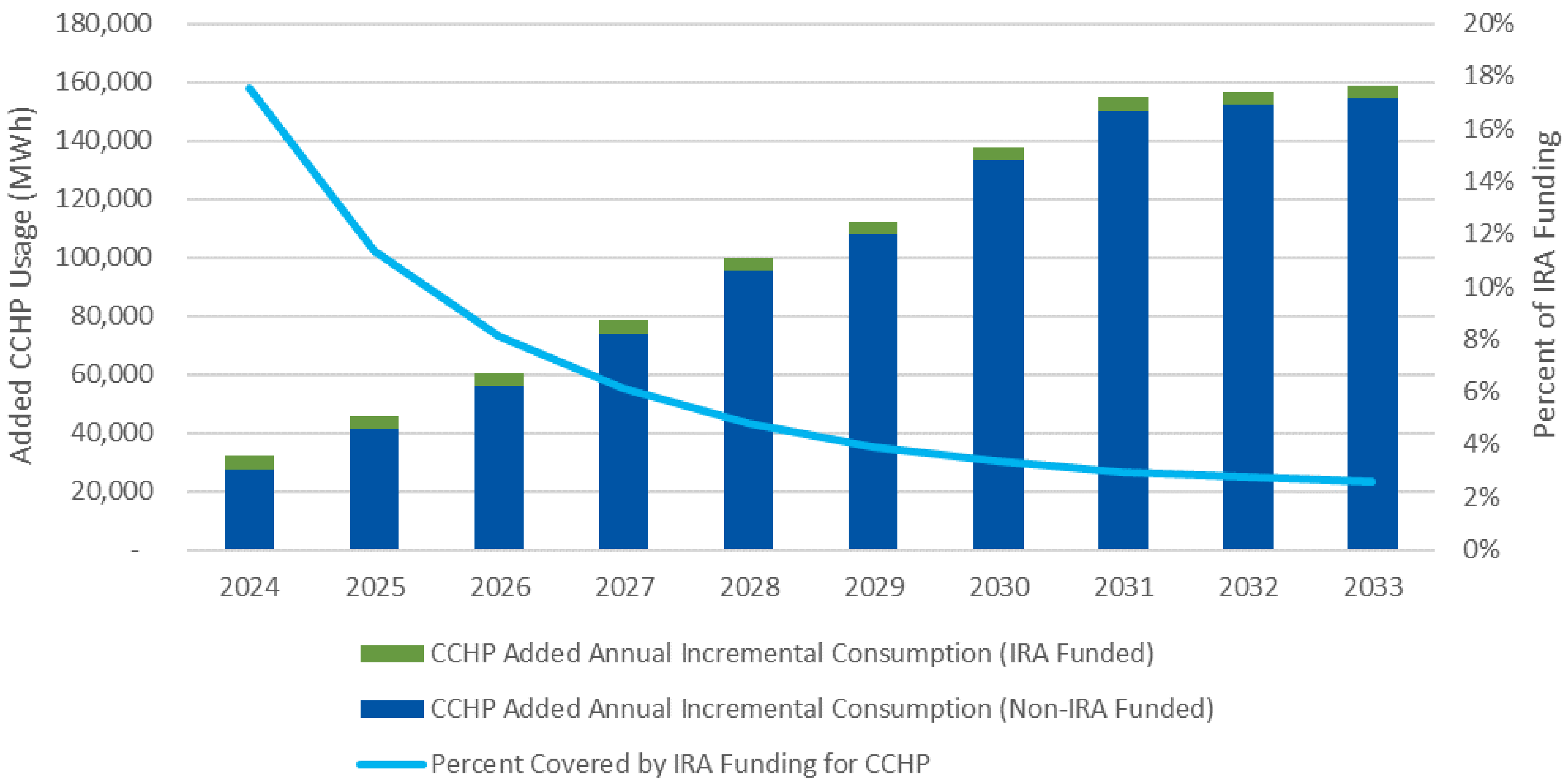
- DOE guidelines published for HOMES and HEEHRA on July 27th, 2023

IRA Guidance/Assumptions:

- HOMES/HEEHRA + 25C tax credits to be combine
- Dual-fuel systems are eligible for HEEHRA and 25C (if electric is the primary fuel)
- PSE IRA funding based on proportion of housing units in PSE service area compared to WA and US
- HOMES program indirectly funds 25% for electrification
- HEEHRA program contributes 75% funds for electrification measures
- 25C only applies to homeowners (primary residence)

PSE IRA Funding for CCHP (Scenario 2)

Share of CCHP Annual Incremental Consumption by IRA and Non-IRA Funding over 10 Yrs



IRA Impact on Heat Pump Costs

Potential Impact of 25C Tax Credit and HEEHRA Rebate on Cost of Heat Pumps for a customer with a household income in the range of 80-150% of AMI

Equipment	Base Cost Estimate	Est. 25C Tax Credit Value	Est. HEEHRA Rebate[a]	Net Cost
Centrally Ducted ASHP				
Centrally Ducted ASHP – Base	$14,800	[b]	[b]	$14,800
Centrally Ducted ASHP – Dual Stage	$17,175	[b]	[b]	$17,175
Centrally Ducted ASHP – ENERGY STAR	$17,800	$2,000[c]	$8,000	$7,800
Centrally Ducted ASHP – Cold Climate	$19,425	$2,000[c]	$8,000[d]	$9,425
Centrally Ducted ASHP – Dual Fuel[c]	$11,277	$983[c]	$8,000	$2,294
Centrally Ducted ASHP + Furnace – Dual Fuel[c]	$16,250	$2,000[c]	$8,000	$6,250
Ductless Mini-Split Heat Pump (assumed 3 tons)				
Ductless Mini-Split Heat Pump – Base	$13,443	[b]	[b]	$13,443
Ductless Mini-Split Heat Pump – ENERGY STAR	$14,886	$2,000[c]	$7,443	$5,443
Ductless Mini-Split Heat Pump – Cold Climate	$15,246	$2,000[c]	$7,623[d]	$5,623

Sources: 26 C.F.R. § 25C; Public Law 117-169 (2022): 1817-2090;

[a] While this table shows the HEEHRA rebate estimate for residents making 80-150% of AMI, customers, residents making <80% AMI would be expected to receive the full $8,000 for all qualifying heat pumps, given the cost estimates used.

[b] Equipment is not assumed to meet the efficiency criteria for ENERGY STAR or for CEE Tier 3.

[c] Equipment meeting ENERGY STAR or different CCHP specifications may not meet CEE Tier 3 criteria.

[d] Equipment meeting CCHP specification may not qualify for ENERGY STAR designation.

PSE PUGET SOUND ENERGY

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Decarbonization Scenarios & Electric and Natural Gas Baseline Sales Impact

Study Scope

RESIDENTIAL (Focused Scope)

- Electric and natural gas baseline sales impact for four different scenarios.
- Space heating, cooking, water heating and dryer end-uses.

COMMERCIAL

- Same assumptions as 2023 CPA and for all four scenarios.
- Space heating (ASHP), cooking and water heating end-uses.

INDUSTRIAL

- Same assumptions as 2023 CPA and for all four scenarios.
- A portion (~30%) of natural gas loads is converted to electric based on prior analysis by Cadmus and E3.

PSE Service Area Load Impacts:

Electric only – natural gas equipment converts to electric (increases PSE electric load)

Natural gas only – converted to electric equipment (reduces PSE natural gas load)

Combination service – converted to electric equipment (increases PSE electric load and reduces PSE natural gas load

Study Implications:

This study investigates at four technology scenarios however this does not represent the likely mix of technologies within programs.

Methodology - Decarbonization Scenarios

SCENARIO 1. FULL ELECTRIFICATION WITH ASHPs for new and existing residential customers → ASHP FULL

Under this scenario the end-of-life replacement of natural gas equipment with ASHPs (with no natural gas backup) will reach 100% annual adoption within the study horizon.

SCENARIO 2. FULL ELECTRIFICATION WITH CCHPs for new and existing residential customers → CCHP FULL

The end-of-life replacement of natural gas equipment with CCHPs will reach 100% annual adoption within the study horizon.

SCENARIO 3. HHP WITH ASHPs for new and existing residential customers → HHP

ASHP or ductless system with the natural gas backup for new and existing residential customers.
The end-of-life replacement of natural gas equipment with HHPs will reach 100% annual adoption within the study horizon.

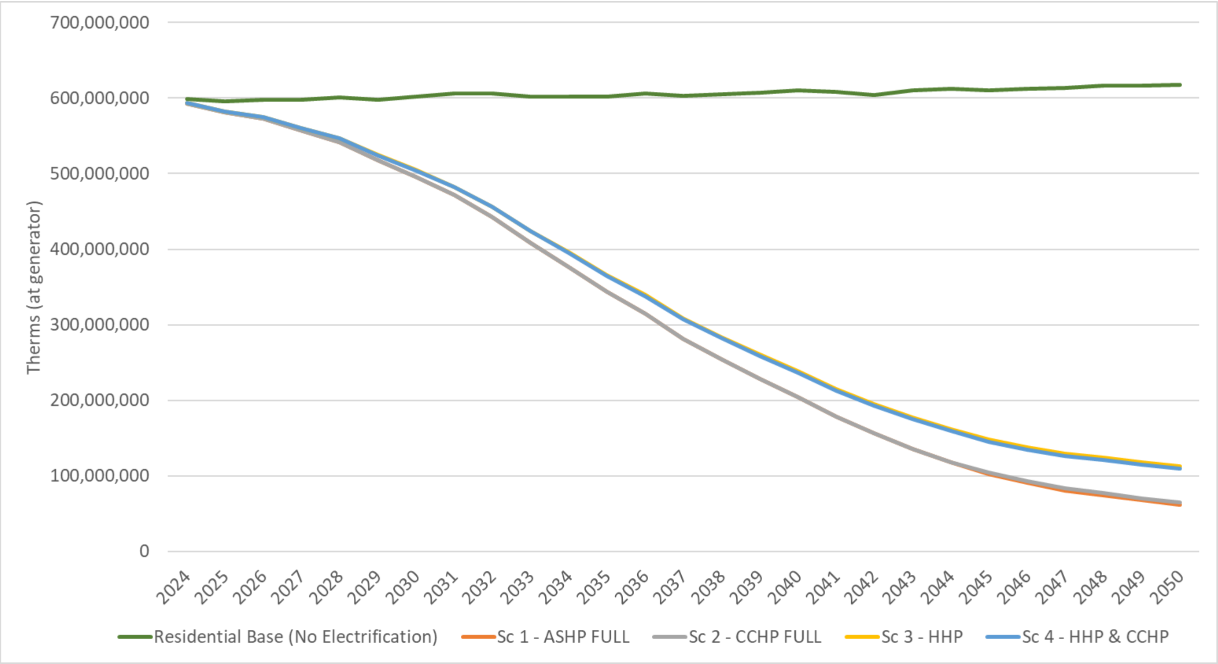
SCENARIO 4. HHP WITH ASHPs for existing customers / CCHPs for new customers → HHP&CCHP

ASHP or ductless system with the natural gas backup for existing residential customers
All new residential customers have CCHPs.
The market adoption rate of HHP or ductless system with natural gas backup was 100% for existing residential applications.

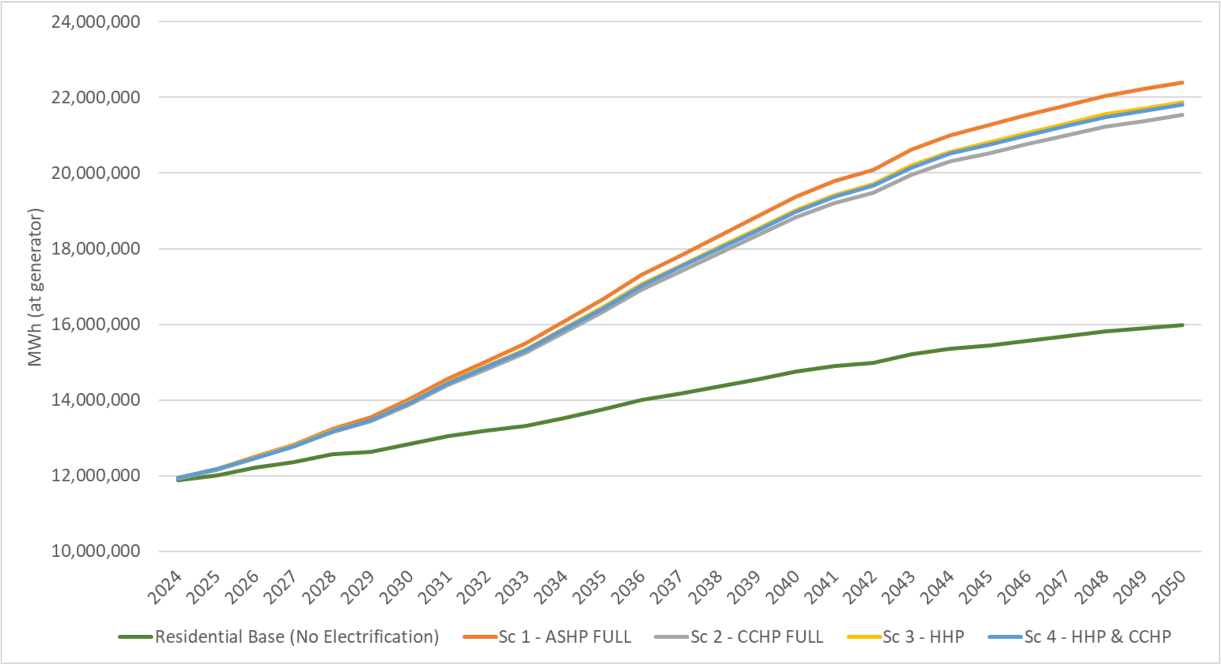
All commercial and industrial customers have the same adoption across all scenarios.

Impact on Residential Baseline Energy Forecast (All End-Uses)

Natural Gas Forecast



Electric Forecast



Sc 1 - ASHP FULL: 40% electric increase and 89% gas decrease in 2050 from the base case forecast

Sc 2 - CCHP FULL: 35% electric increase and 89% gas decrease in 2050 from the base case forecast

Sc 3 - HHP: 37% electric increase and 82% gas decrease in 2050 from the base case forecast

Sc 4 - HHP&CCHP: 36% electric increase and 82% gas decrease in 2050 from the base case forecast

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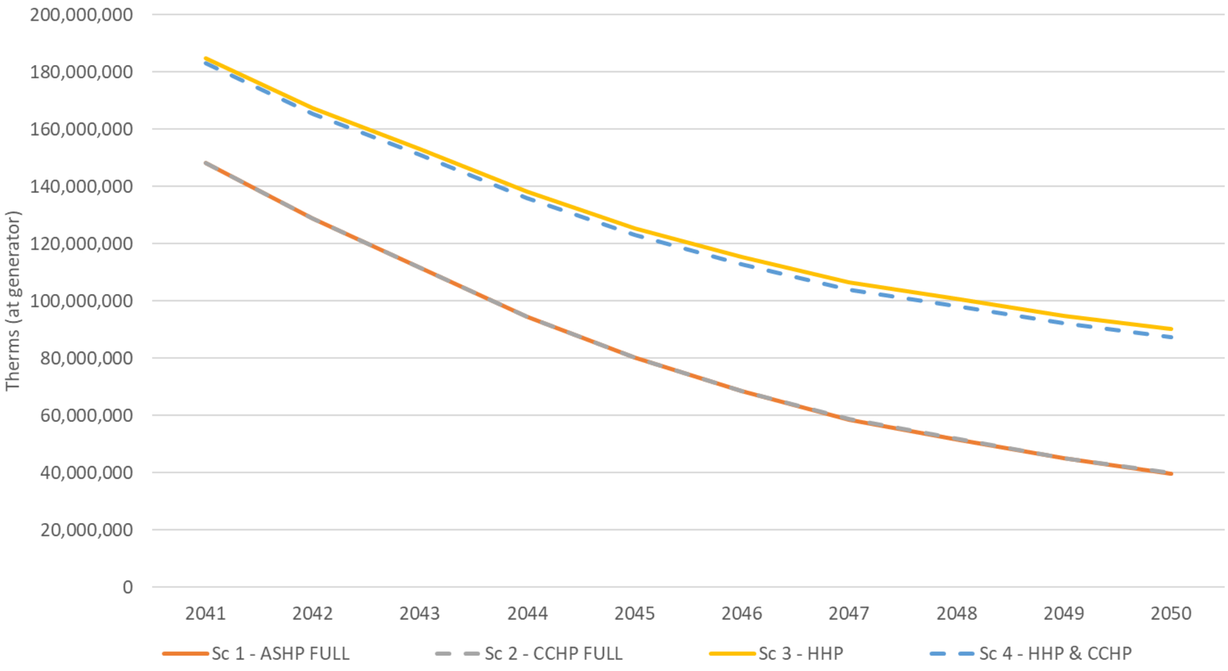
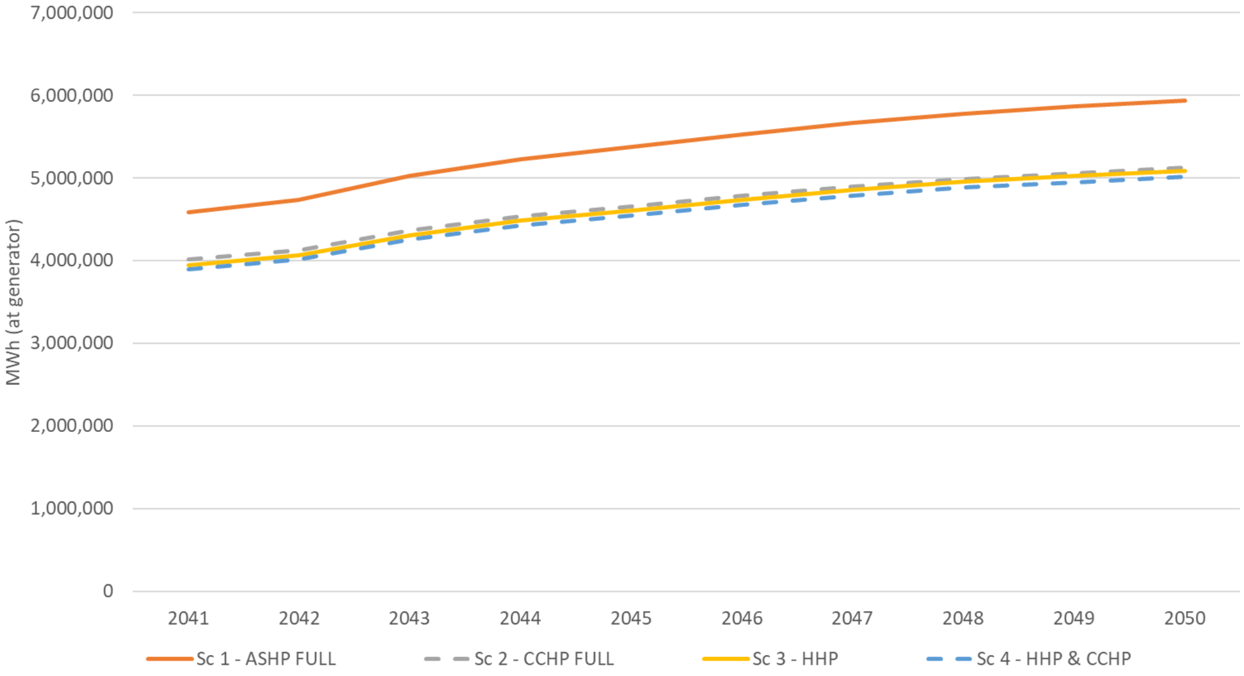
Impact on Residential Energy Forecast (Gas Heating / Heat Pump End Uses)

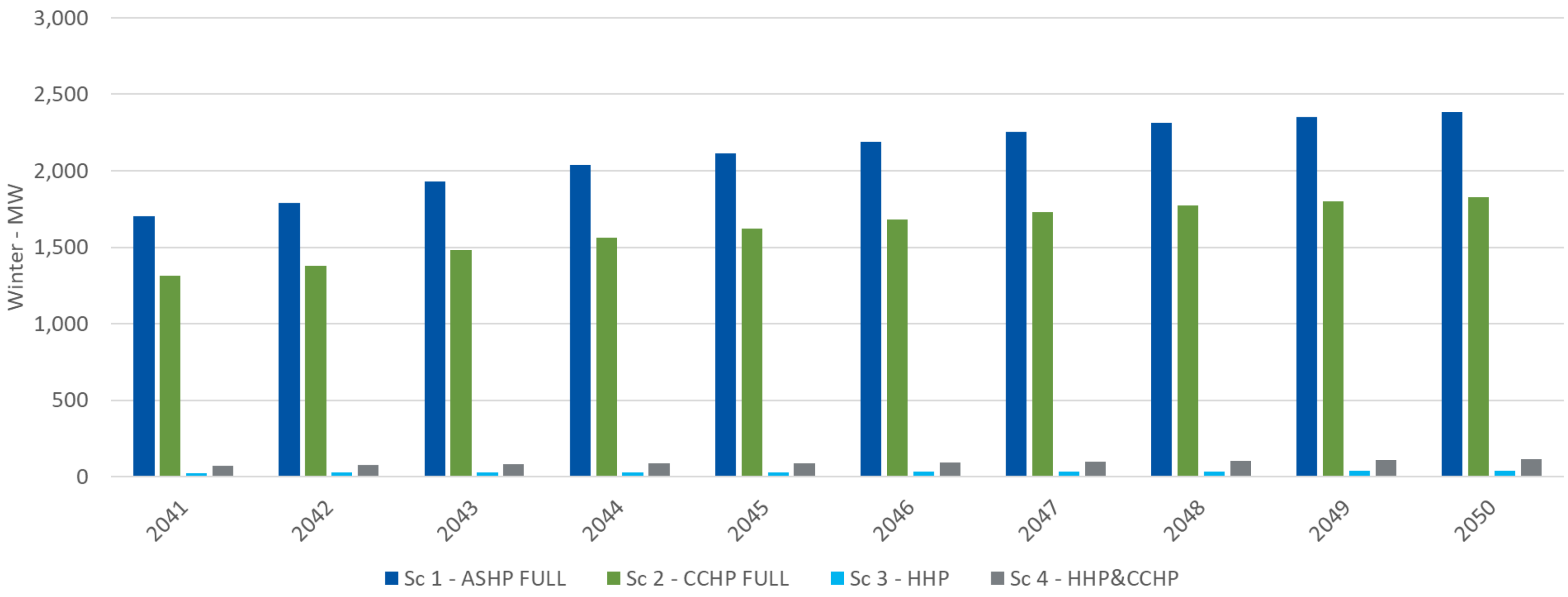
Natural Gas Heating Load Forecast (2041-2050)



Electric Heat Pump Forecast (2041-2050)



Added Peak Demand – Residential, Heat Pump End Uses (2041-2050)



Sc 1 - ASHP FULL shows 2,383 MW increase to the PSE system peak by 2050

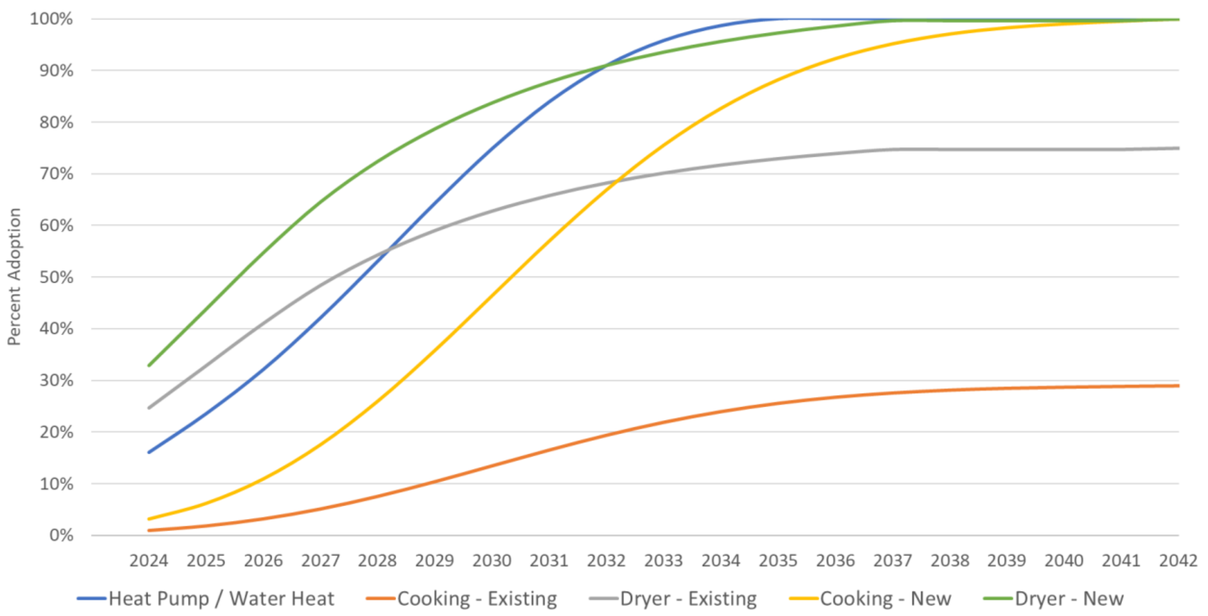
Sc 2 - CCHP FULL has added winter peak equals to 77% of Sc 1 - ASHP FULL (1,828 MW) by 2050

Sc 3 - HHP shows 39 MW increase to the PSE system peak by 2050, which is 2% of Sc 1 - ASHP FULL

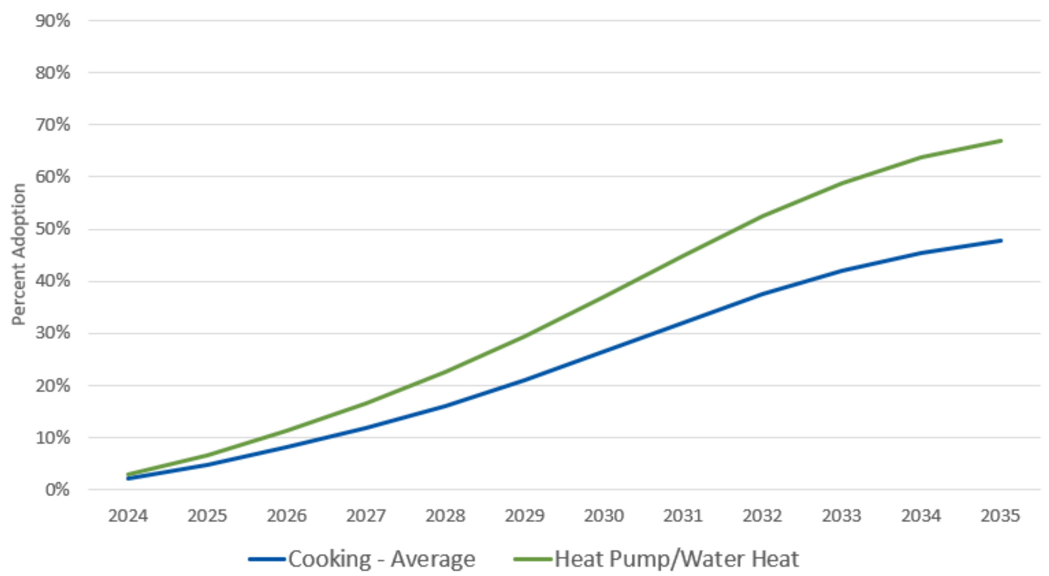
Sc 4 - HHP&CCHP shows 115 MW increase (5% of Sc 1 - ASHP FULL) to the PSE system peak by 2050

Adoption Curves

Residential Adoption Curves



Commercial Adoption Curves



Residential Adoption Estimated:

End of life equipment reaches maximum adoption of 100% for all heat pumps and water heaters, and dryers and cooking in new construction.

75% adoption for existing dryers

29% adoption for existing cooking

Ramp rates based on Council 2021 Power Plan

Commercial Adoption Estimated:

Heat Pump and water heat (70% max) – based on ACEEE 2020 study "Electrifying Space Heating in Existing Commercial Buildings: Opportunities and Challenges"

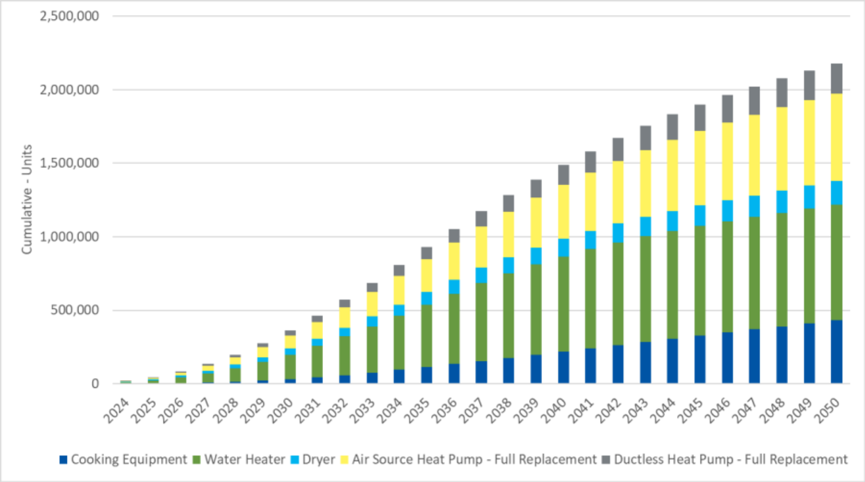
Cooking (50% max) - assume market barriers for converting some gas cooking equipment (estimated)

Ramp rates based on Council 2021 Power Plan

Residential Equipment Adoption Forecast

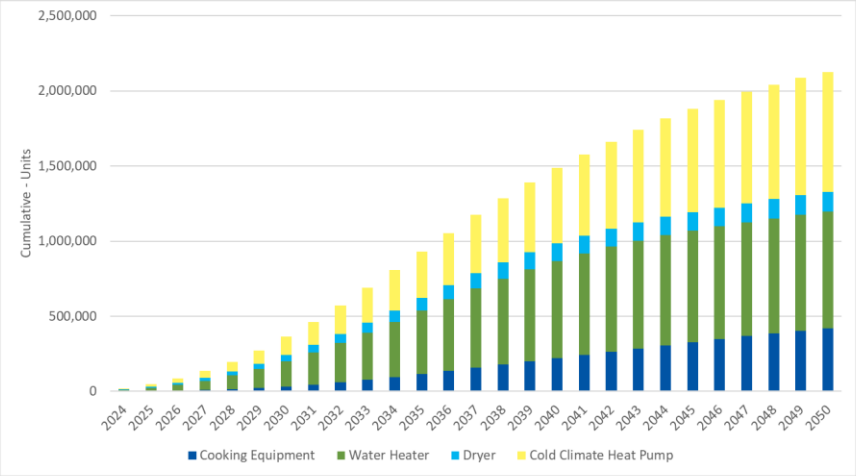
~314k Water heaters, ~67k Dryers, ~77k Cooking equipment **in 10 years**; ~778k Water heaters, ~132k Dryers, ~418k Cooking equipment **in 27 years**

Scenario 1 ASHP FULL



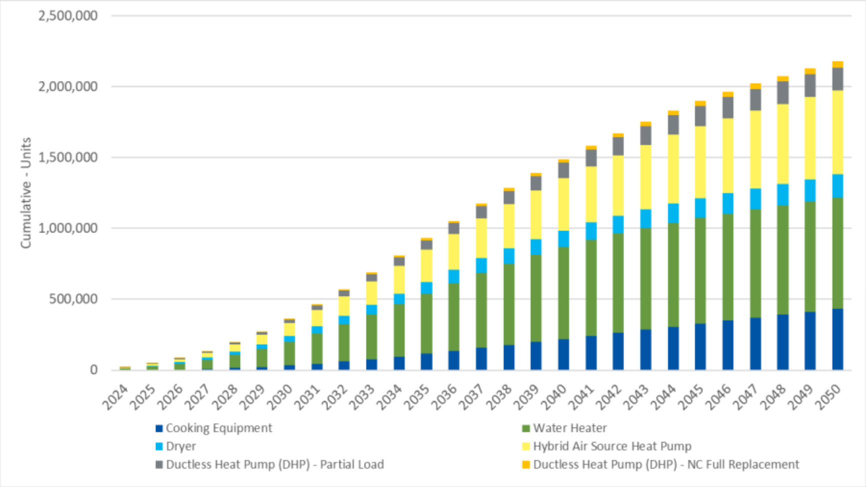
Units in 10 years:
~167k ASHPs
~61k Ductless HPs
Units in 27 years:
~591k ASHPs
~206k Ductless HPs

Scenario 2 CCHP FULL



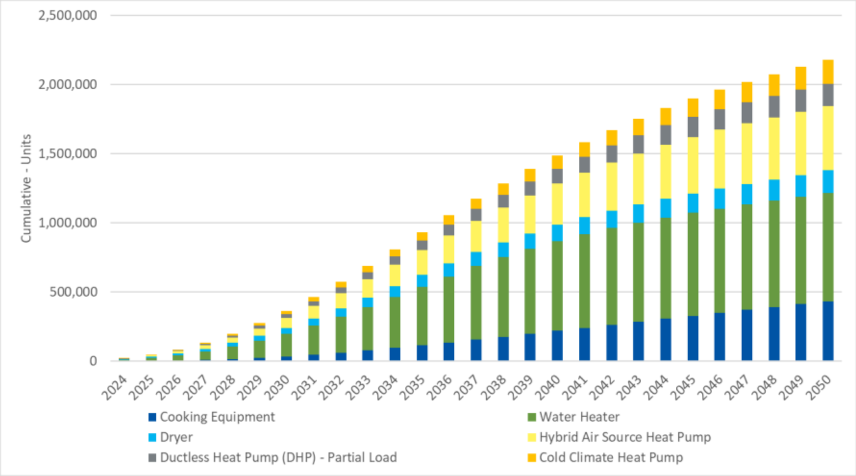
Units in 10 years:
~229k CCHPs
Units in 27 years:
~797k CCHPs

Scenario 3 HHP



Units in 10 years:
~167k Hybrid ASHPs
~61k Ductless HPs
Units in 27 years:
~591k Hybrid ASHPs
~206k Ductless HPs

Scenario 4 HHP&CCHP



Units in 10 years:
~134k Hybrid ASHPs (existing cons.)
~44k CCHPs (new cons.)
~49k Ductless HPs
Units in 27 years:
~464k Hybrid ASHPs
~172k CCHPs
~161k Ductless HPs

CADMUS

PSE PUGET SOUND ENERGY

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Questions

GRC Stipulation O – updated decarbonization study

E3's Outputs: Regional Electrification Assumptions

Shared with Parties
to the Settlement
on August 24th , 2023

PSE PUGET SOUND ENERGY

Puget Sound Energy (PSE) GRC Settlement Study: Regional Context

Stakeholder Meeting

August 24, 2023

Energy+Environmental Economics

Study Description

+ **Overarching Goal of E3's Analysis:**
  - Develop a set of metrics for the **regional infrastructure**, **electric resource availability** and **renewable fuels** that can be expected due to Washington's and neighboring jurisdictions' decarbonization policy commitments and plans

+ **Three core tasks provide input to PSE's ongoing gas decarbonization study and future electric system studies such as the next IRP analysis**
  1. Impacts of Heating Decarbonization Pathways on Regional Infrastructure
  2. Renewable Electric Resource Supply and Costs
  3. Renewable Fuels Supply and Costs

1. Impacts of Heating Decarbonization Pathways on Regional Infrastructure – Electric Peak Demand

+ Objectives

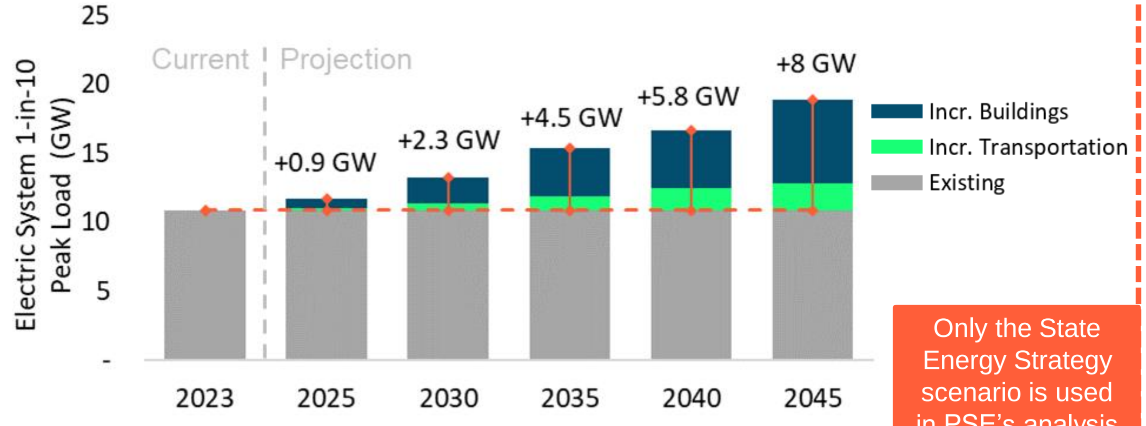
- Assess impacts of heating electrification on electric firm capacity requirements West of the Cascades
- Estimate the impact on regional gas infrastructure requirements considering design day gas demand for both buildings and power generation

+ Key Findings

- Peak electric demand in Western Washington will increase by 8 GW in 2045, mainly driven by heating electrification, if the state follows the electrification trajectory envisioned in the 2021 State Energy Strategy.
- A hybrid electrification approach using dual-fuel heat pumps will reduce peak impact on the electric system to 3.6 GW by utilizing the capacity of existing gas distribution systems.

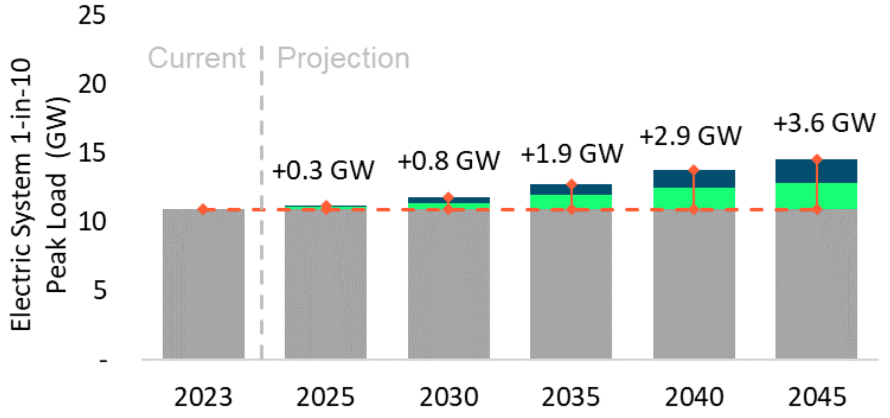
Electric System 1-in-10 Peak Demand – Western WA

State Energy Strategy Scenario



Only the State Energy Strategy scenario is used in PSE's analysis

Hybrid Scenario



1. Impacts of Heating Decarbonization Pathways on Regional Infrastructure – Capacity Requirements in 2045

+ **Serving new heating peak demands West of Cascades will require investments in local generation and transmission.**
  - **Cross-Cascades transmission expansion** to connect to renewables or thermal generation outside of Western WA
  - **Local Non-GHG Emitting Emissions Resources** such as hydrogen, nuclear SMR or off-shore wind.
    - **Clean Firm Resources** such as hydrogen CTs and nuclear SMR meet CETA requirements of 100% clean energy.
    - **Off-shore wind** does not provide firm capacity, so nameplate capacity additions to meet winter peaks are very large.
+ **In practice, a portfolio of solutions will likely be most appropriate.**
+ **Some clean resources also provide clean energy to the system in addition to the capacity.**

Scenario	Alternative 1: Cross-Cascades Transmission Expansion + East-side Resources	Alternative 2 Local Non-GHG Emitting Resources	
		2a. Clean Firm Resources	2b. Offshore Wind
Capacity of resources *required if incremental peak were served entirely with one resource type (in practice, a portfolio of options could be deployed)*			
State Energy Strategy	8.2 GW	8.2 GW*	20-80 GW*
Hybrid	3.7 GW	3.7 GW	9-36 GW
Upfront capital costs *of resources required if incremental peak were served entirely with one resource type*			
State Energy Strategy	$15-50 Billion**	$11-46 Billion***	$58-264 Billion
Hybrid	$9-25 Billion	$7-23 Billion	$26-119 Billion

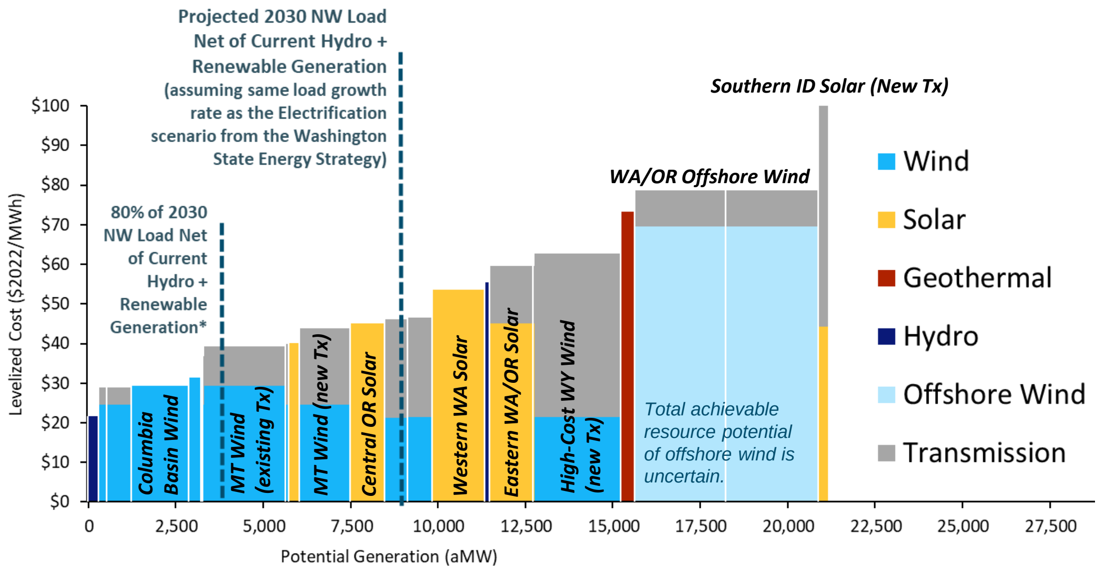
* An ELCC value of 98% is applied to the clean firm resources assuming a 2% forced outage rate. Offshore wind is assumed a wide range of ELCC at 10-40% given changing values with system load profiles and penetration levels
** Transmission expansion cost is assumed at $435/kW based on costs of two proposed cross-Cascades transmission expansion projects in BPA's 2022 Transmission Cluster Study. Total cost for Alternative 1 is calculated as transmission expansion cost plus clean firm resource cost
*** Upfront cost assumptions are $950-9,000 for clean firm resources (representing cost ranges of example technologies with hydrogen CT on the low end and a mix of hydrogen CT and nuclear SMR on the high end) and $2,900-3,300 for offshore wind, based on technology cost ranges from NREL ATB 2022. Hydrogen pipeline cost to bring hydrogen produced from outside of Western WA is added assuming $10 million per mile of pipeline cost and 350-800 miles of pipeline needs to be built to bring hydrogen from Eastern WA or Wyoming/Utah.

2. Renewable Electric Resource Supply and Costs

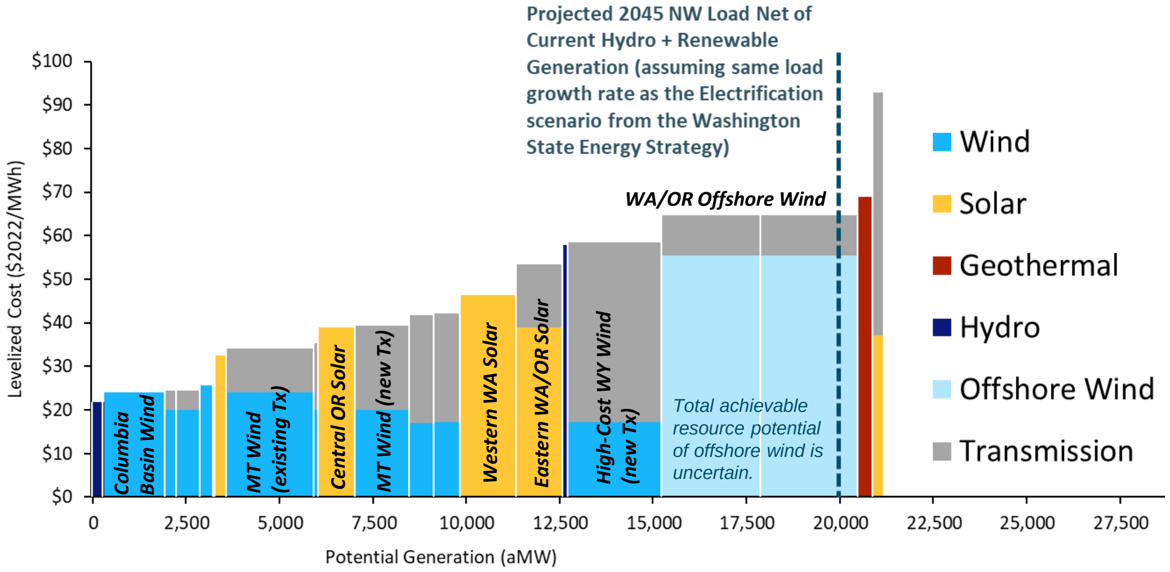
+ **Objective:** Assess the renewable resource availability to serve loads in the Northwest under the impacts of regional heating decarbonization and provide inputs for future PSE work on clean resource cost potential

+ **Key Findings:**
  - To meet clean electricity targets in 2030, Pacific Northwest will need to leverage a combination of renewable resources, including local wind and remote wind from Montana.
  - To meet 100% clean electricity requirements with renewables by 2045, the Pacific Northwest will need require a portfolio of local and remote solar and wind resources, potentially including offshore wind
  - By 2045, significant transmission upgrades will be needed to access the full potential of high-quality out-of-state resources, as well as offshore wind

2030 Renewable Resource Supply Curve



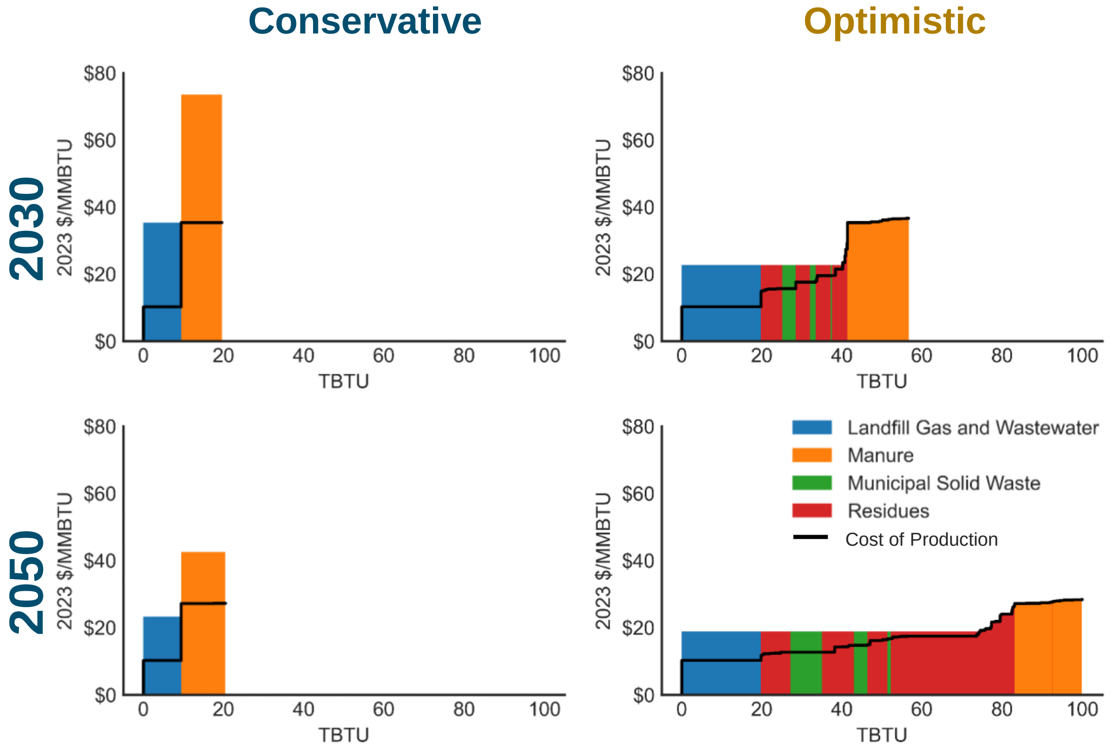
2045 Renewable Resource Supply Curve



* 80% of 2030 load is shown above given that CETA might allow provisions for up to 20% in offsets in 2030 to help achieve carbon-neutral electricity

3. Renewable Fuels Supply and Costs - Biomethane

- **Objective:** Update renewable fuel supply curves from the previous E3 gas decarbonization studies for PSE to reflect recent federal policies and impacts from low-carbon fuel market conditions
- **Key Findings for Biomethane (RNG)**
  - Competition in low-carbon transportation fuel markets, not the cost of production, will likely drive biomethane fuel costs for PSE
  - RNG costs are high across most feedstocks and worldviews
  - Under a conservative worldview, limited resource types are available and transportation policies provide high premiums over production costs.
  - Under an optimistic worldview, a broader set of resource types become available and transportation sector demand is lower.



	Conservative	Optimistic
Feedstock Availability	Biomethane only sourced from **WA/OR/ID** as a part of a **regional market**	**National market** with access to resources **in all states west of Mississippi River + British Columbia**
Conversion Pathways	**Anaerobic digestion** using landfill & wastewater gas, and manure	**+ Thermal gasification** after 2030 using municipal solid waste, and agricultural & forest residues
Access to clean fuels markets	**High demand from LCFS and RFS markets**, with full credits from the two markets internalized in fuel cost	**Less demand,** assuming partial RFS credits and no LCFS credits due to transportation electrification driving a reduction in RNG demand.

3. Renewable Fuels Supply and Costs – Synthetic Fuels

+ **Key Findings for Synthetic Fuels**
  - PSE has a variety of options for hydrogen and synthetic natural gas production, each with their own risks and benefits.
  - Using dedicated wind resources maximizes IRA incentives but increases challenge of matching hydrogen supply to hydrogen demand
  - Using grid electricity provides more flexibility in meeting demand but may be more expensive depending on how much IRA incentive can be internalized.

Summary of hydrogen resource assumptions, costs, benefits & risks

Resource	Mid-Term Costs	Benefits	Risks
Dedicated Wind, Eastern Washington	\$(5)-\$20/ MMBTU	• Guaranteed full 45V credit under annual and hourly-matching rules • Hedges against risk of procuring hydrogen made with higher-quality WY wind	• Storage challenges reduce suitability to meet high-load-factor demands • Competition for highest-quality wind for direct electric loads
Dedicated Wind, Wyoming	\$(5)-\$25/ MMBTU	• If highest-quality wind is used, becomes the cheapest hydrogen resource available • Storage helps supply high-load-factor demands	• High cost of transportation costs requires pairing with highest-quality wind • Competition for highest-quality wind for direct electric loads
Grid-Tied Eastern Washington	\$0-\$30/ MMBTU	• High-load-factor demands easily met with baseload operation • Flexible operation can reduce costs and increase 45V tax credit	• May not be possible to secure full 45V credit • Deliverability, additionality, and hourly matching may increase costs
Distributed, Grid-Tied Western Washington	\$(5)-30/ MMBTU	• Can be built even when new hydrogen pipelines can't	• Similar risks to grid-tied eastern Washington wind
British Columbia	\$20-\$45/ MMBTU	• May be helpful to balance hydrogen blending into LDC	• Low-capacity factor wind and inability to secure 45V credit increases cost • Competition for highest-quality wind for direct electric loads

GRC Stipulation O – Updated decarbonization study

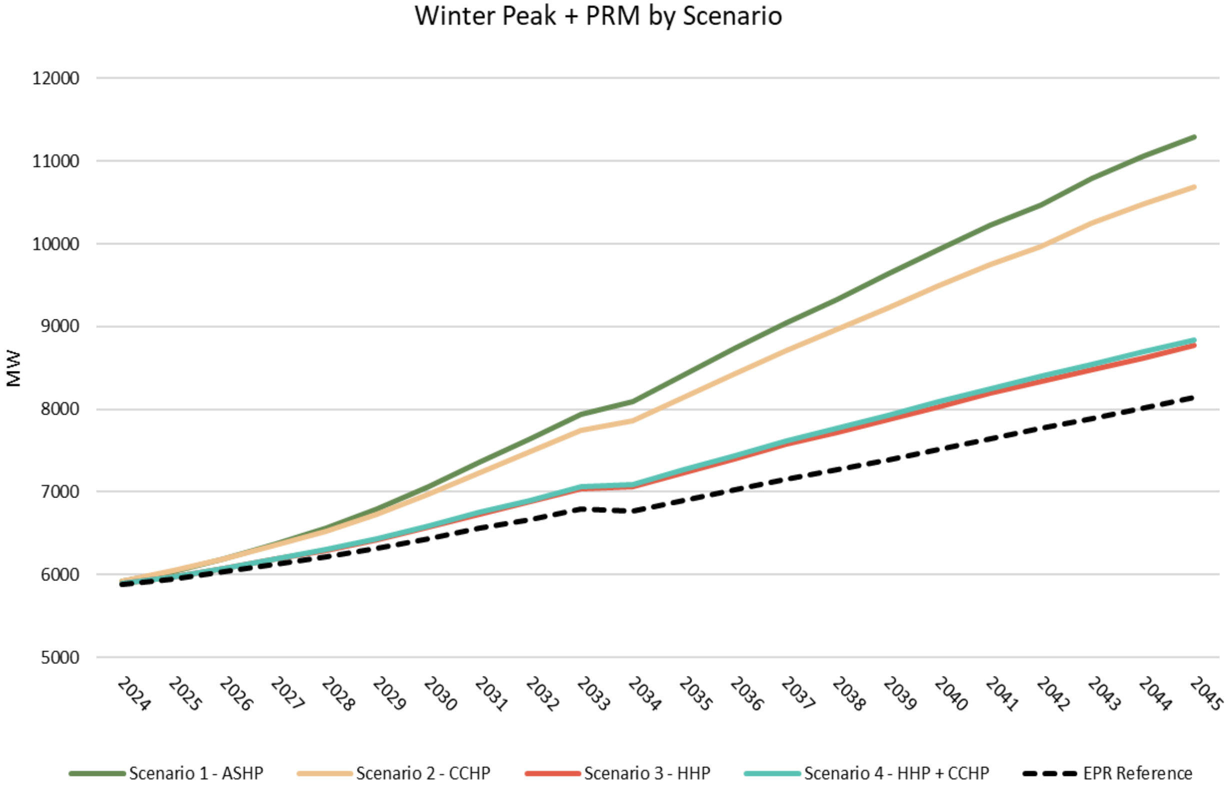
Electric Portfolio Model Output

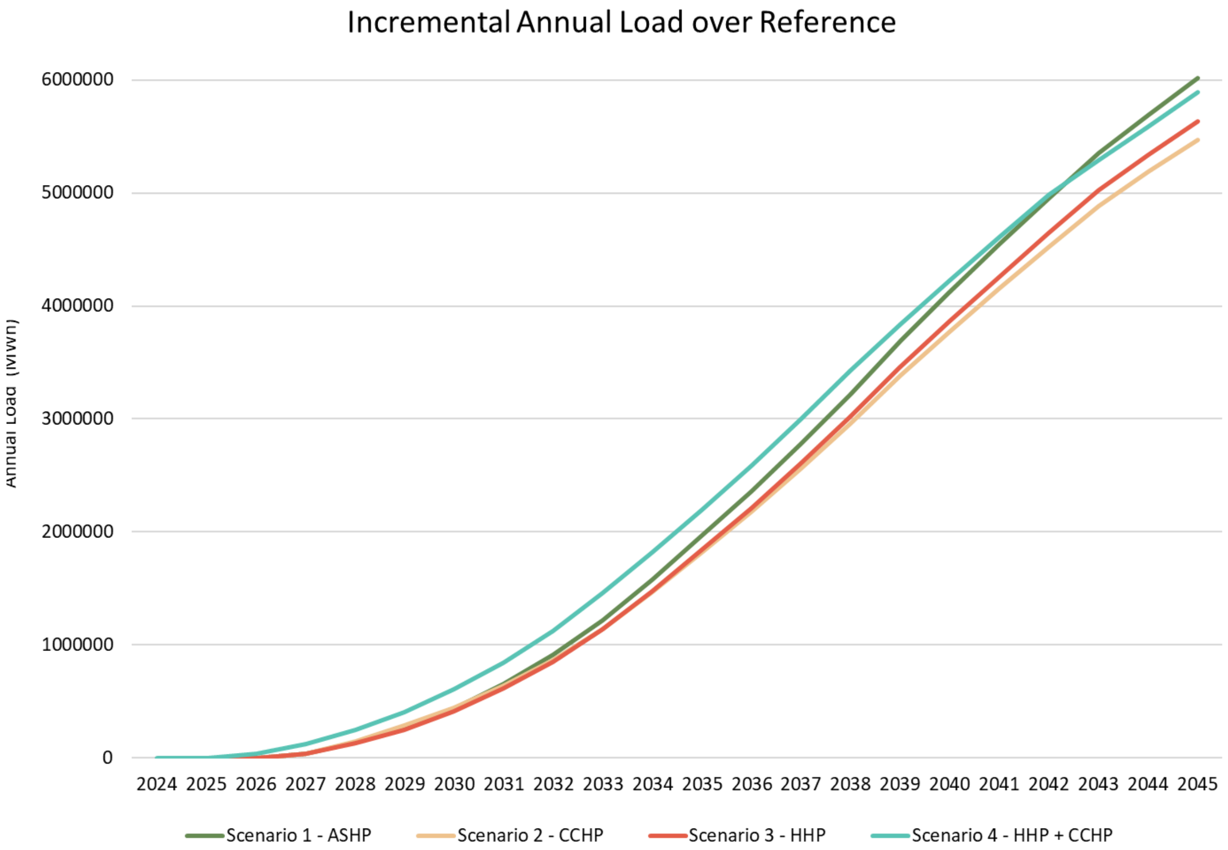
Updates made to the 2023 Electric Progress Report model to evaluate the Stipulation O decarbonization study scenarios

- Start with the 2023 Electric Progress Report reference portfolio
  - Leveraging Aurora model

- Key Changes:
  - Adjust load/peak to reflect each scenario
  - Increase the cost of hydrogen to that provided by E3’s regional study
  - Updated resource costs from E3
  - Updated conservation potential and costs
  - Updated demand response potential and costs

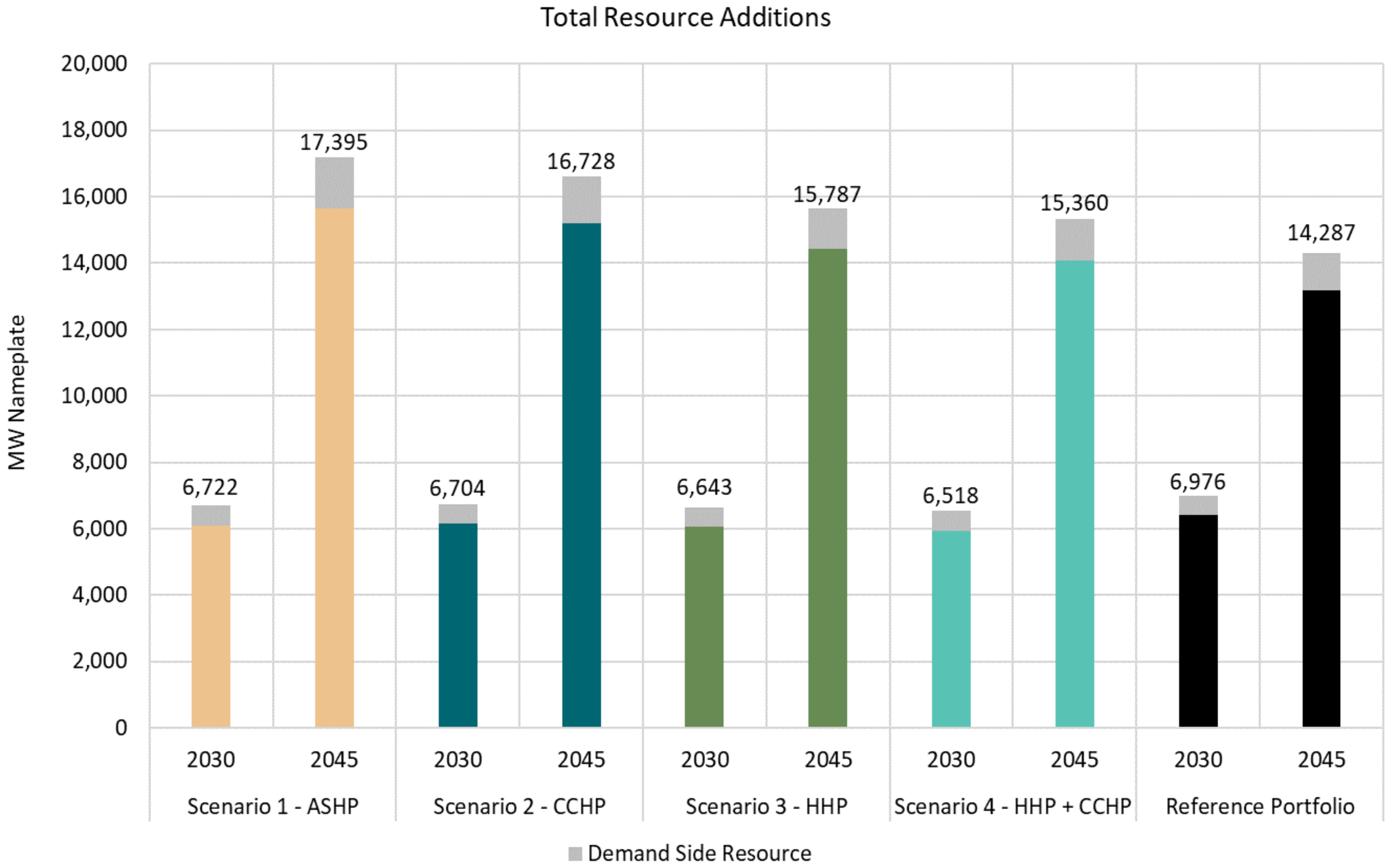
Electric peak and load impacts for each scenario





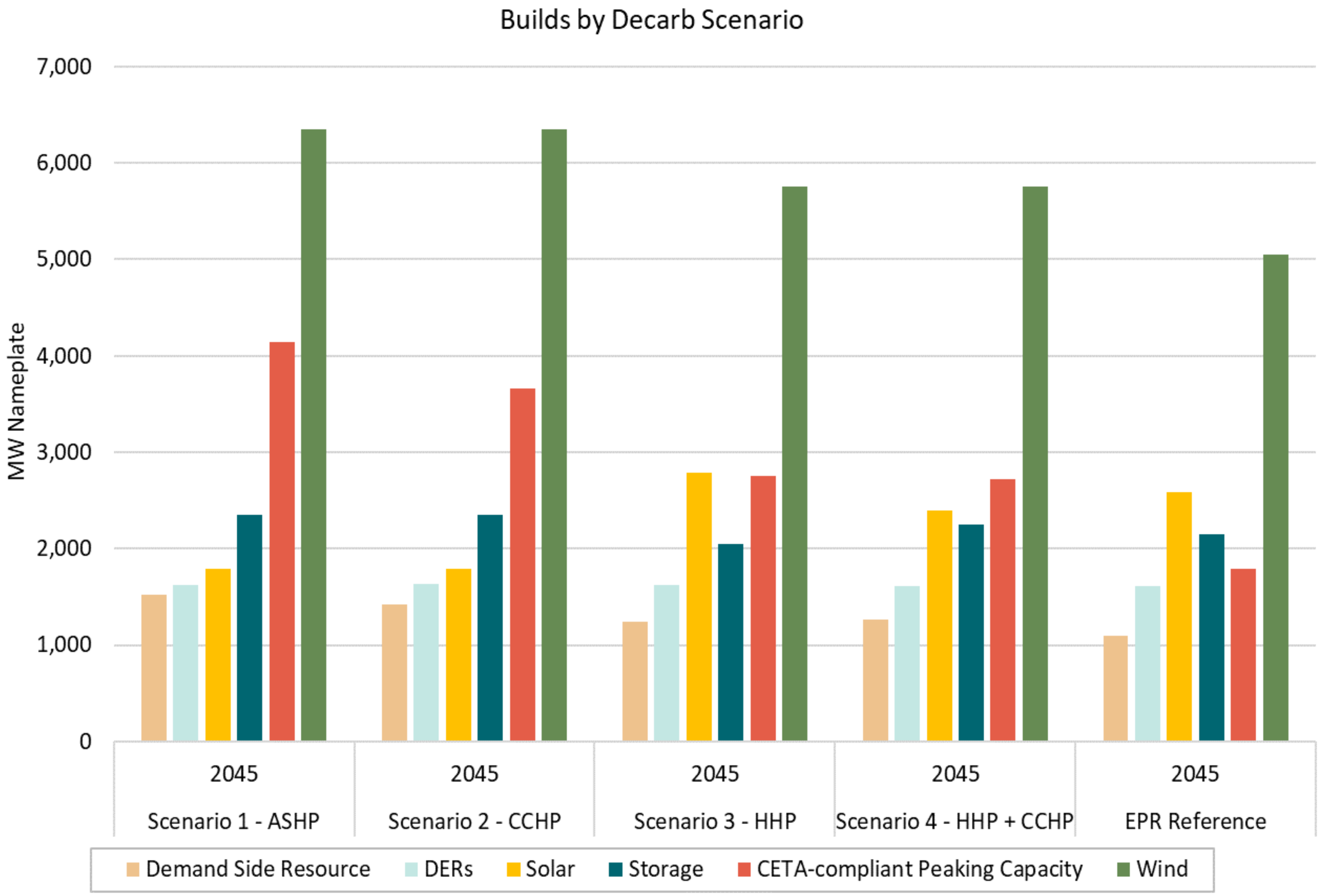
Key:
ASHP = Air source heat pump
CCHP = Cold climate heat pump
HHP = Hybrid heat pump (dual fuel heat pump, of gas back up heat pump)
EPR = Electric Progress Report

Electric portfolio outputs, showing megawatts (MW) of new builds for each scenario



Key:
ASHP = Air source heat pump
CCHP = Cold climate heat pump
HHP = Hybrid heat pump (dual fuel heat pump, of gas back up heat pump)
EPR = Electric Progress Report

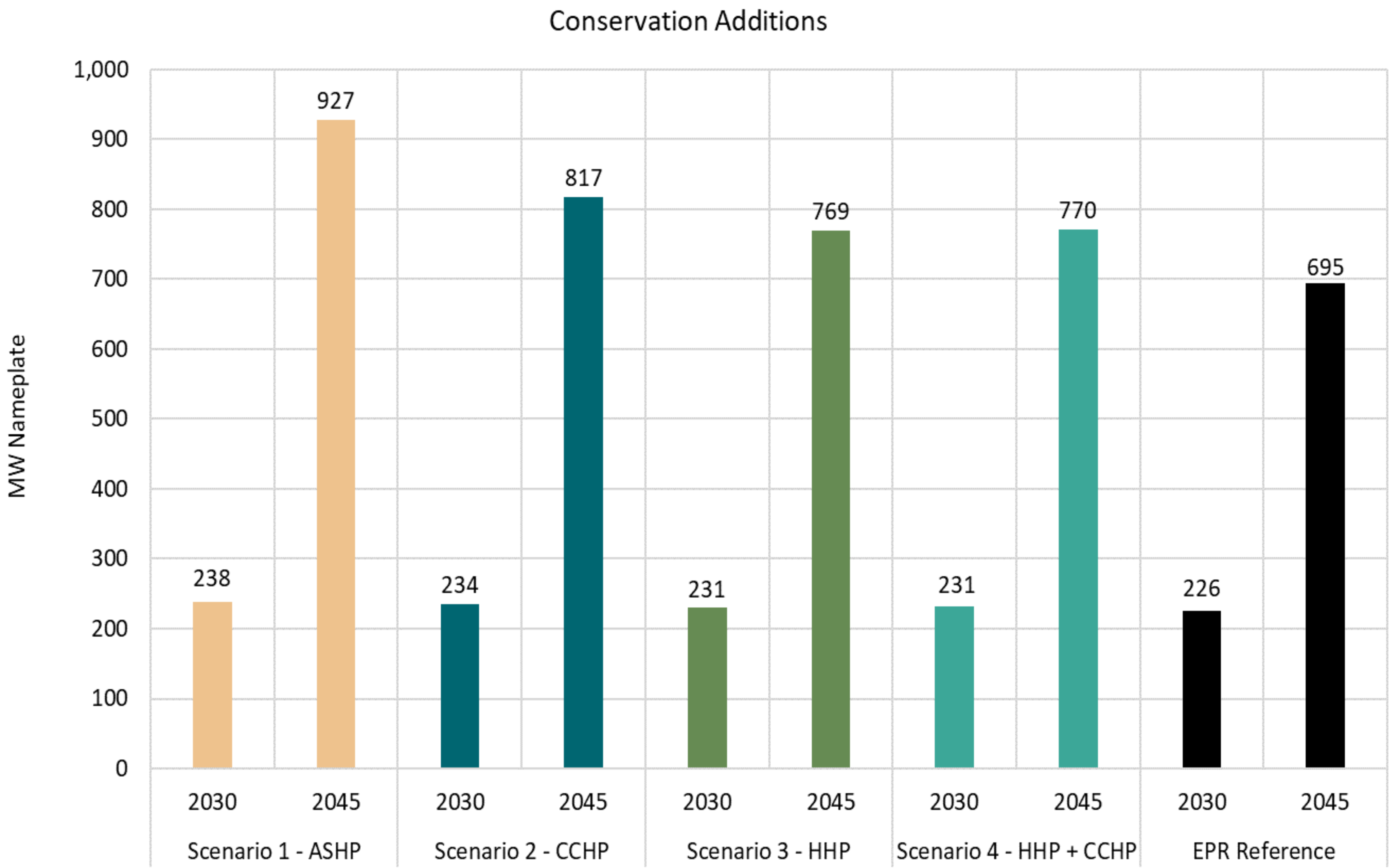
Electric portfolio outputs, showing megawatts of builds by resource type for each scenario



Key:
ASHP = Air source heat pump
CCHP = Cold climate heat pump
HHP = Hybrid heat pump (dual fuel heat pump, of gas back up heat pump)
EPR = Electric Progress Report

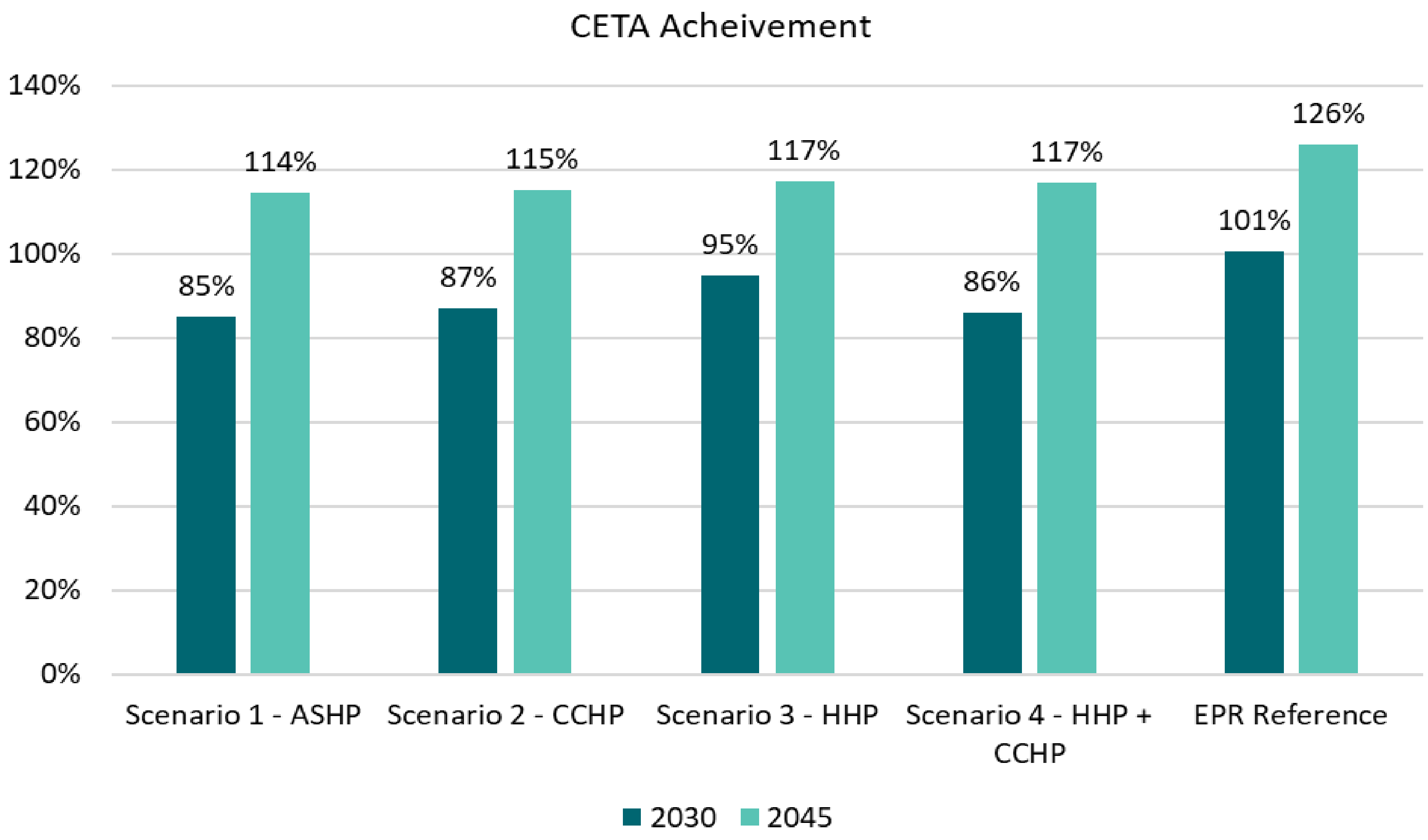
PUGET SOUND ENERGY

Electric portfolio megawatts of conservation for each scenario



Key:
ASHP = Air source heat pump
CCHP = Cold climate heat pump
HHP = Hybrid heat pump (dual fuel heat pump, of gas back up heat pump)
EPR = Electric Progress Report

Electric portfolio clean energy transformation act (CETA) achievement for each scenario



Key:
ASHP = Air source heat pump
CCHP = Cold climate heat pump
HHP = Hybrid heat pump (dual fuel heat pump, of gas back up heat pump)
EPR = Electric Progress Report

Electric portfolio cost outputs for each scenario

	EPR Reference	Scenario 1 - ASHP	Scenario 2 – CCHP	Scenario 3 - HHP	Scenario 4 – HHP + CCHP
$ 1000s					
NPV without Social Cost of GHG	$ 17,606,979	$ 22,908,342	$ 22,515,887	$ 22,100,974	$ 21,683,514
Social Cost of Greenhouse Gases	$ 3,239,669	$ 3,701,943	$ 3,602,939	$ 3,364,238	$ 3,562,271
Total Scenario NPV	**$ 20,846,648**	**$ 26,610,284**	**$ 26,118,826**	**$ 25,465,212**	**$ 25,245,785**

Key:
ASHP = Air source heat pump
CCHP = Cold climate heat pump
HHP = Hybrid heat pump (dual fuel heat pump, of gas back up heat pump)
EPR = Electric Progress Report

PUGET SOUND ENERGY

GRC Stipulation O – Updated decarbonization study

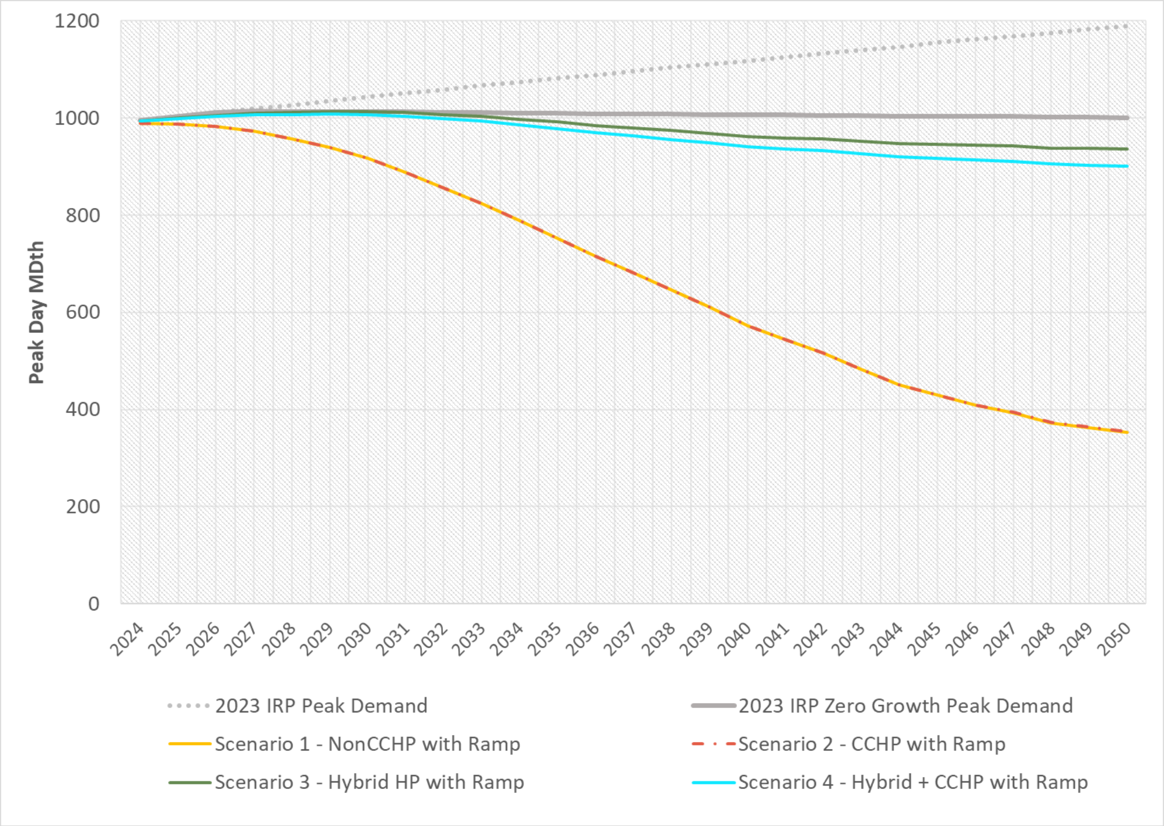
Gas Portfolio Model Output

PUGET SOUND ENERGY

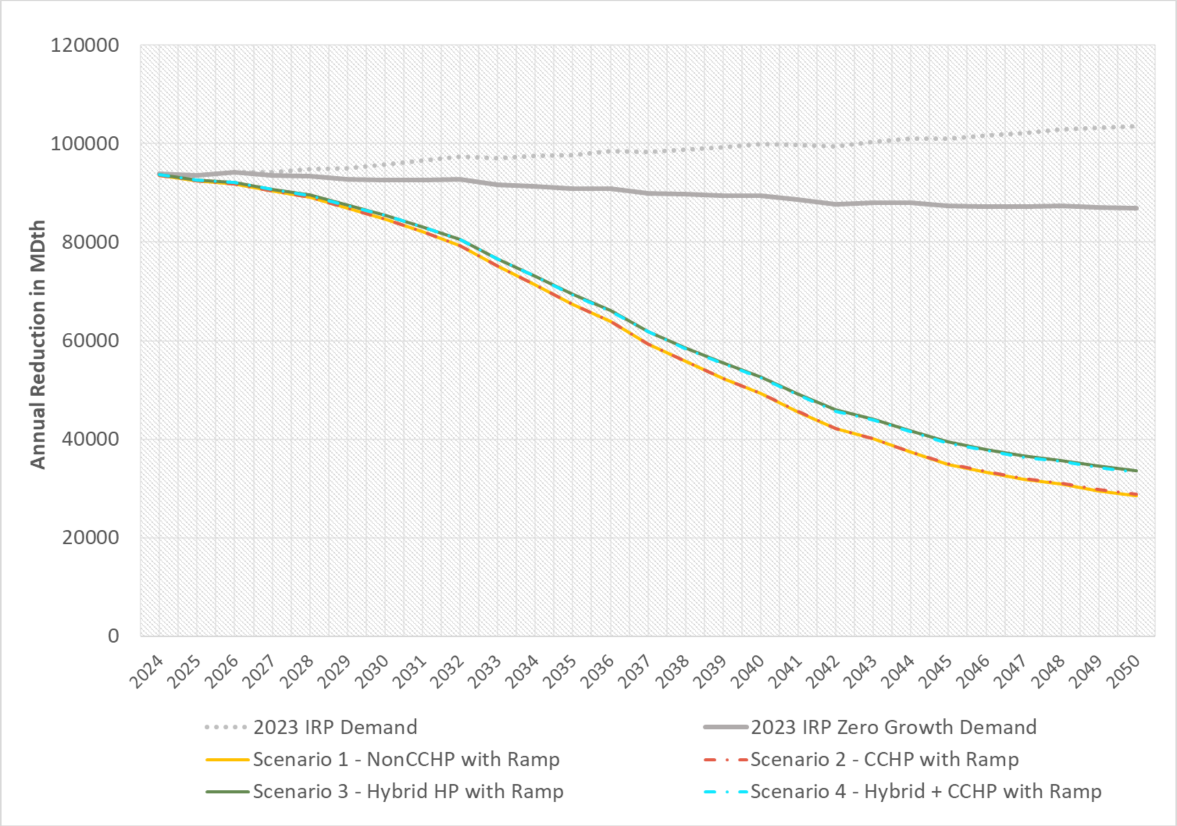
Updates made to the 2023 Gas Integrated Resource Plan model to evaluate Stipulation O decarbonization study scenarios

- Started with the 2023 Gas Utility IRP – Mid Demand forecast
  - Leveraging SENDOUT Model
- Equipment costs for CCHP and Performance based on Cadmus CCHP memo
- Incorporate costs updated to reflect the IRA demand side impacts from Cadmus
- The Cadmus load shapes were incorporated for each scenario
- Did not include Carbon Offsets as they are equivalent to Climate Commitment Act (CCA) allowance purchases
- Updated renewable natural gas (RNG) supply curve from E3 regional analysis
- Green Hydrogen supply curve from E3 regional analysis

Gas peak and load impacts for each scenario



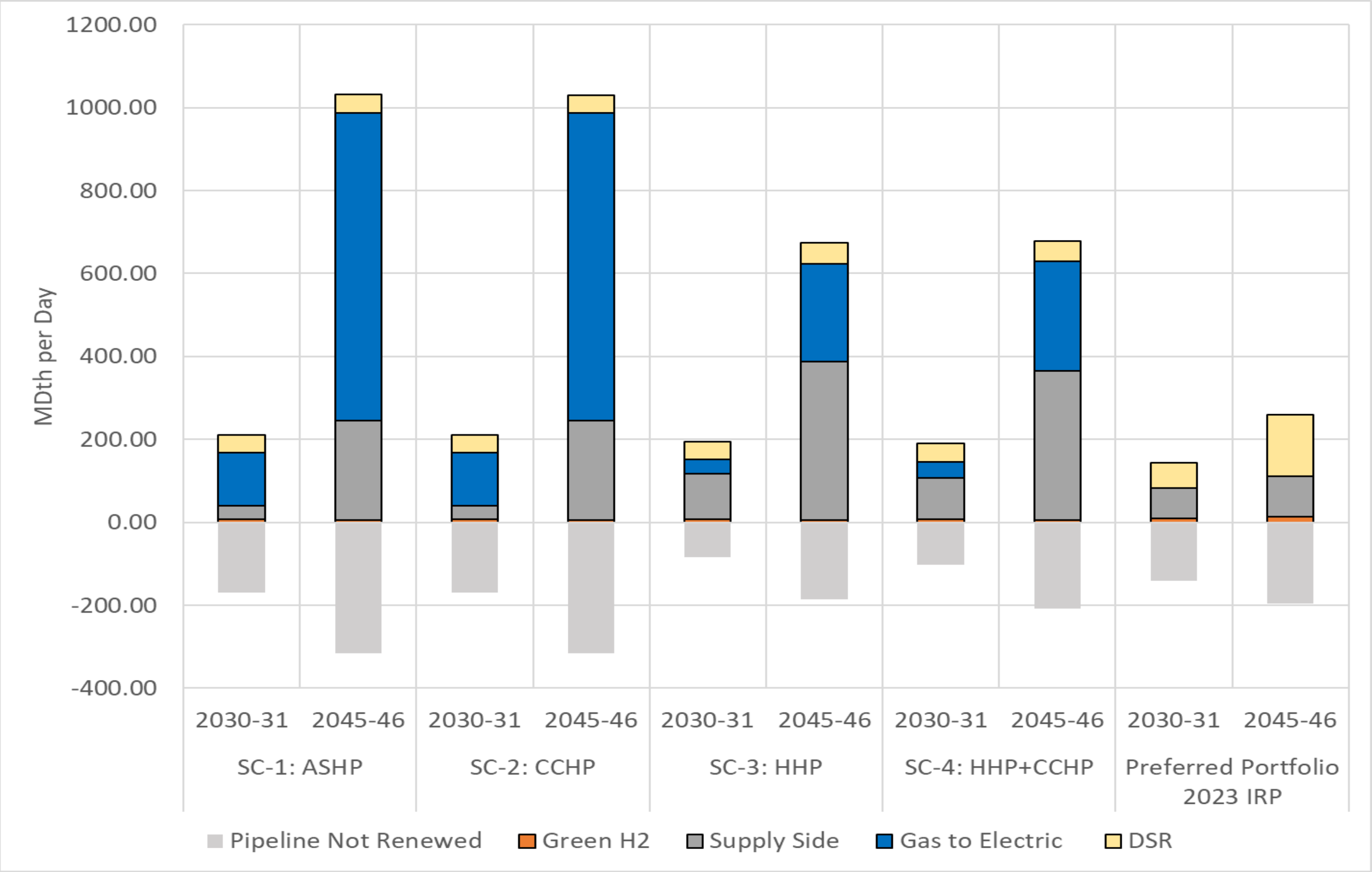
Peak Day impacts



Gas Load impacts

PUGET SOUND ENERGY

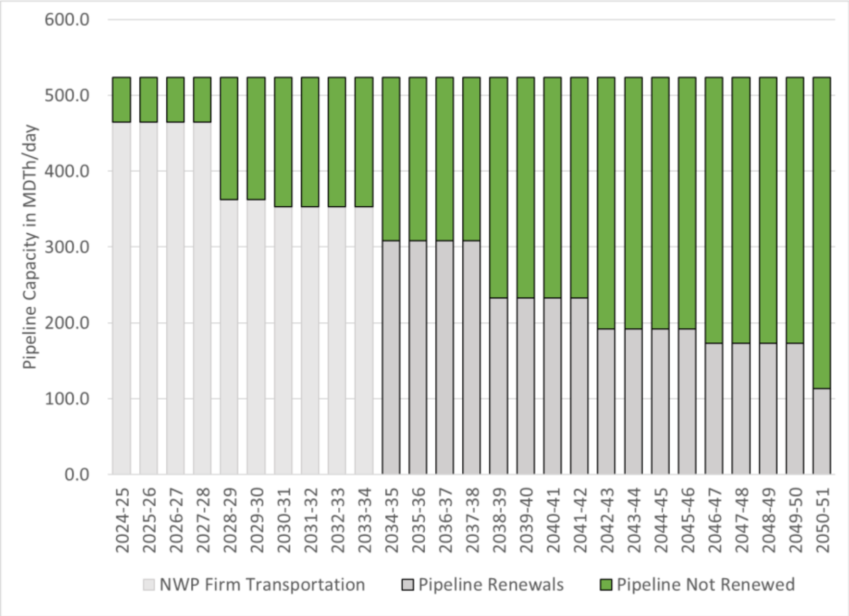
Gas portfolio volume of output resources for each scenario



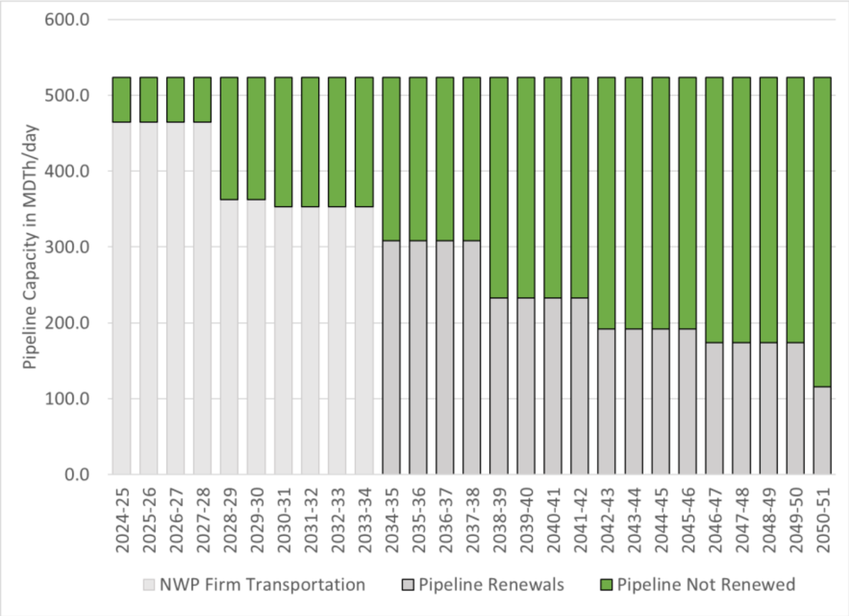
Key:
SC = Scenario
ASHP = Air source heat pump
CCHP = Cold climate heat pump
HHP = Hybrid heat pump (dual fuel heat pump, of gas back up heat pump)
DSR = Demand side resources (energy efficiency, conservation)
MDth = 1000 Deka Therms

Pipeline renewals per scenario

Scenario 1 - ASHP

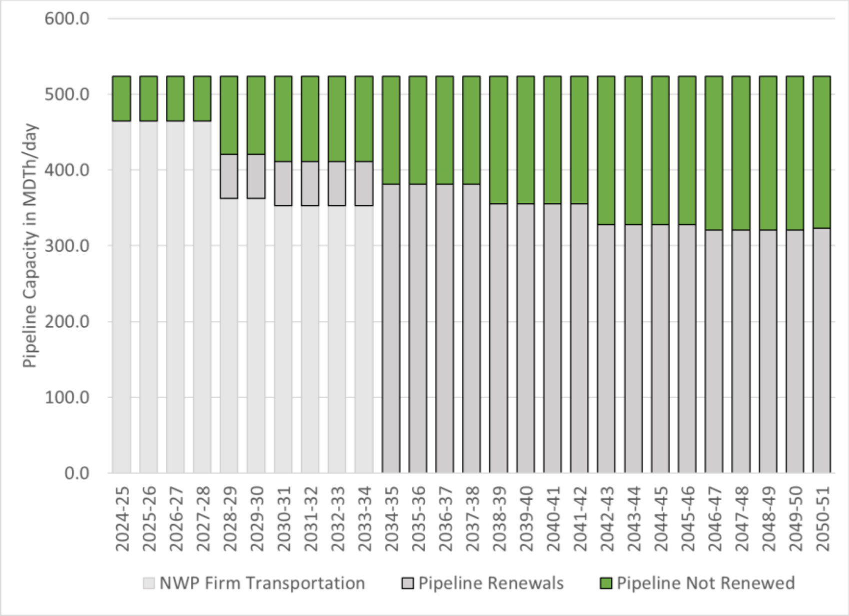


Scenario 2 - CCHP

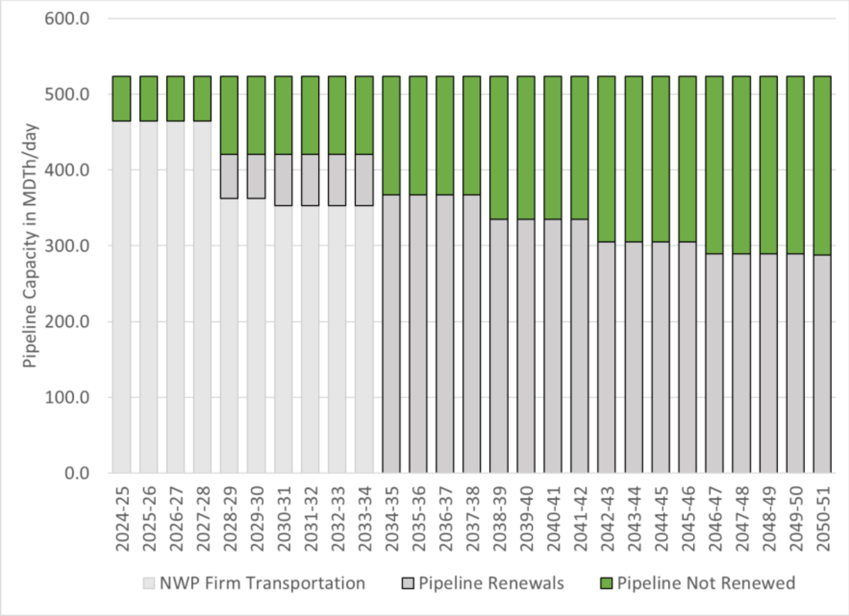


Key:
ASHP = Air source heat pump
CCHP = Cold climate heat pump
HHP = Hybrid heat pump (dual fuel heat pump, of gas back up heat pump)
MDth = 1000 Deka Therms

Scenario 3 - HHP

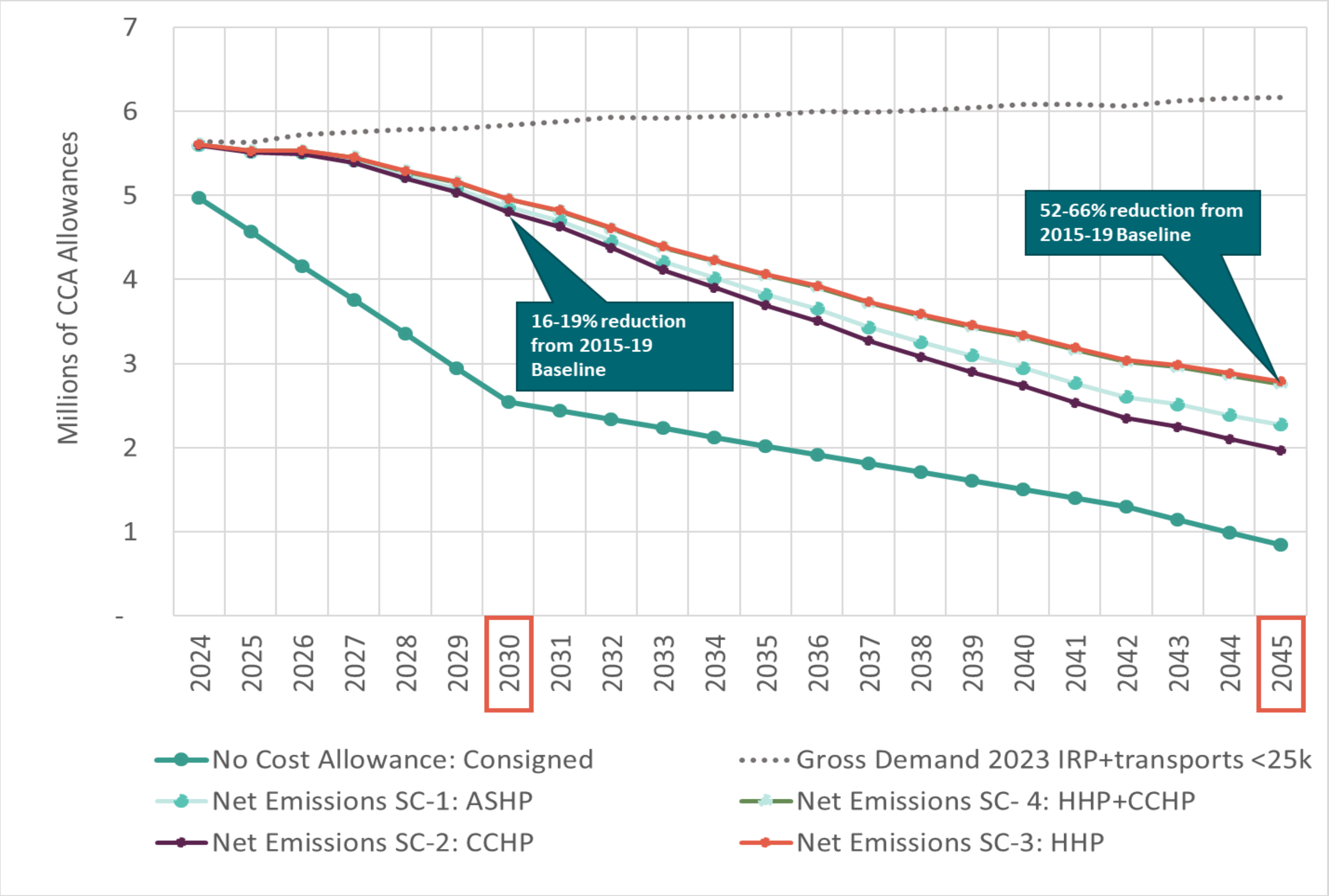


Scenario 4 – HHP+CCHP



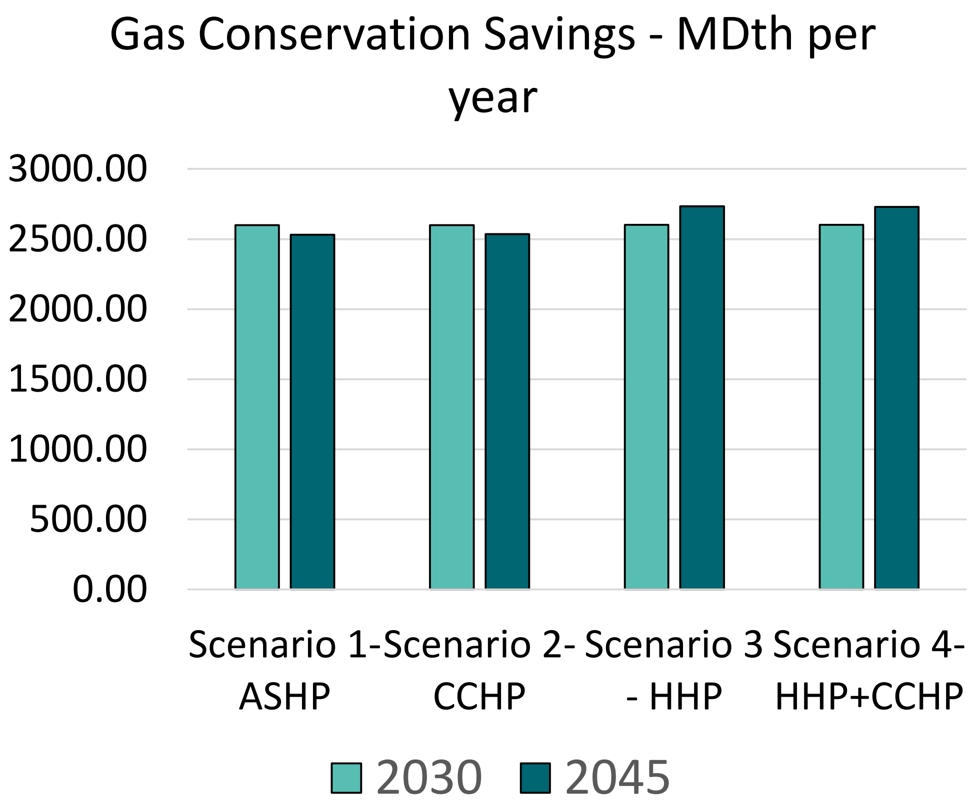
PSE PUGET SOUND ENERGY

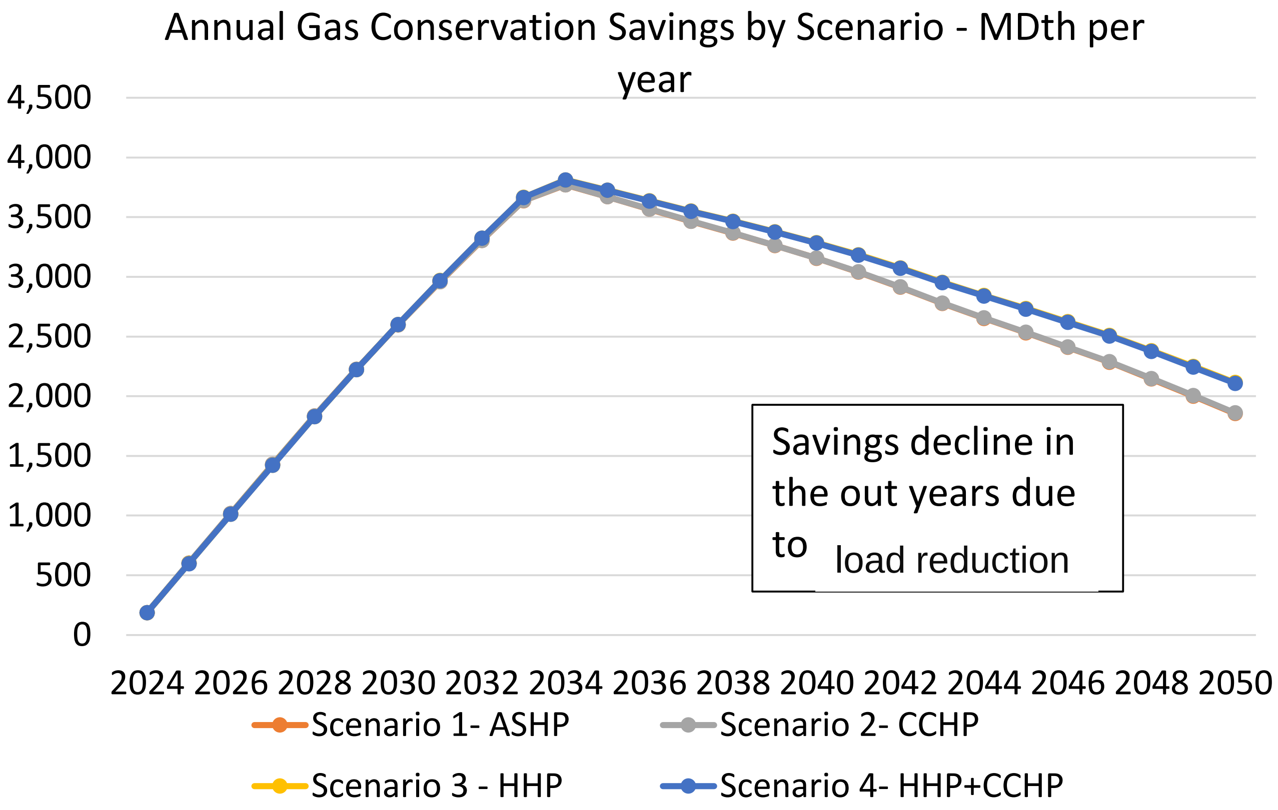
Gas portfolio emission reductions by scenario



Key:
SC = Scenario
ASHP = Air source heat pump
CCHP = Cold climate heat pump
HHP = Hybrid heat pump (dual fuel heat pump, of gas back up heat pump)
MDth = 1000 Deka Therms

Cost effective gas conservation by scenario





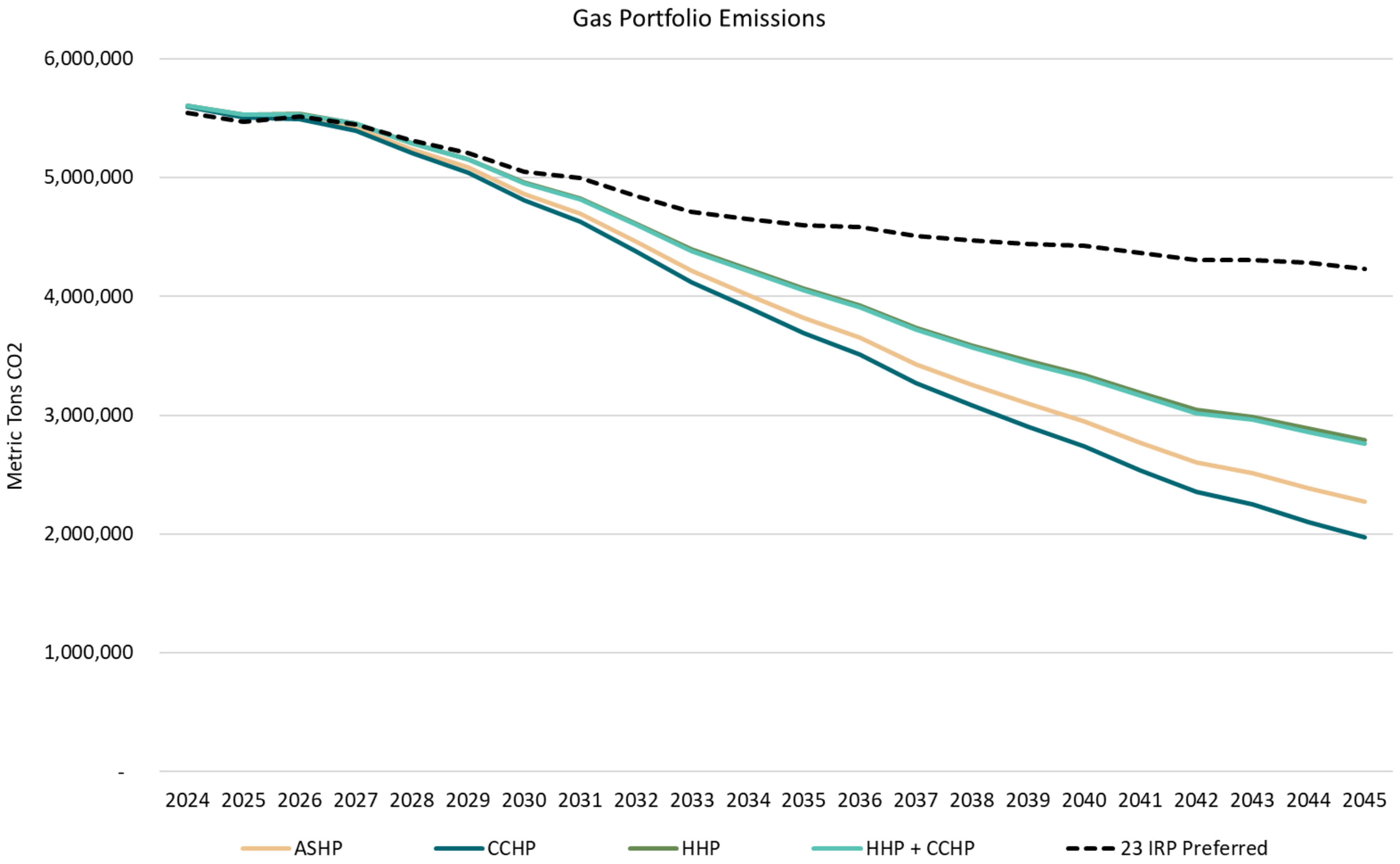
Key:
SC = Scenario
ASHP = Air source heat pump
CCHP = Cold climate heat pump
HHP = Hybrid heat pump (dual fuel heat pump, of gas back up heat pump)
MDth = 1000 Deka Therms

PUGET SOUND ENERGY

GRC Stipulation O – Updated decarbonization study

Gas & Electric Emission Reduction

Gas portfolio emissions reductions per scenario



Key:
SC = Scenario
ASHP = Air source heat pump
CCHP = Cold climate heat pump
HHP = Hybrid heat pump (dual fuel heat pump, of gas back up heat pump)

Electric portfolio emissions reduction per scenario

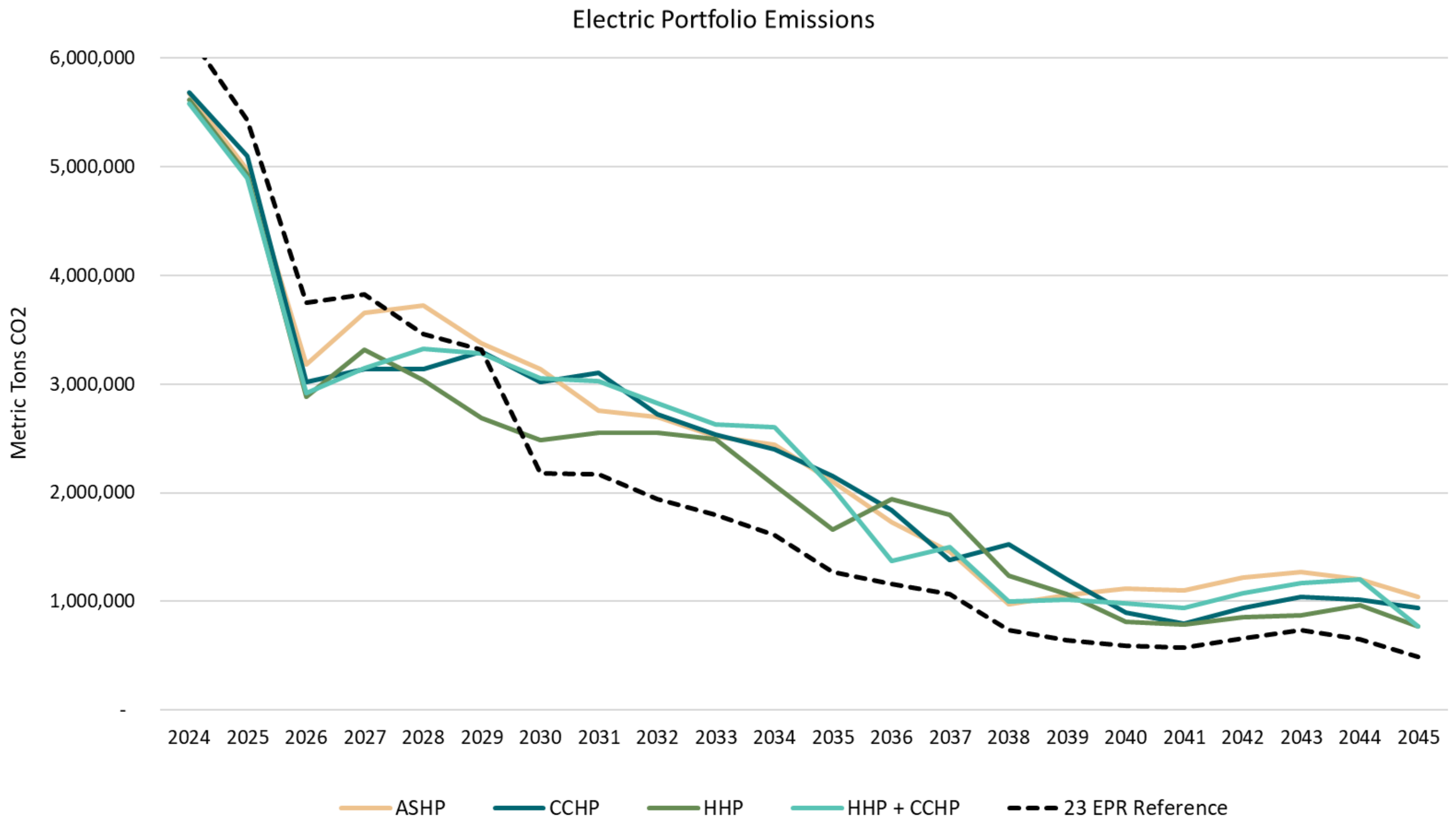
CETA Market Emission Rate

Per CETA, PSE must use a static **0.437 mt/MWh** emission rate for unspecified market purchases.

- This does not accurately reflect a market with an increased share of renewables.
- **For reference PSE Average CCCT = 0.420 mt/MWh**

Ecology Rate (using CETA rate requirement)

- **CCHP Scenario** --
  - 2030: 38% **above Reference**
  - 2045: 91% **above Reference**
- **HHP Scenario** --
  - 2030: 14% **above Reference**
  - 2045: 57% **above Reference**



Electric portfolio emissions reduction per scenario

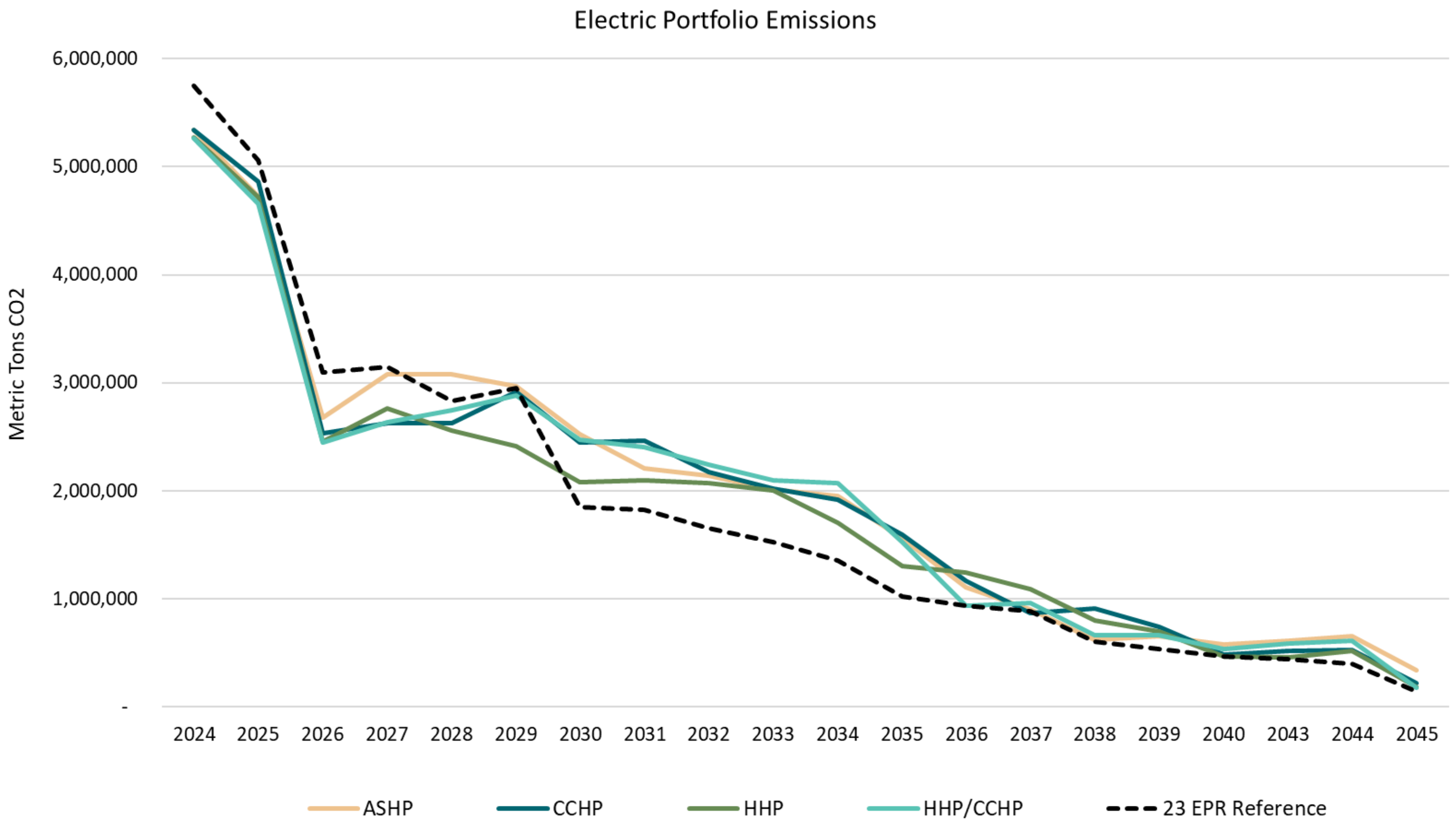
WECC Market Emission Rate

WECC rates starts at **0.25 mt/MWh** and goes to **0.10 mt/MWh** by 2045

- This is a better representation of the market incorporation of renewables over time

Using the WECC Emission Rate (to reflect regional electrification)

- **CCHP scenario** --
  - 2030: **32% above Reference**
  - 2045: **51% above Reference**
- **HHP scenario** --
  - 2030: **13% above Reference**
  - 2045: **26% above Reference**



PUGET SOUND ENERGY

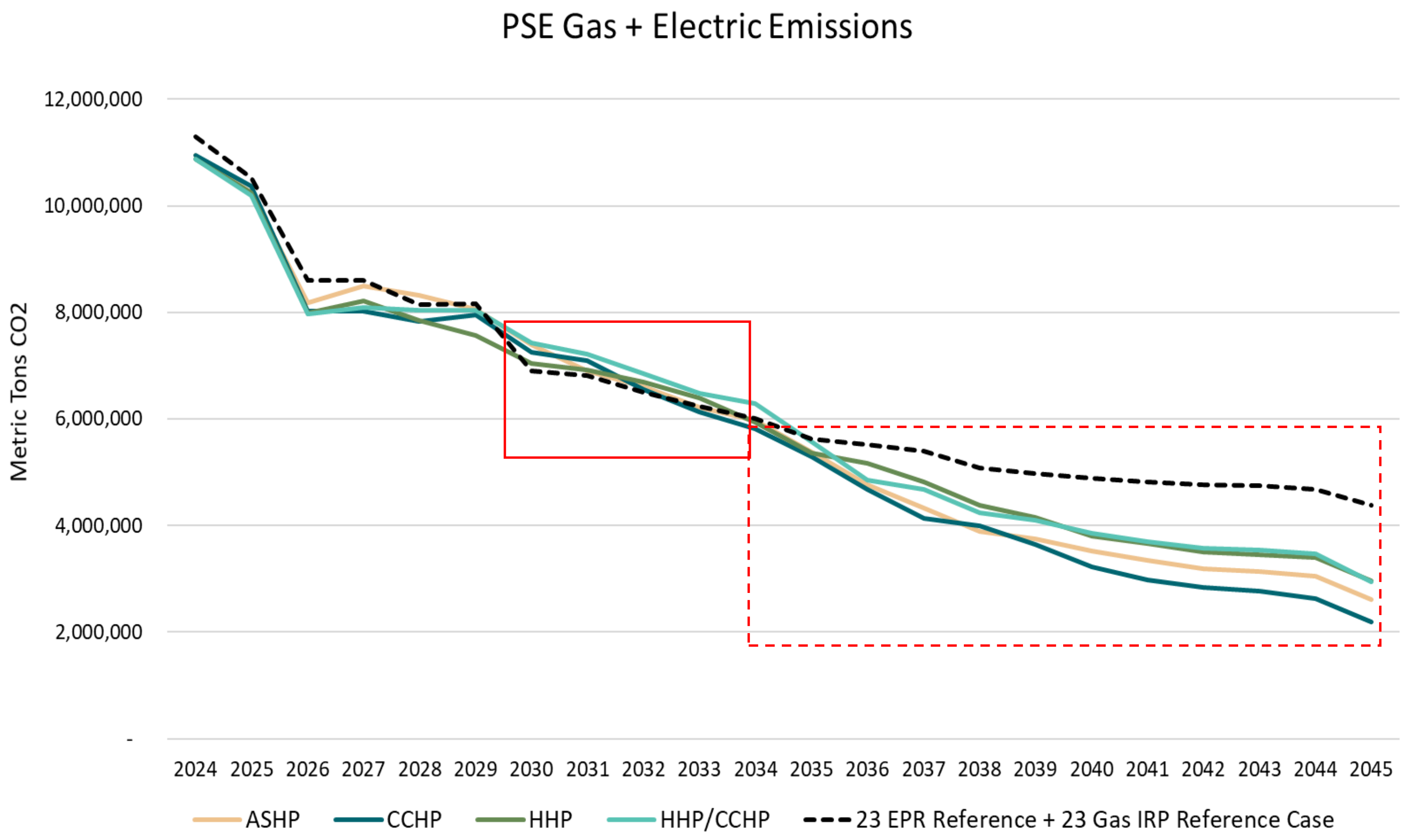
PSE Gas + Electric system emissions reduction per scenario

Near term increase while system builds, followed by long-term reduction

Benchmarked to 23 IRP (Reference)

Using the WECC Emission Rate (to reflect regional electrification)

- **CCHP scenario** --
    - 2030: **5% above Reference**
    - 2045: **50% below Reference**
- **HHP scenario** --
    - 2030: **2% above Reference**
    - 2045: **32% below Reference**



PUGET SOUND ENERGY

Societal benefit of reduced emissions

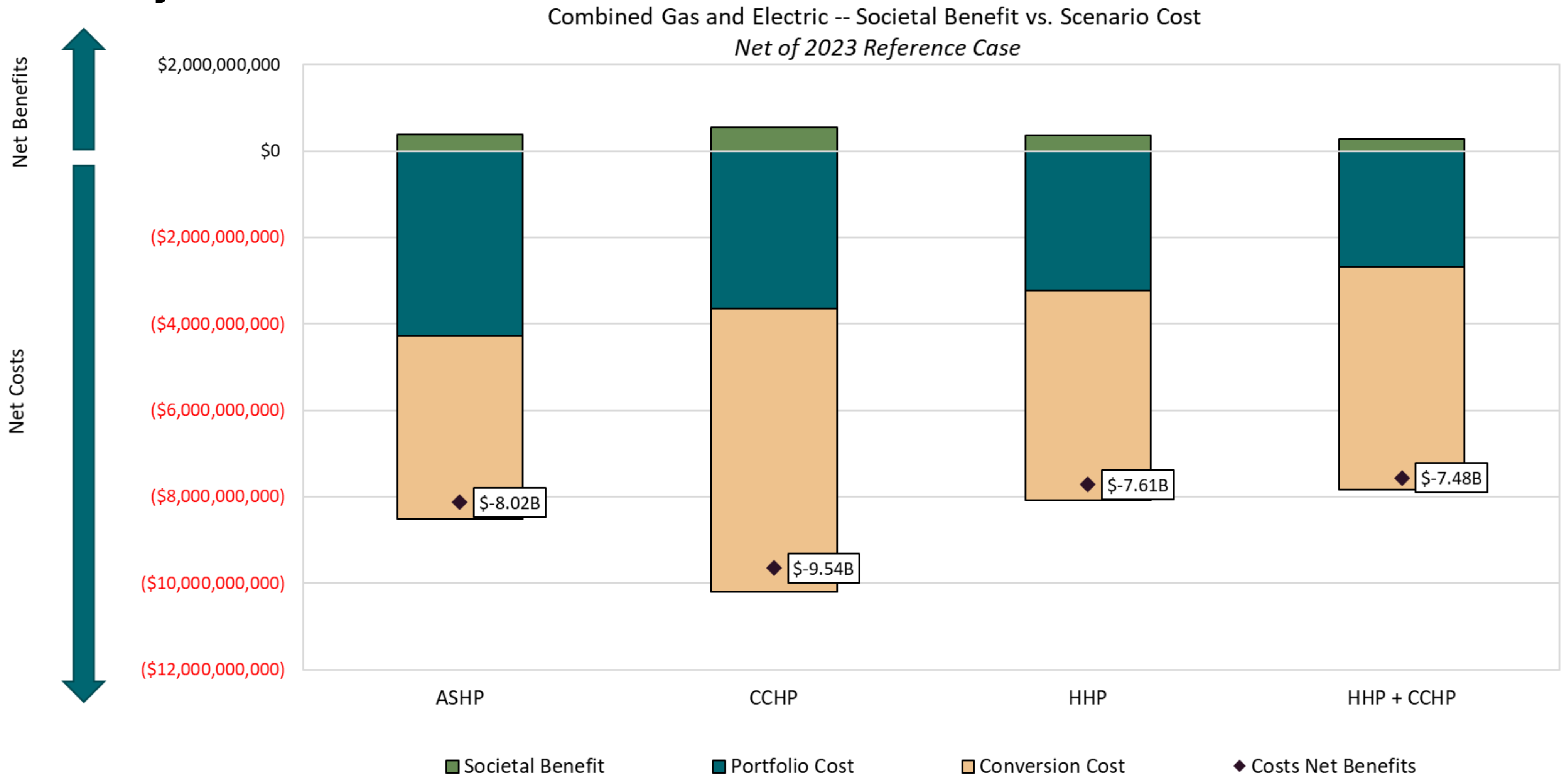
Per the CETA requirements an electric utility must incorporate the societal cost of carbon into their integrated planning process.

- Societal benefit aims to quantify the benefit to society associated with reducing emissions
- This methodology avoids discounting emissions directly
- Steps to calculate societal benefit:
  - Find annual net emissions between a given scenario and the reference case
  - Multiply those net emissions by the Social Cost of Greenhouse Gases (SCGHG) value in each year
  - Take the Net Present Value (NPV) of the resulting cost strip to get a monetized societal benefit value

- The resulting societal benefit can be compared to the total scenario cost

PUGET SOUND ENERGY

Portfolio and conversion costs outweigh the emission reduction benefit to society



*Societal benefit is calculated using net emissions which use the WECC wide market emission rate which changes year to year.

PUGET SOUND ENERGY

Key takeaways for emission reduction potential

- All four scenarios decrease emissions in the long term, but acceleration of electrification drives an increase in near-term emissions

- The gap in electric emissions in the late years is largely a function of electric market purchases
  - These values change depending on the emission rate applied
  - Holding the Ecology emission rate constant results in higher emitting scenarios, while WECC-wide results in lower emitting scenarios

GRC Stipulation O – Updated decarbonization study

Gas System Output

PUGET SOUND ENERGY

Gas system analysis assumptions used for each scenarios

- Pipe can only be retired if the entire use of gas at a site is eliminated.
- Tariff changes on new customer connections have established and incorporated into the baseline. Avoided costs due to fewer connections are reflected in the cost to operate/maintain the system.
- Cadmus provided range of remaining customers per scenario, for the analysis, maximum adoption of electrification technologies was used.
- Load reductions are applied across the system, not in specific areas.
- Pipe is to be retired in place (PSE not required to remove pipe).
- Investments may still be required to ensure system safety.
- System Reliability investments driven by peak load on 52DD minimized to local area enhancements.
- Cost for conversion to residential heat pump is est $15K.

Gas system analysis approach

Category	Driver	Approach
New Customer	No changes to capital due to changes in margin allowance per settlement	
System Reliability	Peak load (volume)/ energy content	Varied by customer change
Maintenance/Integrity	# customers/ miles of pipe	80% varied by customer change
Emergent	# customers/ miles of pipe	50% varied by customer change

- Used current plan through 2050
- Analyzed the scenarios based on the loads/customer counts from Cadmus and potential fuel heat content in the future using the load forecast from the 2023 IRP filing using thermal models
- Used 2.5% inflation factor
- Separated capital investments into 4 areas

Avoided gas infrastructure costs assumptions for addressing bullet B of Stipulation O

Addressing bullet B - **near-term** (3-5 years) and long-term costs and benefits of electrification, including carbon reductions and **avoided gas system infrastructure costs** due to fewer new customer connections.

General changes since 2021 E3 decarb study:

- Margin allowance for new construction will be 0 by 2025. Reducing annual capital by around $100M per year
- System projects for future growth have been cut. Any projects increasing the pipeline capacity relate to existing system needs

Financial Impact for next 3 – 5

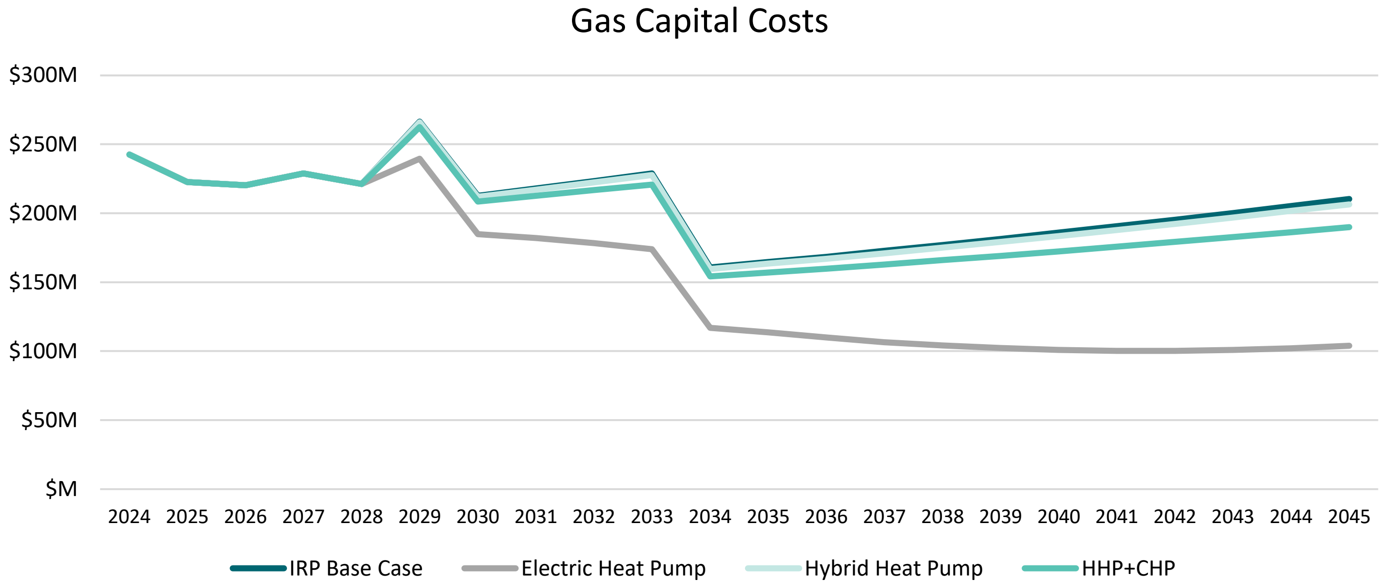
- Same for every scenario due to timelines for converting to heat pumps
- Fuel switching opportunities for constrained areas will be incorporated into the Targeted Electrification Strategy
    - To either potentially defer, eliminate, or reduce the size of the project needed

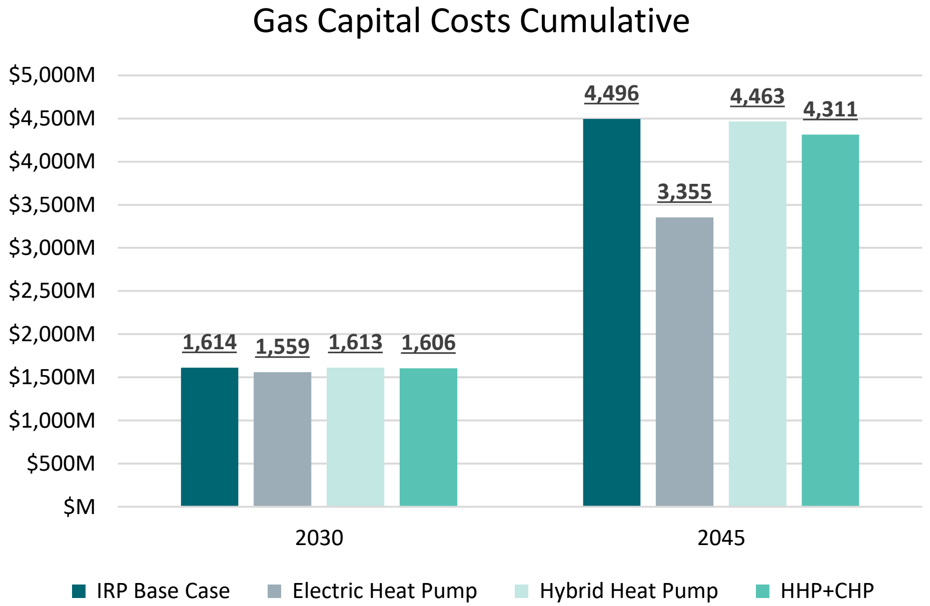
PSE PUGET SOUND ENERGY

Avoided gas infrastructure costs findings per scenario

Addressing bullet B - **near-term** (3-5 years) and long-term costs and benefits of electrification, including carbon reductions and **avoided gas system infrastructure costs** due to fewer new customer connections.

- Most of the gas infrastructure costs are related to miles of pipe and numbers of customers – not volume
- Hybrid heat pump scenario has the same number of customers, but less volume
- These costs assume the maximum customer adoption of the technology





Note: Electric Heat Pump is reflective of both Standard Heat Pumps & CCHP, in the electrification scenarios they have the same impact on the gas system. Therefore, they are represented with the same line/bar.

PSE PUGET SOUND ENERGY

Gas system outputs per scenario

Addressing bullet F - Study the impacts and benefits of electric heat pump technologies on PSE's gas constrained delivery systems.

Scenario	Time period	Fuel blend	Total load constraint	# Conversions	Estimated cost to convert	Benefits/ opportunities
Base case – 100% NG	current	100% NG (1046 BTU)	472,000 scf/hr*	11,800	$177M	
Scenario 1 – ASHP Scenario 2 – CCHP	2032	100% RNG	322,000 scf/hr	6,600	$99M	Reduces constrained areas on system occurring with lower carbon fuel
Scenario 3 – HHP	2032	100% RNG	642,000 scf/hr	16,050	$240M	Reduces temperature where actions are needed
Scenario 4 – HHP + CCHP	2032	100% RNG	610,000 scf/hr	15,250	$228M	Reduces temperature where actions are needed

*scf/hr: standard cubic foot per hour

The study of the gas system impacts found the following impacts:

- Location and population matters
- Heat content changes over time with low carbon fuels, targeted electrification can offset impacts in most areas
- Electrification costs are greater than gas pipeline upgrades for largely constrained areas

GRC Stipulation O – Updated decarbonization study

Electric System Output

Electric system analysis summary of outputs for each scenario

The four scenarios were modeled in Microsoft Excel using planner-level estimates (+/- 50%) based on historical costs and making assumptions based on $/MW peak added.

Costs were evaluated across the following key components of the electric transmission and distribution system using assumptions 115/230 kV Transmission, Bulk 115/230 kV Transformers, Transmission Switching Stations, Distribution Substation Transformers, Distribution Feeders, and Distribution Service Transformers.

The costs shown are in nominal form and therefore do not account the impacts of inflation. The high-level summary is depicted in the following table:

Scenario	2030 MW	2030 $M	2045 MW	2045 $M
Scenario 1 - ASHP	431	$ 649	2027	$ 4,283
Scenario 2 - CCHP	387	$ 583	1731	$ 3,665
Scenario 3 - HHP	94	$ 156	435	$ 960
Scenario 4 – HHP + CCHP	89	$ 135	390	$ 865

Electric system analysis outputs – 2030 key components per scenario

Description	Unit	$/unit	2024-2030 (units / $M)							
			S1: ASHP		S2: CCHP		S3: HHP		S4: HHP+CCHP	
		Total Load (MW)	439		419		101		106	
115 kV Transmission (incl. substation transmission)	Miles	$4.6M	0	$-	0	$-	0	$-	0	$-
230 kV Transmission	Miles	$6.9M	0	$-	0	$-	0	$-	0	$-
Bulk 230/115 kV Transformers	Transformers	$9.2M	0	$-	0	$-	0	$-	0	$-
Transmission Switching Stations	Switching Stations	$17.2M	0	$-	0	$-	0	$-	0	$-
Distribution Substation Transformers	Transformers	$12.1M / transformer	10	$121	10	$121	3	$36	3	$36
Distribution Feeder	Miles	$2.3M / mile	42	$97	40	$92	10	$23	10	$23
Distribution Service Transformers	Transformers	$18,100 / transformer	12,271	$222	11,708	$211	2,815	$51	2,965	$54
		Sub-Total ($M)		$439		$424		$110		$113
		Planning Estimate (+50%)		**$658**		**$636**		**$165**		**$169**

Typical permitting, design and construction timelines for long-lead items:

- Substation 5 – 7 years
- Transmission line 10 years

Key:
S = Scenario
ASHP = Air source heat pump
CCHP = Cold climate heat pump
HHP = Hybrid heat pump (dual fuel heat pump, of gas back up heat pump)

PUGET SOUND ENERGY

Electric system analysis outputs – 2045 key components per scenario

Description	Unit	$/unit	2024-2045 (units / $M)							
			S1: ASHP		S2: CCHP		S3: HHP		S4: HHP+CCHP	
		Total Load (MW)	2,013		1,714		417		432	
115 kV Transmission (incl. substation transmission)	Miles	$4.6M	135	$621	115	$529	28	$129	29	$133
230 kV Transmission	Miles	$6.9M	4	$28	4	$28	1	$7	1	$7
Bulk 230/115 kV Transformers	Transformers	$9.2M	7	$64	6	$55	2	$18	2	$18
Transmission Switching Stations	Switching Stations	$17.2M	6	$104	5	$86	2	$35	2	$35
Distribution Substation Transformers	Transformers	$12.1M / transformer	72	$869	61	$737	15	$181	16	$193
Distribution Feeder	Miles	$2.3M / mile	91	$209	78	$179	19	$44	20	$46
Distribution Service Transformers	Transformers	$18,100 / transformer	52,039	$940	44,331	$800	10,792	$195	11,181	$202
		Sub-Total ($M)		$2,835		$2,414		$608		$634
		Planning Estimate (+50%)		**$4,252**		**$3,622**		**$912**		**$951**

Typical permitting, design and construction timelines for long-lead items:

- Substation 5 – 7 years
- Transmission line 10 years

Key:
S = Scenario
ASHP = Air source heat pump
CCHP = Cold climate heat pump
HHP = Hybrid heat pump (dual fuel heat pump, of gas back up heat pump)

GRC Stipulation O – Updated decarbonization study

Requirement H

Requirement H – Use biennial conservation planning process to advance least-cost decarbonization

- Evaluate how to use the biennial conservation planning process to advance least-cost decarbonization strategies in PSE's gas utility service area, including by promoting fuel switching to electric utility service.

    1. UTC regulations require utilities to evaluate conservation measures on a total resource cost basis.
    2. The current BCP process evaluates potential measures to determine what is programmatically cost effective and all existing measures and programs help reduce overall energy use.

PSE PUGET SOUND ENERGY

Requirement H – Use biennial conservation planning process to advance least-cost decarbonization

- Fuel switching was evaluated in the 2023 Integrated Resource Plan analysis and was determined to miss the cost effectiveness threshold
  - Even though PSE included the social cost of greenhouse gas emissions and other non-energy impacts in the total resource cost test, the fact that we also need to account for the offsetting use of electricity to operate the heat pump lowers the value of the benefit and results in none of the fuel-switching measures being cost-effective.

PSE PUGET SOUND ENERGY

GRC Stipulation O – Updated decarbonization study

PSE Customer Financial Results

Customer costs of the conversion from gas to electric in **2030 (provided by Cadmus)**:

End Use	Air Source Heat Pump	Cold Climate Heat Pump	Hybrid Heat Pump	Gas Furnace
Heat Pump	20,093	25,292	13,740	-
Gas Furnace	-	-	6,555	6,555
Total	20,093	25,292	20,295	6,555
Term Year	10	10	10	10
Interest Rate	8%	8%	8%	8%
Annual Amortization				
Heat Pump	2,994	3,769	2,048	
Gas Furnace	-	-	977	977
Total	**2,994**	**3,769**	**3,025**	**977**

Per the latest legislative policy (10 CFR 430.2) on gas furnaces, high efficiency gas furnace is estimated to be $1,700 more
For the ASHP system, you need an air mover (air handler) while for the HHP system, the gas furnace is the air mover.

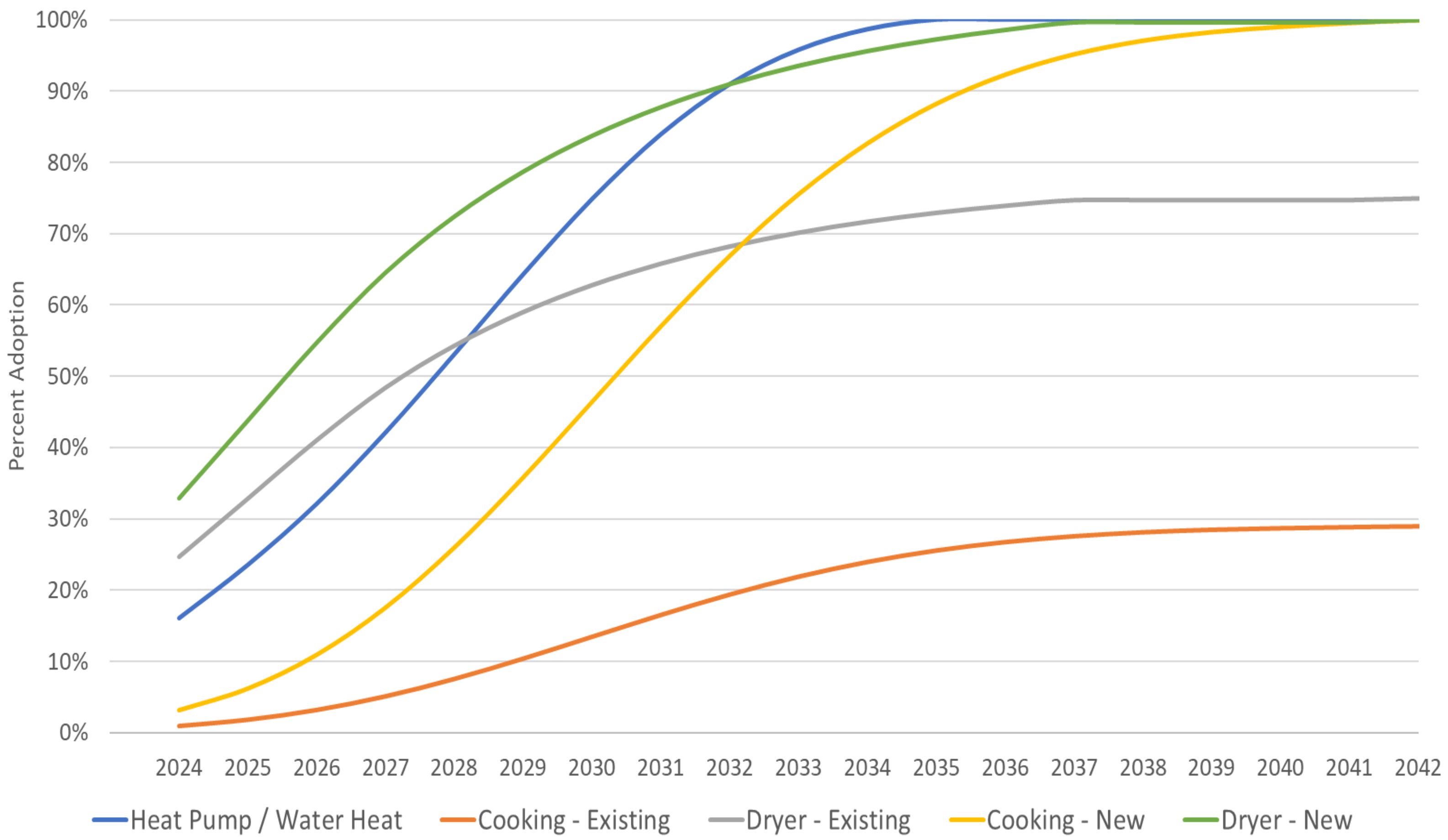
PSE PUGET SOUND ENERGY

Financial analysis assumptions used

- The analysis compares the economics among the four heat pump technologies independently - no cross over between scenarios
- PSE accelerated the depreciation of the gas assets, 70% of the assets are depreciated by 2045
- Looked into impacts on a representative low-income customer (that qualifies for all the incentives)
- Looked at a few different gas rate schedules for larger commercial and industrial (C&I) customers
  - We were unable to complete an electric rate impact at this time due to unknown conversion costs
- Bill analysis for C&I customers assume rate spread consistent with PSE's last GRC (Dockets UE-220066 and UG-220067)
- As the gas furnaces burn out the analysis assumes the furnace will be replaced with each of the heat pump technologies
- Billing information assumes the electrification of the gas heat only
- Billing information refers to those customer who haven't moved over to heat pump technology yet
- Bill increases are somewhat mitigated with the reduction in overall usage as a result of climate change

Customer end-use equipment adoption curve provided by the Cadmus Group

100% adoption potential for electrification of Heat Pump and Water Heater replacements by 2035 in each of the scenarios reflected by the blue line



PUGET SOUND ENERGY

How the customer financial bar graphs were developed and tips for how to read them

Based on estimated annual average residential bill

Includes conversation cost + equipment cost for specific scenarios (provided by Cadmus)

Scenario 1 - ASHP	Scenario 2 - CCHP	Scenario 3 - HHP	Scenario 4 – HHP + CCHP
HP Converted: Customer who converted to **ASHP**	**HP Converted:** Customer who converted to **CCHP**	**HP Converted:** Customer who converted to **HHP**	**HP Converted: Existing** customer converted to **HHP, new** customers converted to **CCHP**
Gas: Customer who hasn't converted to ASHP	**Gas:** Customer who hasn't converted to CCHP	**Gas:** Customer who hasn't converted to HHP	**Gas:** Customer who hasn't converted to HHP or CCHP based on burnout

***These are independent of one another**. It's showing if a customer did not switch, remained on the gas system, vs one whom did switch*

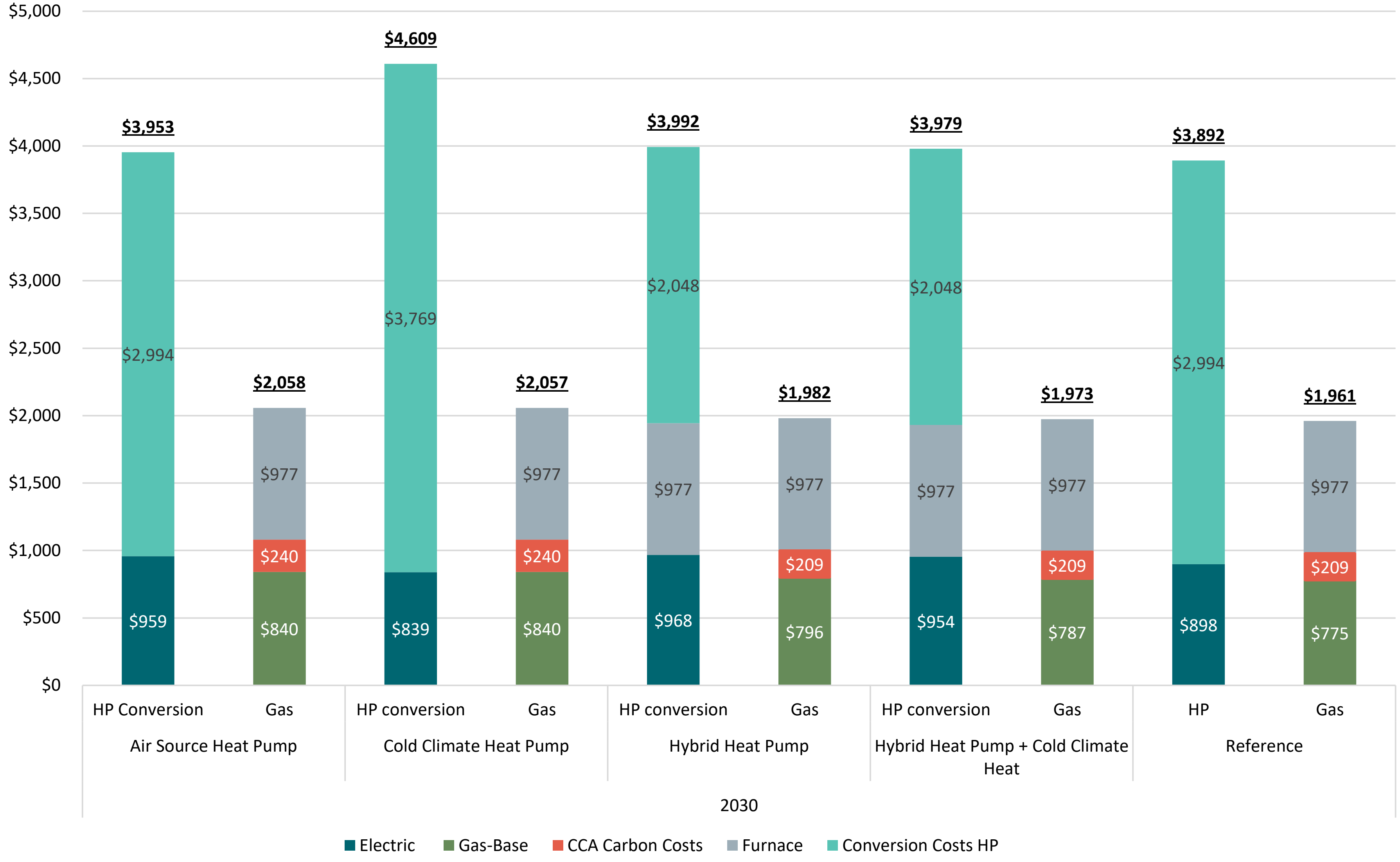
PSE PUGET SOUND ENERGY

Annual residential costs for heat pump customers vs all gas customer in **2030, costs are similar across all scenarios**

Dollars are shown in 2030 dollars

2030 residential bill impacts

- Billing impacts across all scenarios are very similar.
- A customer would likely not get a price signal to move if their equipment does not need replaced.



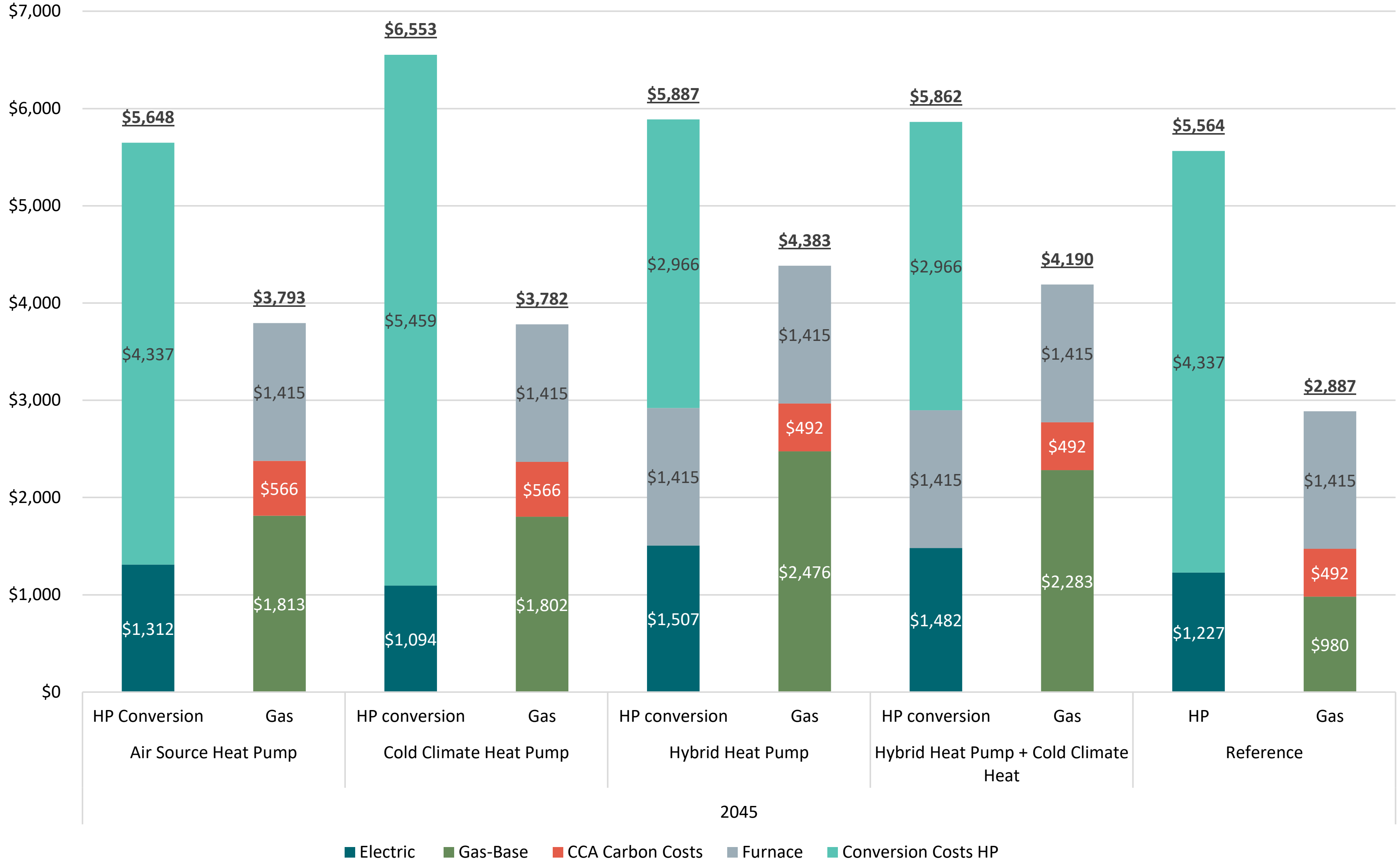
Note- the equipment costs are annualized over 10 years (refer to slide 22 for total equipment investment).

Annual residential costs for heat pump customers vs all gas customer in **2045, costs are similar across all scenarios**

Dollars are shown in 2045 dollars

2045 residential annual impacts

- Looking out 20 years, any of these scenarios could flex in either direction



Note- the equipment costs are annualized over 10 years (refer to slide 22 for total equipment investment).

PUGET SOUND ENERGY

Example of **low-income customer** costs for the conversion from gas to electric in **2030 (provided by Cadmus)**:

Equipment	Base Cost Estimate	Est. 25C Tax Credit Value	Est. HEEHRA Rebate[a]	Net Cost
Centrally Ducted ASHP				
Centrally Ducted ASHP – Base	$14,800	[b]	[b]	$14,800
Centrally Ducted ASHP – Dual Stage	$17,175	[b]	[b]	$17,175
Centrally Ducted ASHP – ENERGY STAR	$17,800	$2,000[c]	$8,000	$7,800
Centrally Ducted ASHP – Cold Climate	$19,425	$2,000[c]	$8,000[d]	$9,425
Centrally Ducted ASHP – Dual Fuel[c]	$11,277	$983[c]	$8,000	$2,294
Centrally Ducted ASHP + Furnace – Dual Fuel[c]	$16,250	$2,000[c]	$8,000	$6,250
Ductless Mini-Split Heat Pump (assumed 3 tons)				
Ductless Mini-Split Heat Pump – Base	$13,443	[b]	[b]	$13,443
Ductless Mini-Split Heat Pump – ENERGY STAR	$14,886	$2,000[c]	$7,443	$5,443
Ductless Mini-Split Heat Pump – Cold Climate	$15,246	$2,000[c]	$7,623[d]	$5,623

Sources: 26 C.F.R. § 25C; Public Law 117-169 (2022): 1817-2090;

[a] While this table shows the HEEHRA rebate estimate for residents making 80-150% of AMI, customers, residents making <80% AMI would be expected to receive the full $8,000 for all qualifying heat pumps, given the cost estimates used.

[b] Equipment is not assumed to meet the efficiency criteria for ENERGY STAR or for CEE Tier 3.

[c] Equipment meeting ENERGY STAR or different CCHP specifications may not meet CEE Tier 3 criteria.

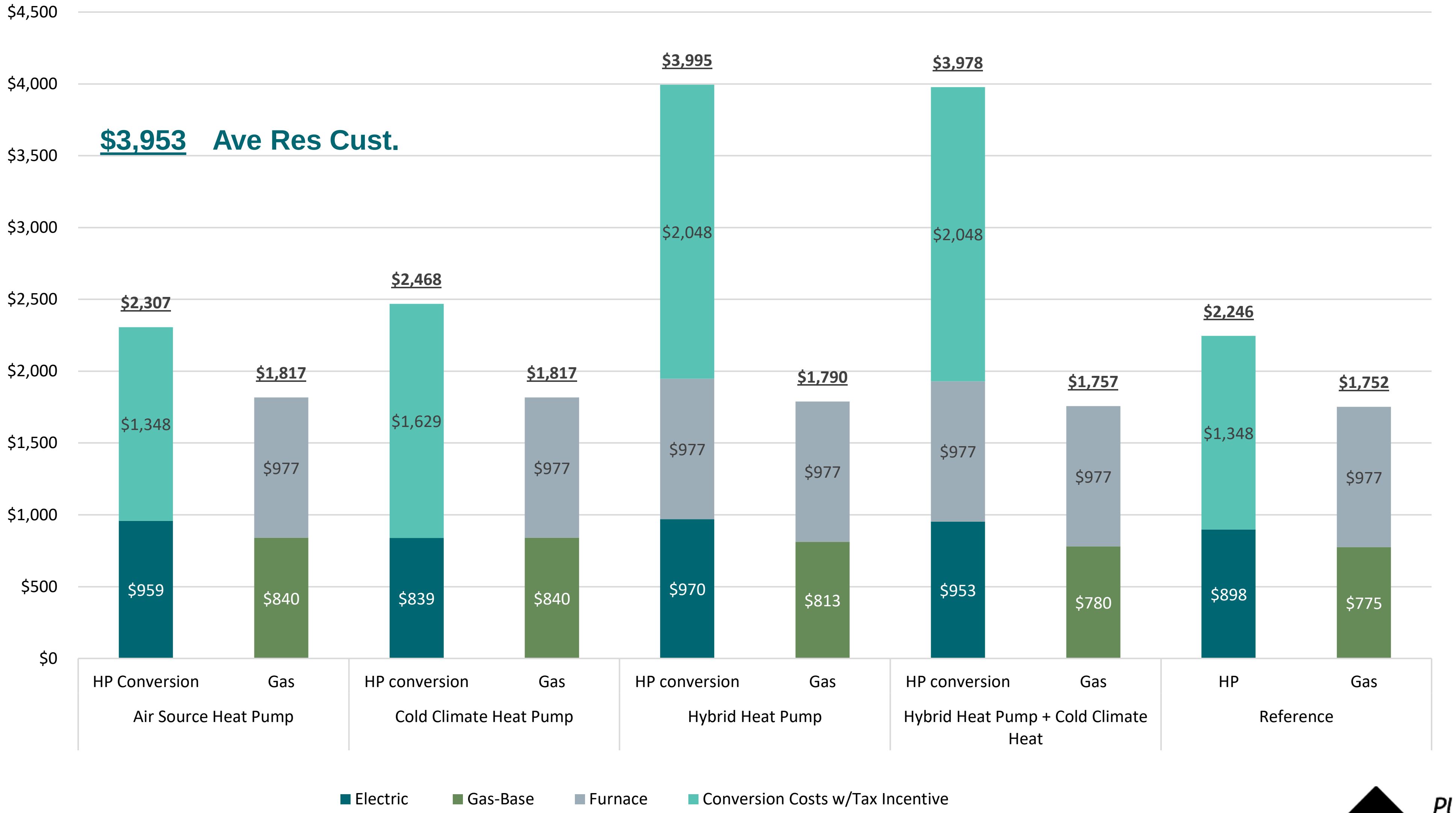
[d] Equipment meeting CCHP specification may not qualify for ENERGY STAR designation.

PUGET SOUND ENERGY

Example of a **low-income customer** that qualifies for the IRA and state incentives - **2030**

Dollars are shown in 2030 dollars

Low-income impacts:
- *CCA costs are mitigated*
- *More incentives offered for end-use equipment*



Note- the equipment costs are annualized over 10 years (refer to slide 16 for total equipment investment).

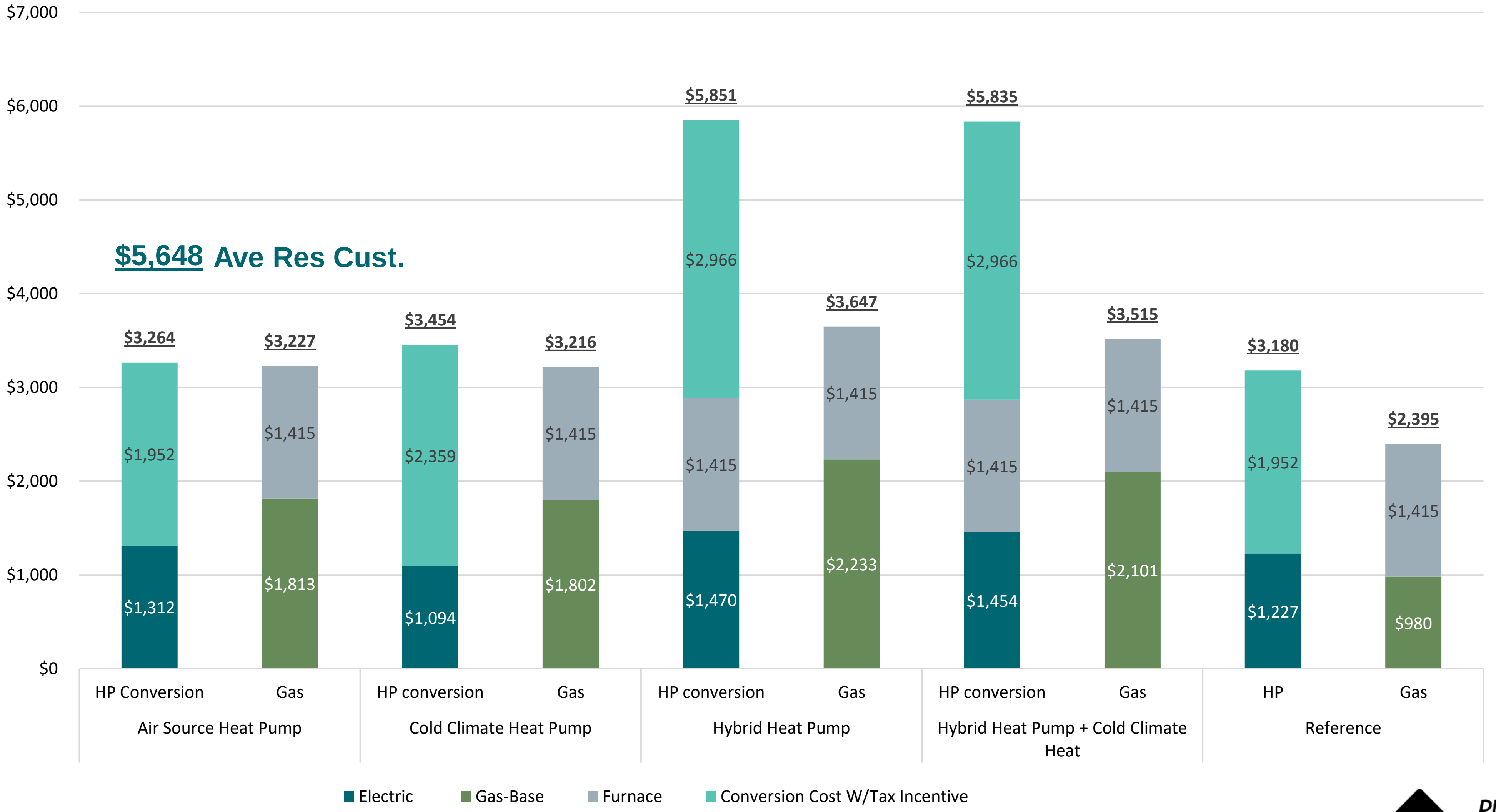
PSE PUGET SOUND ENERGY

Example of **a low-income customer** that qualifies for the IRA and state incentives - **2045**

Dollars are shown in 2045 dollars

Low-income impacts:

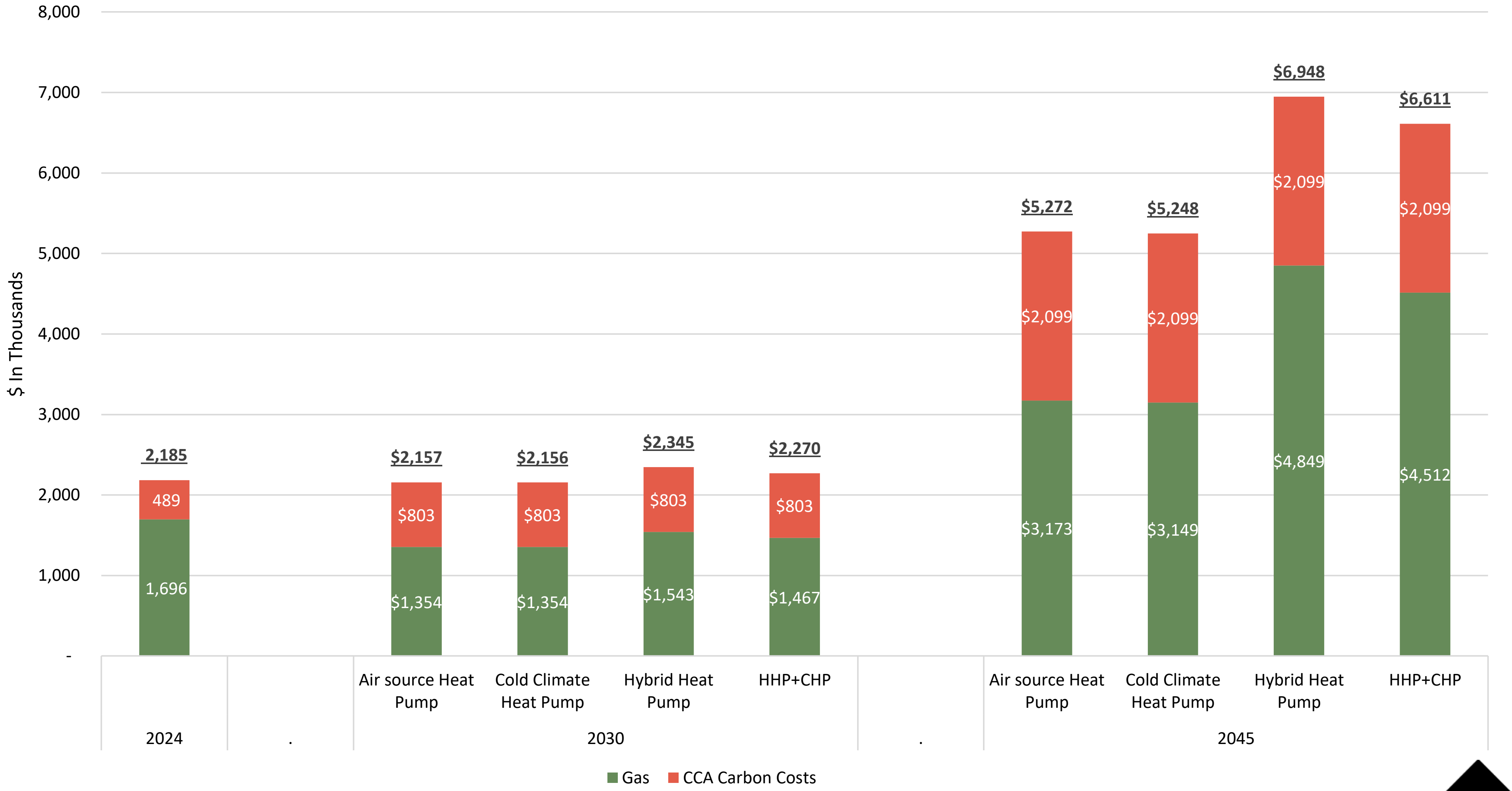
- *CCA costs are mitigated*
- *More incentives offered for end-use equipment*



Note- the equipment costs are annualized over 10 years (refer to slide 16 for total equipment investment).

PSE PUGET SOUND ENERGY

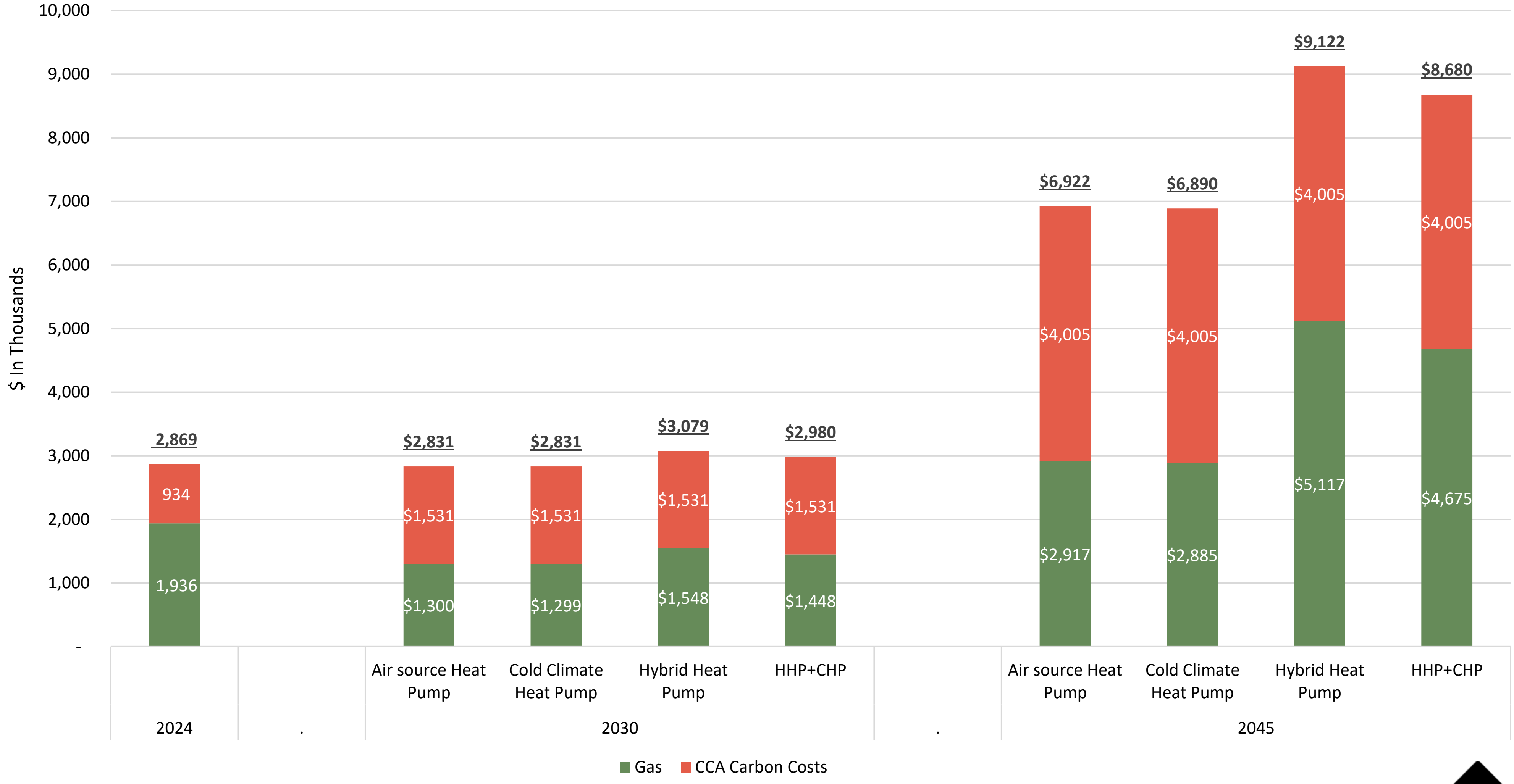
Industrial customer schedule 41 per average usage, showing total annual gas bill



PUGET SOUND ENERGY

Dollars are shown in terms of the respective year

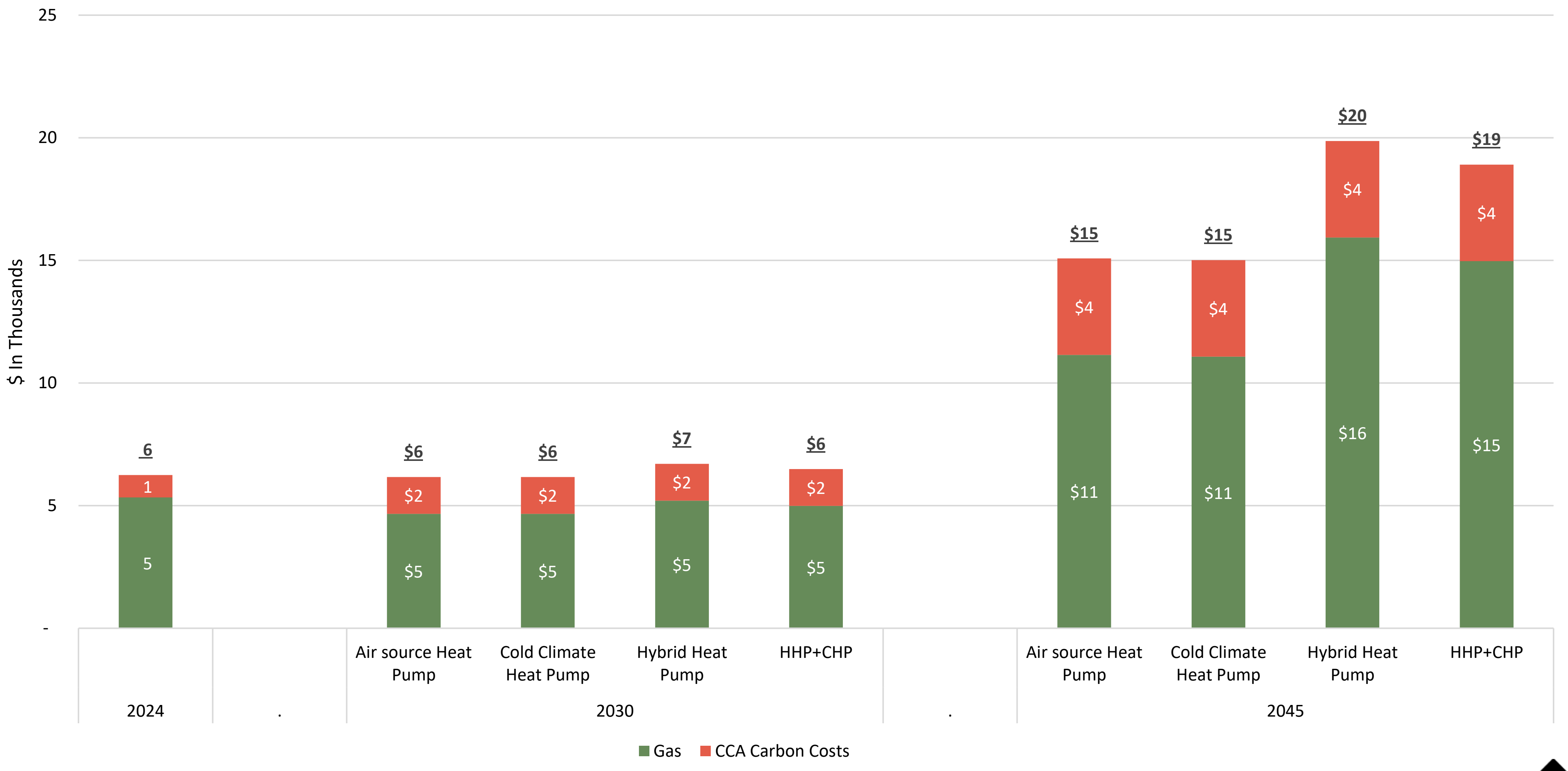
Industrial customer schedule 87 per average usage, showing total annual gas bill



PUGET SOUND ENERGY

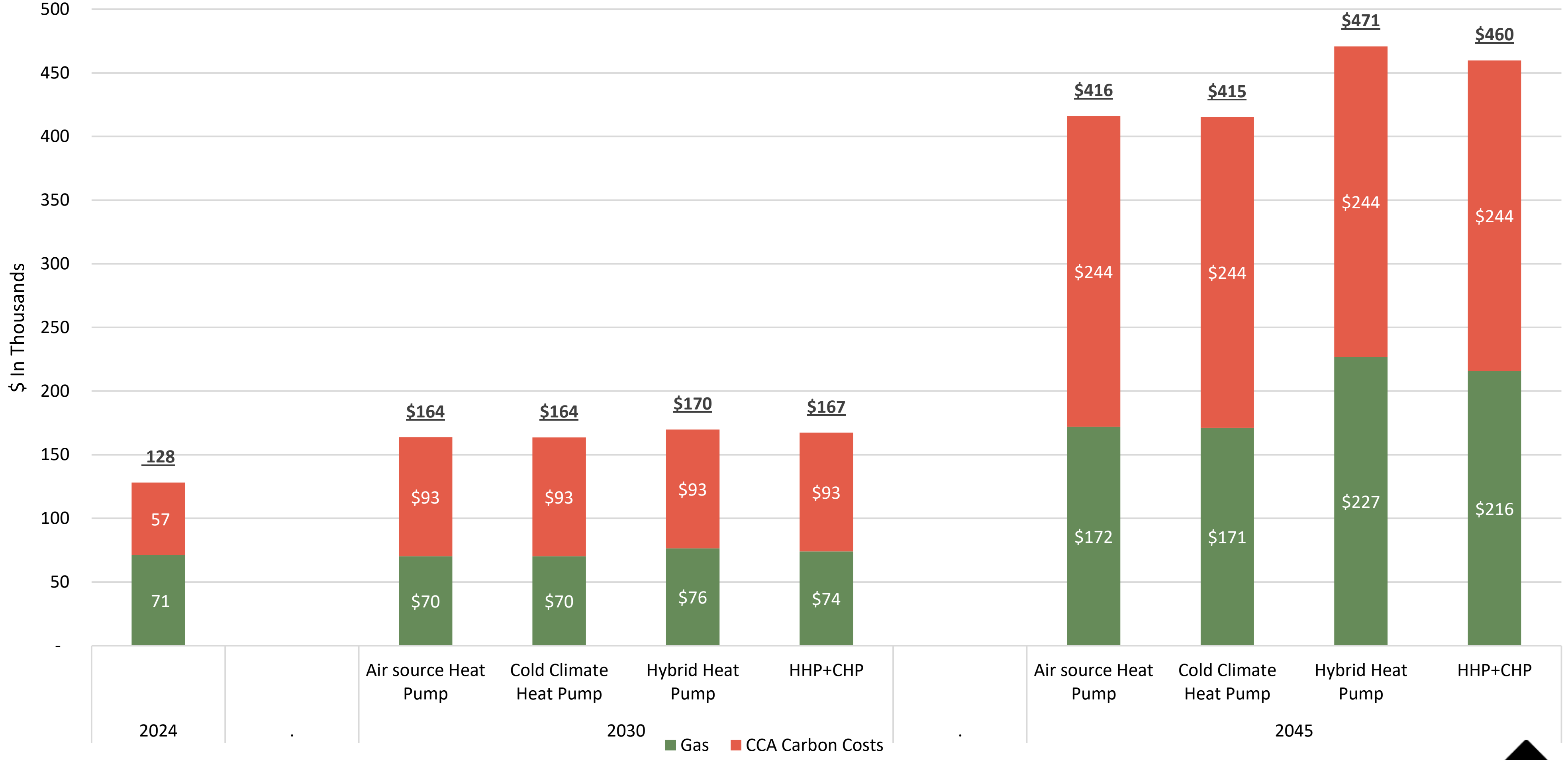
Dollars are shown in terms of the respective year

Industrial customer schedule 31 per average usage, showing total annual gas bill



Dollars are shown in terms of the respective year

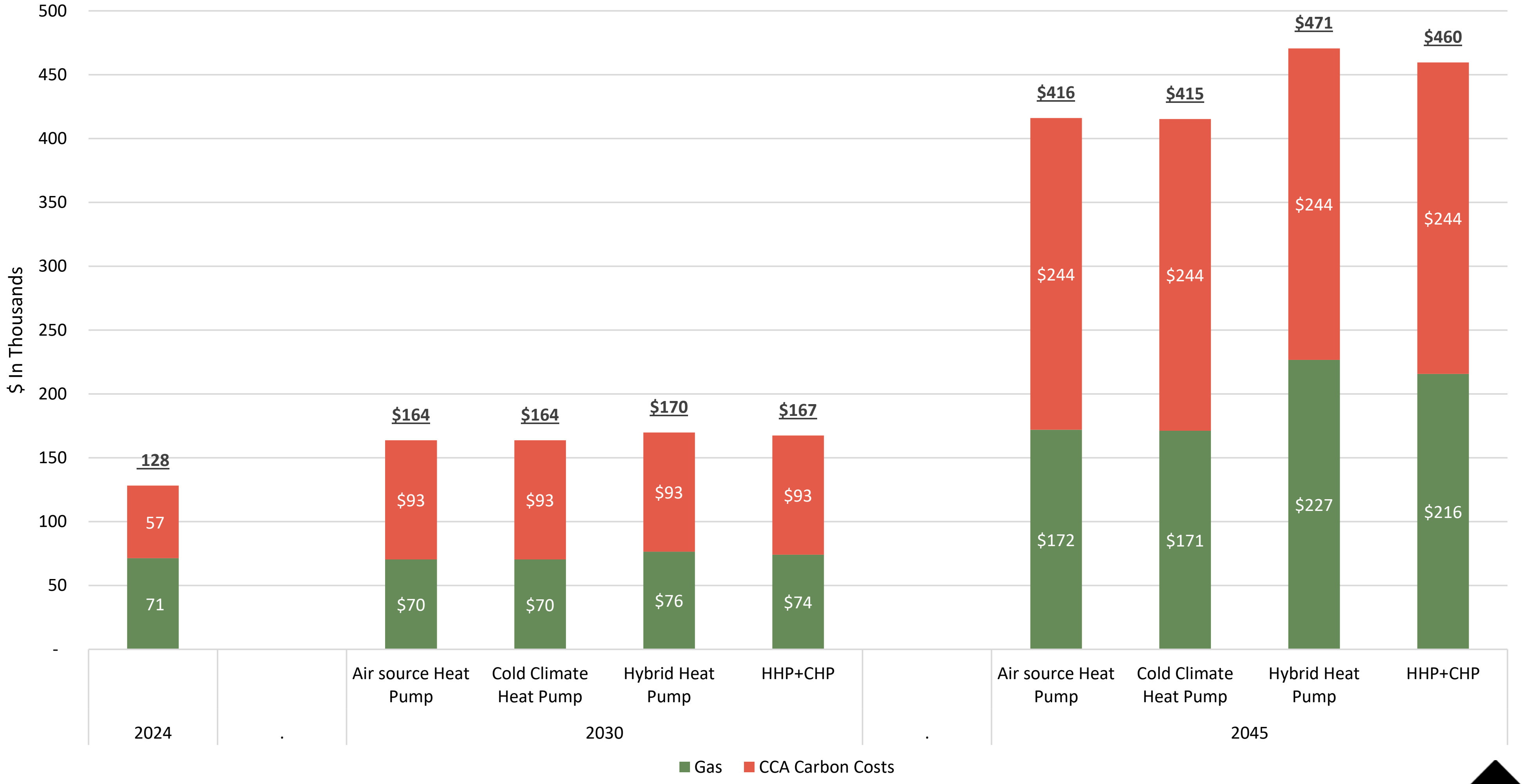
Industrial customer schedule 31T per average usage, showing total annual gas bill



PUGET SOUND ENERGY

Dollars are shown in terms of the respective year

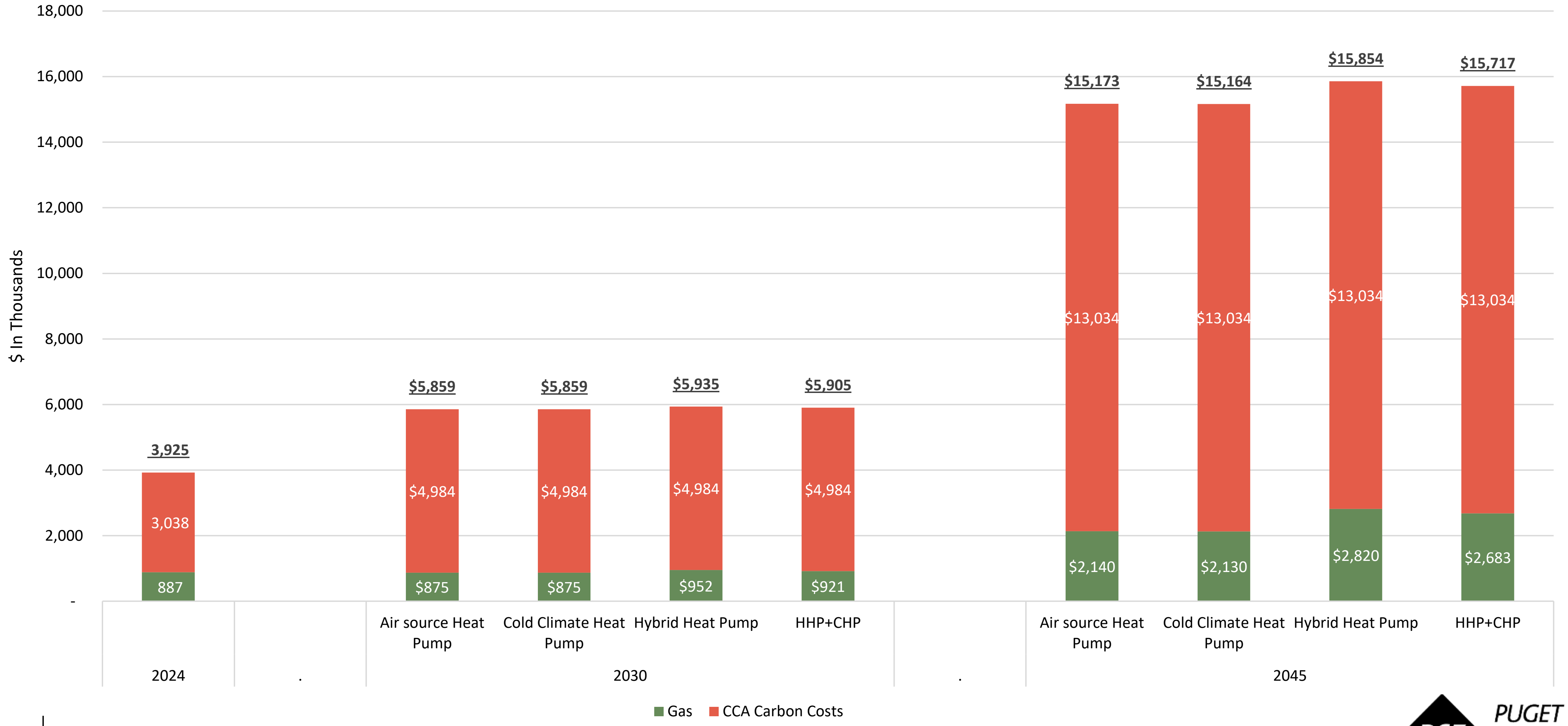
Industrial customer schedule 41T per average usage, showing total annual gas bill



PUGET SOUND ENERGY

Dollars are shown in terms of the respective year

Industrial customer schedule 87T per average usage, showing total annual gas bill



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Dollars are shown in terms of the respective year

Appendix

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Appendix

Model Inputs & Key Assumptions

Model Input	Value
Reporting Level (Generator or Meter)	Generator
Study Period	2024-2050
Cost Year	2022
Line loss	**Electric:** 8.14% , **Natural Gas:** 1.12%
Avoided T&D ($/kW-Year)	**Electric:** $74.70, **Natural Gas:** $0.00
Conservation Credit	10%
Admin Adder	21%
Discount Rate	6.62%
Includes non-energy impacts (NEIs)	Yes

Cold Climate Heat Pumps (CCHPs): Definition

- The Northeast Energy Efficiency Partnerships (NEEP), a U.S. Department of Energy (DOE) Regional Energy Efficiency Organization, established the Cold Climate Air Source Heat Pump Specification in 2014. → The NEEP specification adds a requirement for efficiency at 5°F as AHRI standard test protocols for determining the Heating Seasonal Performance Factor (HSPF) do not include testing at temperatures below 17°F.
- The Northwest Energy Efficiency Alliance (NEEA) has adopted the NEEP standard for its own specification for ductless CCHPs while including an additional capacity requirement.
- Further, in 2022, ENERGY STAR adopted a cold-climate designation for residential ASHPs.

<table>
<tr><th>Organization</th><th>HSPF2</th><th>SEER2</th><th>Low-Temp Efficiency</th><th>Capacity Requirement</th><th>Variable-Speed Requirement</th></tr>
<tr><td>NEEP (non-ducted) [a]</td><td>≥8.5</td><td>≥15</td><td rowspan="7">Coefficient of Performance (COP) ≥1.75 at 5°F at maximum capacity</td><td rowspan="3">N/A</td><td rowspan="3">Yes</td></tr>
<tr><td>NEEP (ducted)</td><td>≥7.7</td><td>≥14.3</td></tr>
<tr><td>NEEP (packaged terminal heat pump)</td><td>N/A</td><td>N/A</td></tr>
<tr><td>NEEA (non-ducted) [b]</td><td>≥8.5</td><td>≥15</td><td>≥80% of rated capacity at 5°F</td><td>Yes</td></tr>
<tr><td>ENERGY STAR (non-ducted) [c]</td><td>≥8.5</td><td>≥15.2</td><td rowspan="3">≥70% of rated capacity at 5°F</td><td rowspan="3">No</td></tr>
<tr><td>ENERGY STAR (ducted)</td><td>≥8.1</td><td>≥15.2</td></tr>
<tr><td>ENERGY STAR (packaged)</td><td>≥8.1</td><td>≥15.2</td></tr>
</table>

[a] Northeast Energy Efficiency Partnerships. January 1, 2023. *Cold Climate Air Source Heat Pump Specification (Version 4.0).* https://neep.org/cold_climate_air_source_heat_pump_specification.pdf

[b] Northwest Energy Efficiency Alliance. August 2022. *Cold Climate Ductless Heat Pump Specification and Recommendations (Version 2.0).* https://neea.org/img/documents/NEEA-Cold-Climate-DHP-Spec-and-Recommendations.pdf

[c] U.S. Environmental Protection Agency. January 2022. *ENERGY STAR Program Requirements: Product Specification for Central Air Conditioner and Heat Pump Equipment.* https://www.energystar.gov/ENERGY-STAR_Central-Air-Conditioner-and-Heat-Pump-Specification.pdf

Winter Peak Loads from Electrification: CCHP Impacts (Detailed)

- While CCHPs are expected to have lower peak demand impacts at all temperatures relative to non-CCHPs due to improved efficiency, actual peak demand impacts may depend on a few factors:
  - **COP during peak conditions.** While CCHPs typically have improved COPs throughout the heating season, many non-CCHPs may have similar COPs at more modest temperatures (around 30°F). During typical PSE winter peak conditions, **demand reductions from CCHPs compared to non-CCHPs may be modest** (and minimal compared to higher-efficiency non-CCHPs), assuming only use of the heat pump and not supplemental electric resistance.
  - **Use of supplemental electric resistance.** The use of **supplemental electric resistance** will be a primary driver of **added electrical demand** from converting natural gas heating to heat pumps. While ductless heat pumps are not installed with supplemental electric resistance, central heat pumps typically use supplemental electric resistance when not installed in a dual-fuel configuration with a backup furnace. Supplemental electric resistance is primarily used when heat pump capacity is inadequate to meet the heating needs of the building. Many models of ducted CCHPs will have a higher heat pump capacity at lower temperatures (5°F to 17°F) than non-CCHPs, which will reduce the overall usage of electric resistance to meet heating demand. Supplemental electric resistance is also used during defrost cycles, as well as to meet heating demand more rapidly—for example, when a system is attempting to recover from a deep setback.
  - **Heat pump balance point.** The balance point is the approximate outdoor temperature at which the heat pump capacity matches the heating load of the home. **Temperatures below the balance point will require the use of backup heating to maintain indoor comfort**. For heat pumps with electric resistance backup, auxiliary resistance heat will be used in conjunction with the heat pump's declining capacity to maintain the indoor thermostat setpoint; for heat pumps in dual fuel configurations, a programmed outdoor air temperature is used to switch from the heat pump to backup gas furnace. From a heat delivery perspective, conventional heat pumps with resistance backup will typically be sized in a manner to target a balance point of 30°F to 40°F, though CCHPs may be able to use a balance point of 20°F to 25°F (or lower), depending on sizing and the capacity reduction at lower temperatures.
- Ductless CCHPs are not installed with integrated electric resistance backup, and they operate with steadily decreasing efficiency (and increasing demand) as outdoor air temperature declines. Ductless CCHPs are expected to provide demand reduction compared to ductless non-CCHPs due to their improved overall and low-temperature efficiency.
- For dual-fuel systems with a backup furnace, the heat pump will switch off entirely when below the balance point and the furnace will provide all heat to the home. Switching over to the furnace would eliminate electrical demand (outside of the furnace fan and air handler operation) during those periods. Cadmus has used a switchover temperature of 35°F in this study.

Average Winter Peak Demand in kW from **Ducted** CCHP Compared to Ducted Non-CCHP (Single Family, Existing)

Average kW	CCHP (total)	CCHP (HP Only)	CCHP (ER)	Non-CCHP (total)	Non-CCHP (HP Only)	Non-CCHP (ER)
Peak Period	2.33	2.01	0.32	2.66	2.06	0.60
Peak Period (≤35°F)	3.57	2.66	0.91	4.24	2.54	1.69
Peak Period (≤27°F)	5.15	2.82	2.34	6.00	2.54	3.46

Average Winter Peak Demand in kW from **Ductless** CCHP Compared to Ductless Non-CCHP (Single Family, Existing)

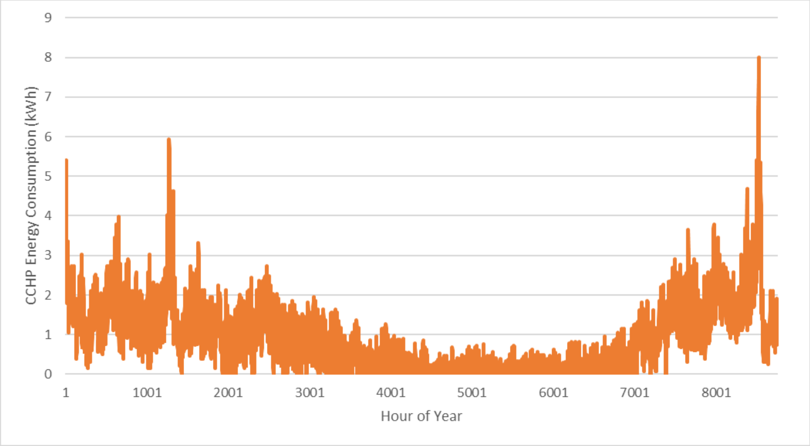
Average kW	CCHP (total)	CCHP (HP Only)	CCHP (ER)	Non-CCHP (total)	Non-CCHP (HP Only)	Non-CCHP (ER)
Peak Period	2.14	2.14	0.00	2.49	2.19	0.30
Peak Period (≤35°F)	3.03	3.03	0.00	3.75	2.91	0.83
Peak Period (≤27°F)	3.78	3.78	0.00	5.36	3.05	2.31

Heat Pump Load Shapes

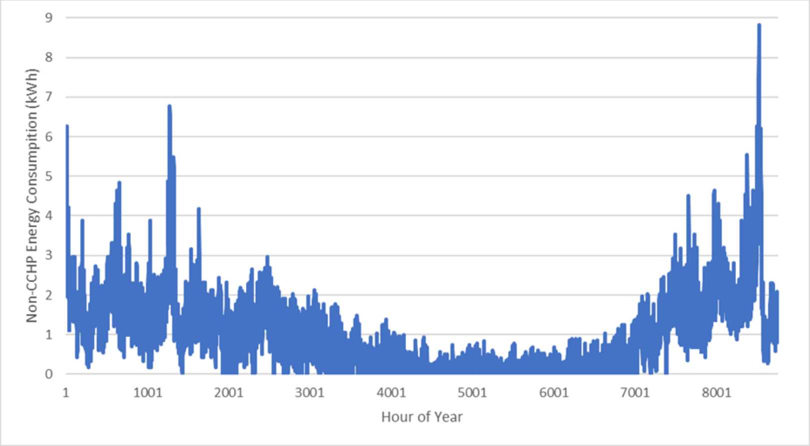
Cadmus created the heat pump load shapes for each residential segment (single family, multifamily, and manufactured) by:

- Data from the National Renewable Energy Laboratory's (NREL) ResStock analysis tool, corresponding temperature data (2018 AMY) with in PSE's service area
- CCHP field data from in MA and NY
- PSE-specific 2022 AMY weather file data.
- Data was weather normalized regression analysis to convert the load shapes from 2018 AMY to 2022 AMY weather file.

Ducted CCHP load shape (for single-family and existing construction)



Ducted non-CCHP load shape (for single-family and existing construction)



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CADMUS

HEEHRA and 25C

Rebate and Tax Credit Summary for Specific Measures

Measure	High-Efficiency Electric Home Rebate		25C Tax Credit	
	Requirements	Rebate Amount	Requirement	Credit Caps
Overall incentive amount and limit	Household <150% AMI	80-150% AMI: 50% of installation cost <80% AMI: 100% of costs for households Total cap of $14,000	Sufficient tax liability to claim credit	30% of installation cost up to $2,000 per year for heat pumps and biomass; 30% of installation cost up to $1,200 per year for all other measures combined
Appliances				
Heat pumps	ENERGY STAR electric	$8,000	Highest CEE non-advanced Tier	$2,000
Heat pump water heaters	ENERGY STAR electric	$1,750	Highest CEE non-advanced Tier	$2,000
Central air conditioner, water heater, furnace, or boiler	N/A	N/A	Highest CEE non-advanced Tier	$600
Stove, cooktop, range, or oven	N/A	$840	N/A	N/A
Heat pump clothes dryer	ENERGY STAR electric	$840	N/A	N/A
Biomass (wood) stove or boiler	N/A	N/A	>75% thermal efficiency (by HHV)	$2,000
Components				
Insulation and air sealing [a]	ENERGY STAR	$1,600	IECC (of two years before)	$1,200
Windows and skylights	N/A	N/A	ENERGY STAR Most Efficient	$600 (total)
Doors	N/A	N/A	ENERGY STAR	$500 ($250 max per door)
Electric panels/load service centers	N/A	$4,000	Enables qualifying equipment, at least 200 amps	$600
Electric wiring	N/A	$2,500	N/A	N/A
Measures	N/A	N/A	N/A	N/A
Energy audit	N/A	N/A	IRS to specify	$150

HOMES Rebate and 179D

Rebate and Tax Deduction Summary for Whole-Building Retrofits

	HOMES Rebate		179D Tax Deduction[a]
	Modeled Savings Approach	**Measured Savings**	
Minimum energy savings	20%	15%	25% (cost savings or EUI)
Energy metric	Savings calibrated to historical energy usage based on BPI 2400 standard	Weather-normalized energy usage of building pre- and post-retrofit using open-source software	Energy cost savings relative to minimum ASHRAE 90.1 building,[b] calculated using DOE-approved qualified energy modeling software OR savings relative to building baseline EUI based on a qualified retrofit plan
Percentage of project cost	≥80% AMI: 50%, <80% AMI[c]: 80%	≥80% AMI: 50%, <80% AMI: 80%	N/A
Incentive amount/cap at minimum savings level	At 20+% energy savings: • ≥80% AMI: 50% of project cost up to $2,000/home or dwelling unit, up to $200,000 per multifamily building • <80% AMI: 80% of project cost up to $4,000/home or dwelling unit, up to $400,000 per multifamily building At 35+% energy savings: • ≥80% AMI: 50% up to $4,000/home or dwelling unit, up to $400,000 per building • <80% AMI: 80% up to $8,000/home or dwelling unit, up to $800,000 per multifamily building	Payment per kilowatt-hour-equivalent saved relative to the average home/dwelling unit in the state. $2,000 incentive earned for 20% energy savings, can increase or decrease based on actual savings realized (no cap)	Base Rate: $0.50/sq ft at 25% savings increasing on sliding scale to $1/sq ft at 50% savings Bonus Rate[d]: $2.50/sq ft at 25% savings increasing on sliding scale to $5/sq ft at 50% savings
Contractor rebate	$200 for each home in a disadvantaged community		N/A

Gas to Electric Technologies: Scenario 1 and 2

Space/water heating systems, stoves/cooktops, and clothes dryers for existing customers and new constructions in the residential and commercial sectors

Sector	Electric Converted Sc 1 - ASHP FULL	Natural Gas Replaced Sc 1 - ASHP FULL	Vintage
Residential	Ductless Non-CCHP	Furnace Full Replacement	New and Existing
Residential	Air Source Heat Pump (ASHP) - Market Average	Furnace Full Replacement	New and Existing
Residential	Ductless Non-CCHP	Boiler Full Replacement	New and Existing
Residential	Ductless Non-CCHP	Gas Wall Unit Full Replacement	New and Existing
Residential	Cooking (Electric) - Market Average	Cooking (Gas)	New and Existing
Residential	Dryer (Electric) - Non-Heat Pump	Dryer (Gas)	New and Existing
Residential	Water Heat - Market Average	Water Heat (Gas)	New and Existing
Commercial	Air Source Heat Pump - Market Average	Furnace/Boiler Full Replacement	New and Existing
Commercial	Cooking (Electric) - Market Average	Cooking (Gas)	New and Existing
Commercial	Water Heat - Market Average	Water Heat (Gas)	New and Existing
Industrial	Target Reduction Conversion of Natural Gas Load 30% Reduction		Existing

Sector	Electric Converted Sc 2- CCHP FULL	Natural Gas Replaced Sc 2 - CCHP FULL	Vintage
Residential	Ductless CCHP	Furnace Full Replacement	New and Existing
Residential	CCHP	Furnace Full Replacement	New and Existing
Residential	Ductless CCHP	Boiler Full Replacement	New and Existing
Residential	Ductless CCHP	Gas Wall Unit Full Replacement	New and Existing
Residential	Cooking (Electric) - Market Average	Cooking (Gas)	New and Existing
Residential	Dryer (Electric) - Non-Heat Pump	Dryer (Gas)	New and Existing
Residential	Water Heat - Market Average	Water Heat (Gas)	New and Existing
Commercial	Air Source Heat Pump - Market Average	Furnace/Boiler Full Replacement	New and Existing
Commercial	Cooking (Electric) - Market Average	Cooking (Gas)	New and Existing
Commercial	Water Heat - Market Average	Water Heat (Gas)	New and Existing
Industrial	Target Reduction Conversion of Natural Gas Load 30% Reduction		Existing

*Green lines highlights the residential difference between Sc 1 - ASHP FULL and Sc 2 - CCHP FULL

Gas to Electric Technologies: Scenario 3 and 4

Sector	Electric Converted Sc 3 – HHP	Natural Gas Replaced Sc 3 – HHP	Vintage
Residential	Ductless Non-CCHP with Furnace Back-up		New and Existing
Residential	Hybrid ASHP with Furnace Back-up		New and Existing
Residential	Ductless Non-CCHP with Boiler Back-up		New and Existing
Residential	Ductless Non-CCHP with Gas Wall Unit Back-up		New and Existing
Residential	Cooking (Electric) - Market Average	Cooking (Gas)	New and Existing
Residential	Dryer (Electric) - Non-Heat Pump	Dryer (Gas)	New and Existing
Residential	Water Heat - Market Average	Water Heat (Gas)	New and Existing
Commercial	Air Source Heat Pump - Market Average	Furnace/Boiler Full Replacement	New and Existing
Commercial	Cooking (Electric) - Market Average	Cooking (Gas)	New and Existing
Commercial	Water Heat - Market Average	Water Heat (Gas)	New and Existing
Industrial	Target Reduction Conversion of Natural Gas Load 30% Reduction		Existing

Hybrid/Back-up Assumptions:

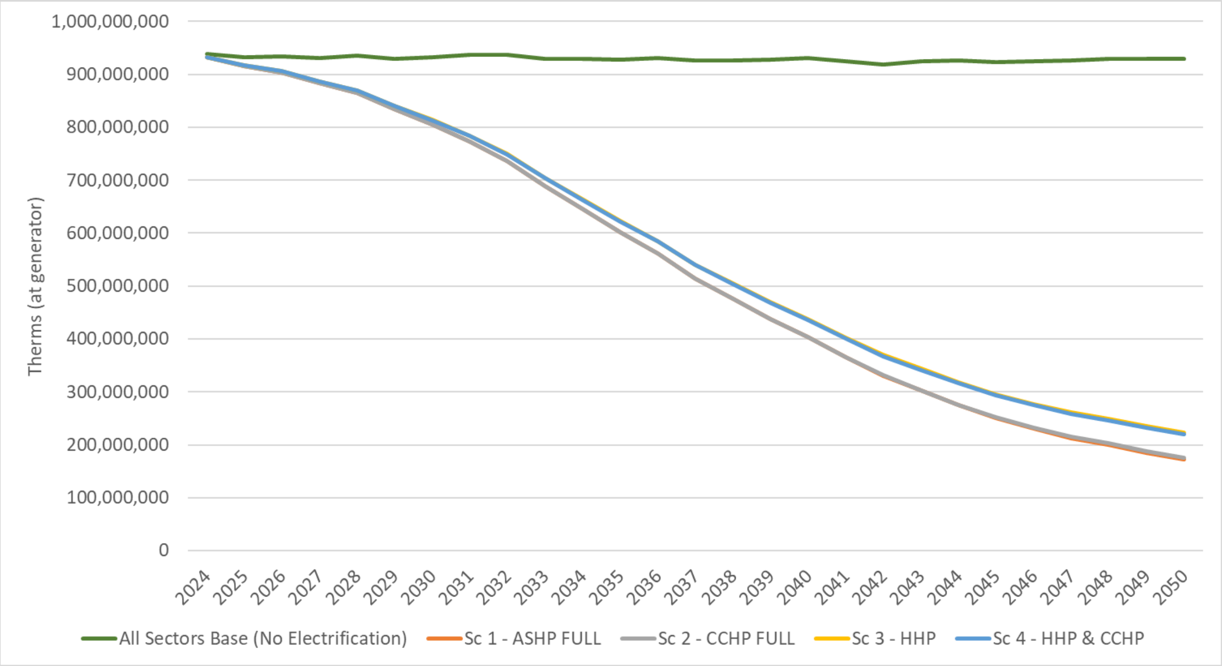
- Assumed a switchover temperature of 35°F

Sector	Electric Converted Sc 4 - HHP&CCHP	Natural Gas Replaced Sc 4 - HHP&CCHP	Vintage
Residential	Ductless Non-CCHP with Furnace Back-up		Existing
Residential	Hybrid ASHP with Furnace Back-up		Existing
Residential	Ductless Non-CCHP with Boiler Back-up		Existing
Residential	Ductless Non-CCHP with Gas Wall Unit Back-up		Existing
Residential	Ductless CCHP	Furnace Full Replacement	New
Residential	CCHP	Furnace Full Replacement	New
Residential	Ductless CCHP	Boiler Full Replacement	New
Residential	Ductless CCHP	Gas Wall Unit Full Replacement	New
Residential	Cooking (Electric) - Market Average	Cooking (Gas)	New and Existing
Residential	Dryer (Electric) - Non-Heat Pump	Dryer (Gas)	New and Existing
Residential	Water Heat - Market Average	Water Heat (Gas)	New and Existing
Commercial	Air Source Heat Pump - Market Average	Furnace/Boiler Full Replacement	New and Existing
Commercial	Cooking (Electric) - Market Average	Cooking (Gas)	New and Existing
Commercial	Water Heat - Market Average	Water Heat (Gas)	New and Existing
Industrial	Target Reduction Conversion of Natural Gas Load 30% Reduction		Existing

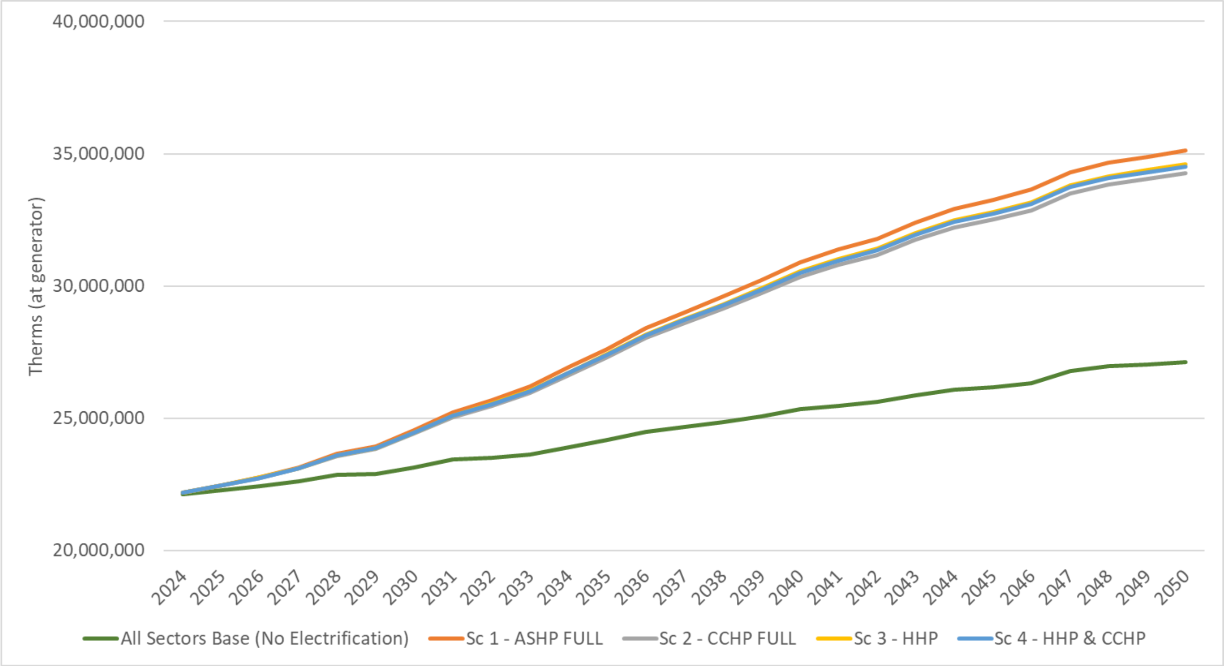
* Green lines highlights the residential difference between Sc 3 - HHP and Sc 4 – HHP&CCHP

Impact on the Baseline Energy Forecast (All Sectors, All End-Uses)

Natural Gas Forecast



Electric Forecast



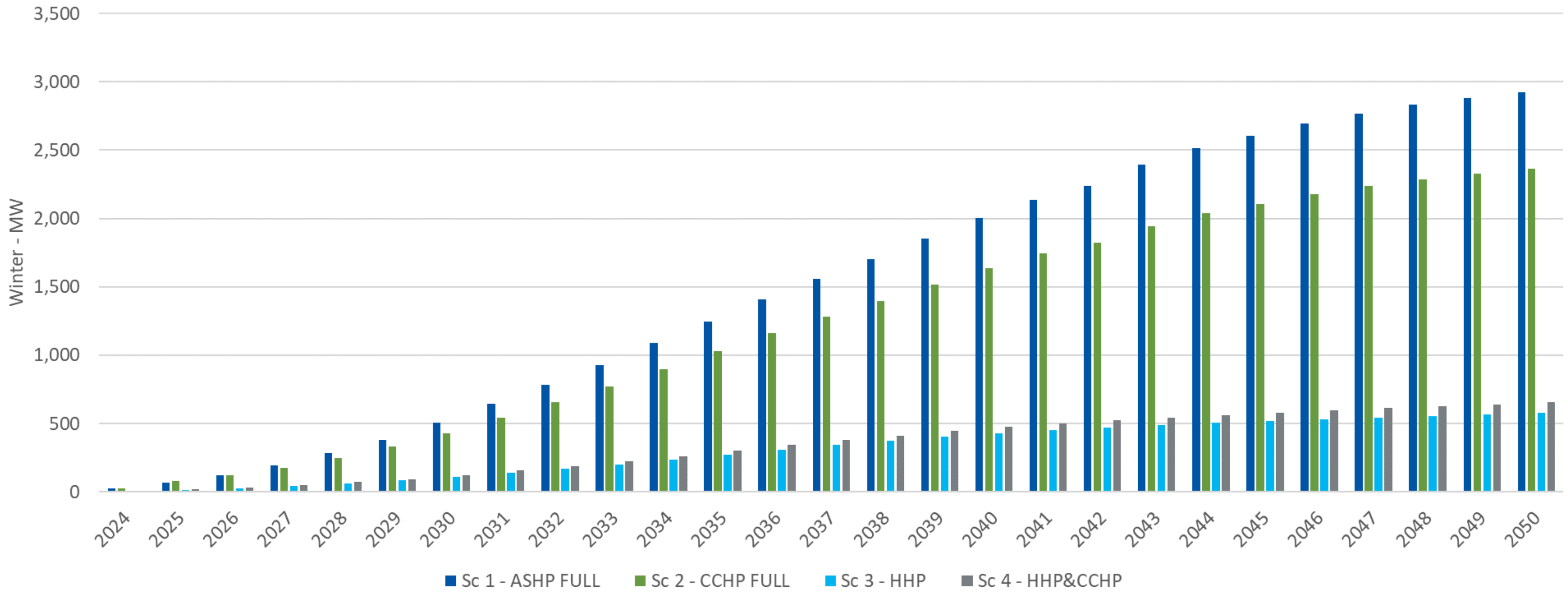
Sc 1 - ASHP FULL: 29% electric increase and 81% gas decrease in 2050 from the base case forecast

Sc 2 - CCHP FULL: 26% electric increase and 81% gas decrease in 2050 from the base case forecast

Sc 3 - HHP: 28% electric increase and 76% gas decrease in 2050 from the base case forecast

Sc 4 - HHP&CCHP: 27% electric increase and 76% gas decrease in 2050 from the base case forecast

Added Peak Demand - All Sectors, All End Uses



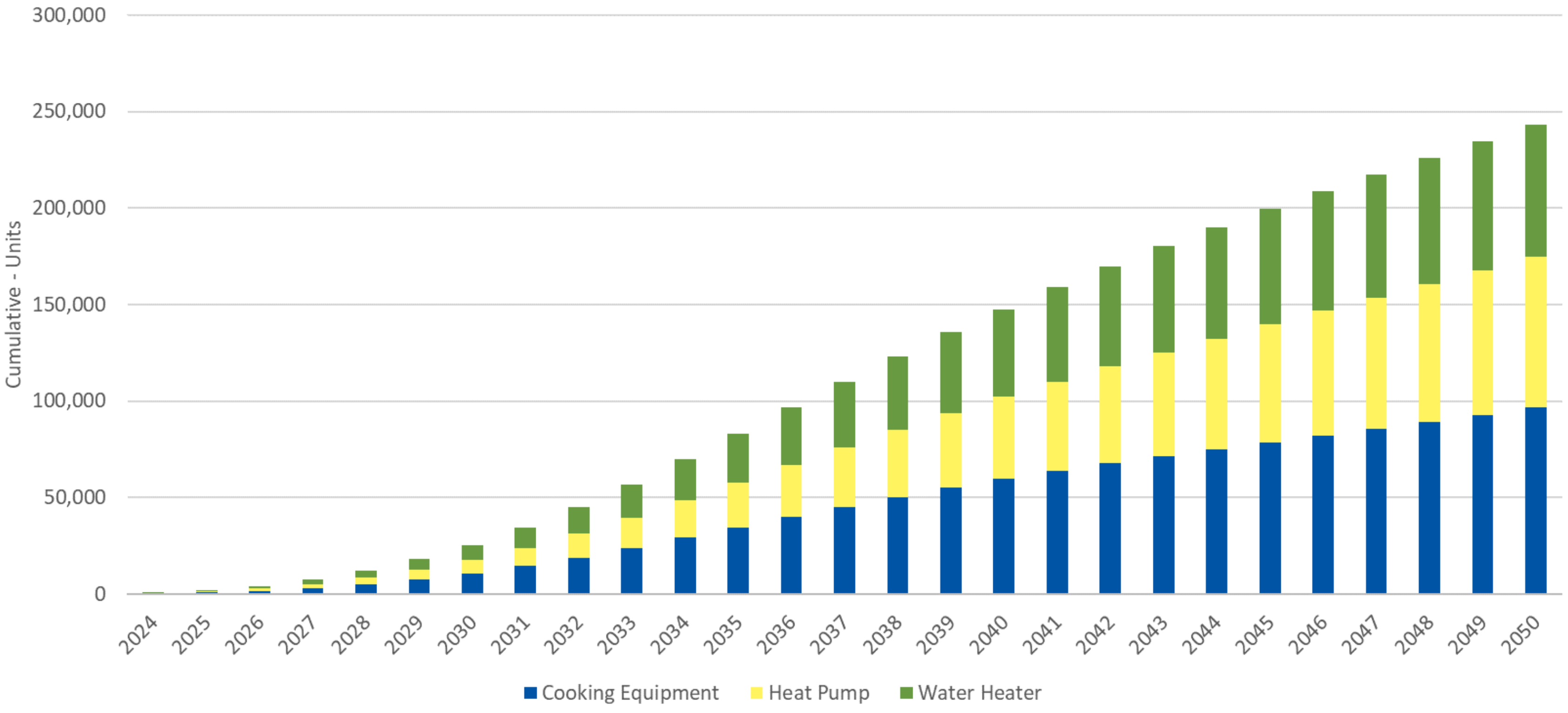
Sc 1 - ASHP FULL shows 2,923 MW increase to the PSE system peak by 2050

Sc 2 - CCHP FULL has added winter peak equals to 81% of Sc 1 - ASHP FULL (2362 MW) by 2050

Sc 3 - HHP shows 580 MW increase to the PSE system peak by 2050, which is 20% of Sc 1 - ASHP FULL

Sc 4 - HHP&CCHP shows 656 MW increase to the PSE system peak by 2050

Commercial Equipment Adoption Forecast



Units in 10-years:

- ~15,800 Heat pump units
- ~17,400 Water heater units
- ~23,800 Buildings with cooking equipment
- **Units in 27-years:**
- ~77,700 Heat pump units
- ~68,500 Water heater units
- ~96,800 Buildings with cooking equipment

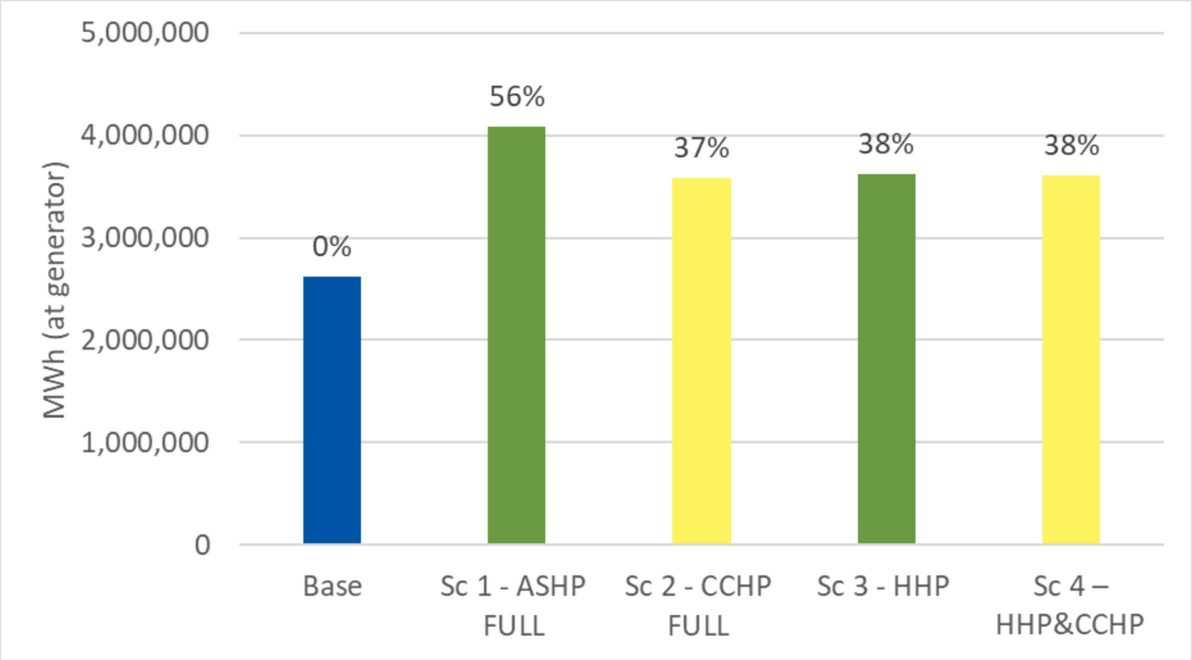
Impacts on Energy Efficiency Potential

Sector	Achievable Technical Potential, Cumulative 2050				
	27-Year Base Energy Efficiency Potential	27-Year Sc 1 - ASHP FULL Energy Efficiency Potential	27-Year Sc 2 - CCHP FULL Energy Efficiency Potential	27-Year Sc 3 - HHP Energy Efficiency Potential	27-Year Sc 4 – HHP&CCHP Energy Efficiency Potential
Electric (MWh)					
Residential	2,624,461	4,083,091	3,585,653	3,617,432	3,613,364
Commercial	2,027,893	2,312,136	2,312,136	2,312,136	2,312,136
Industrial	162,604	164,545	164,545	164,545	164,545
Total	**4,814,958**	**6,559,772**	**6,062,334**	**6,094,112**	**6,090,045**
Natural Gas (MMTherms)					
Residential	111	25	25	30	30
Commercial	51	19	19	19	19
Industrial	3	3	3	3	3
Total	**165**	**47**	**47**	**52**	**52**

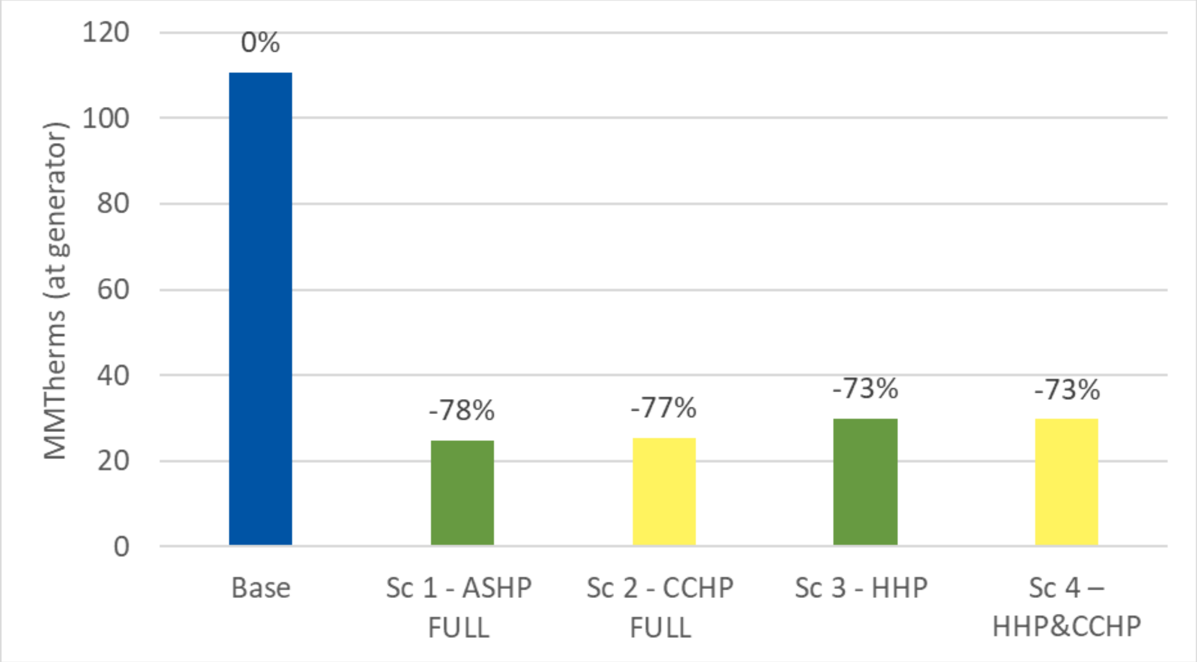
*Table excludes transport customers

Impacts on Energy Efficiency Potential

Cumulative Electric EE Potential in 2050



Cumulative Natural Gas EE Potential in 2050



Sc 1 - ASHP FULL has the highest electric EE potential (56% higher than the base potential) and lowest natural gas EE potential (78% lower than the base potential)

Sc 2 - CCHP FULL has the lowest electric EE potential (37% higher than the base potential) and almost the same natural gas EE potential with Sc 1 - ASHP FULL (77% lower than the base potential)

Sc 3 - HHP has 38% higher electric EE potential than the base potential and 73% lower natural gas EE potential than the base potential

Sc 4 - HHP&CCHP has 38% higher electric EE potential than the base potential and 73% lower natural gas EE potential than the base potential

Puget Sound Energy (PSE) GRC Settlement Study: Regional Context

Appendix - Detailed Results

August 2023

Energy+Environmental Economics

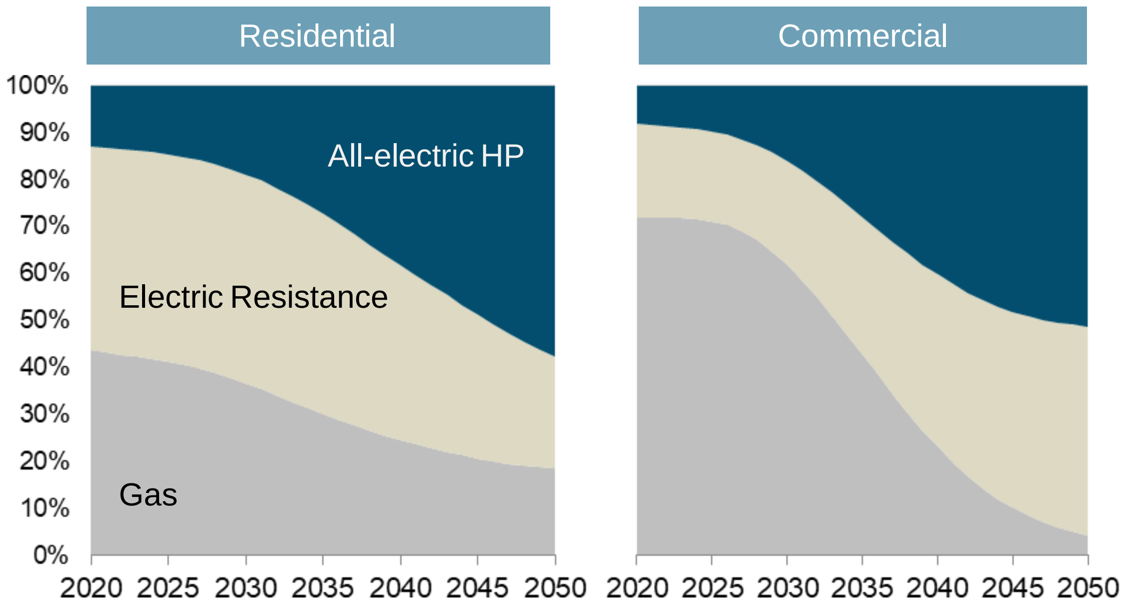
Impacts of Heating Decarbonization Pathways on Regional Infrastructure

Energy+Environmental Economics

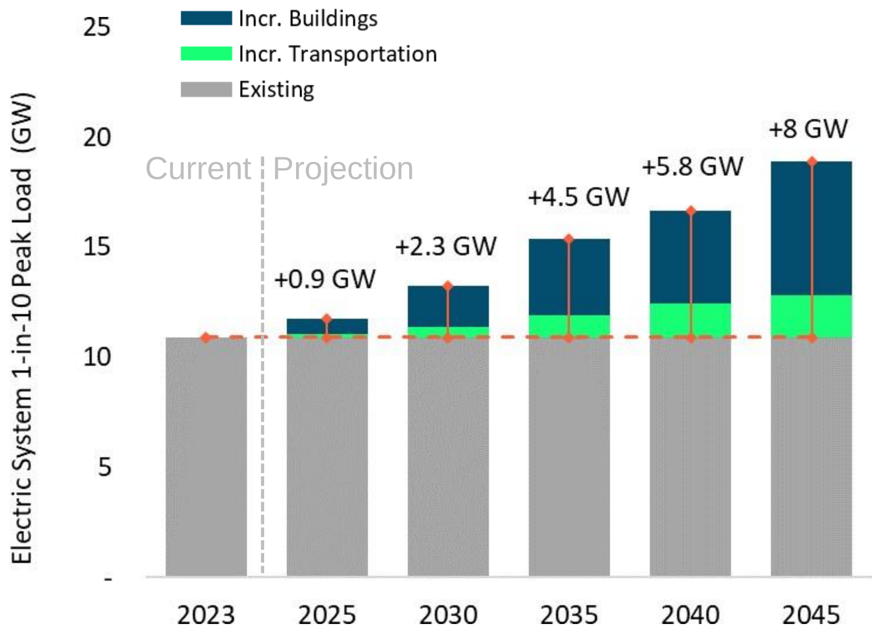
The State Energy Strategy envisions a transition towards electric heating

+ The State Energy Strategy envisions a rapid transition towards all-electric heating.
+ E3 estimates that the heating transition envisioned in the SES will increase peak demands by 2.3 GW in 2030 and 8 GW in 2045 if current cold-climate air source heat pump technologies are used.

HVAC Stocks by Technology – SES



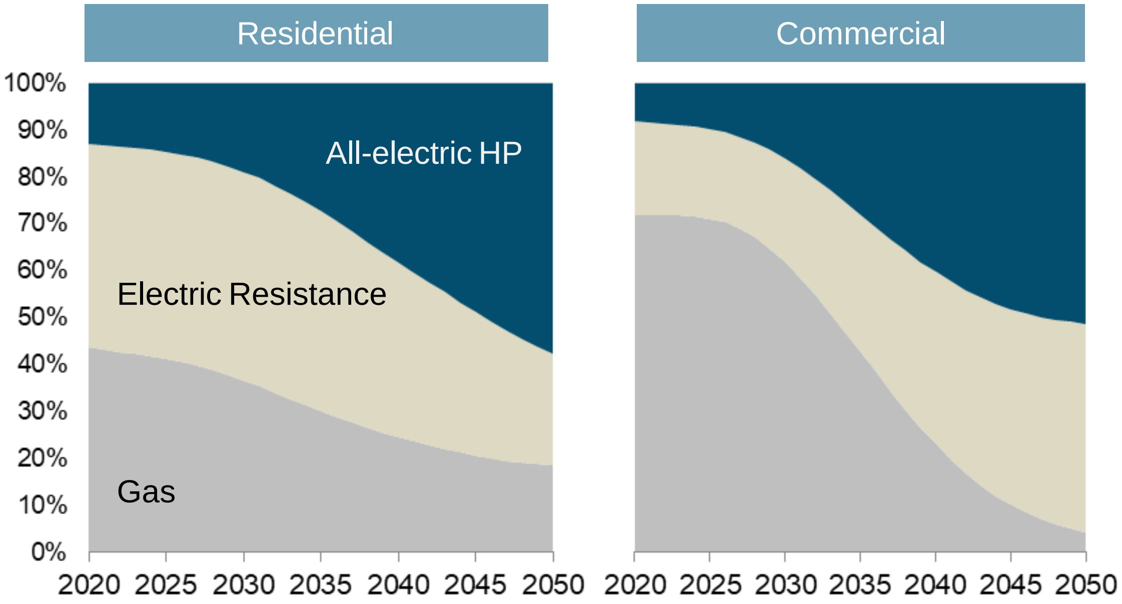
Electric System 1-in-10 Peak Demand – Western WA



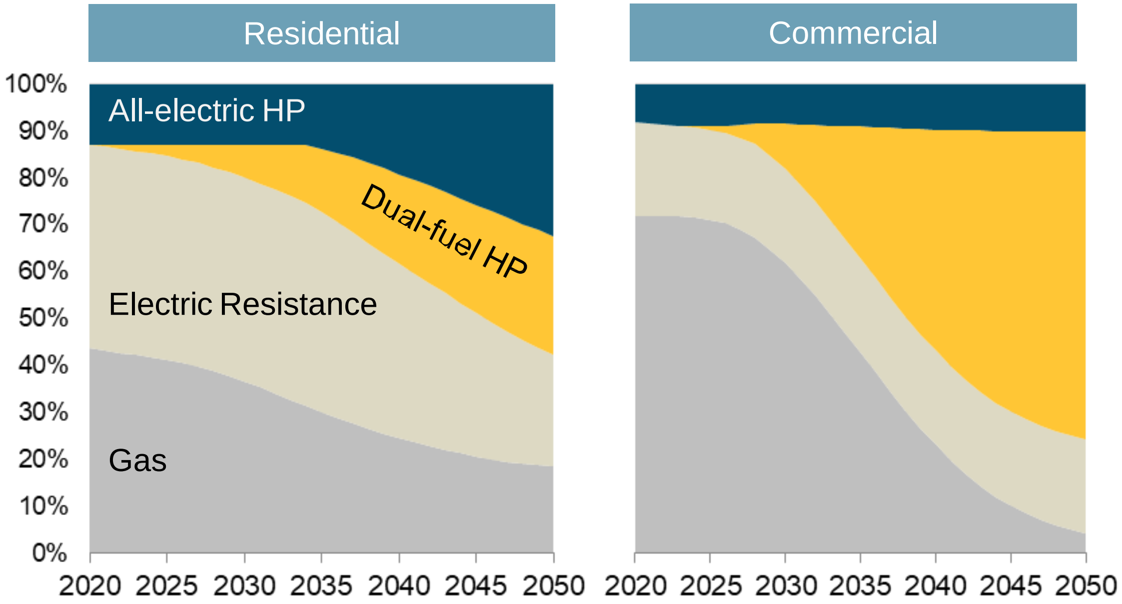
Electrification Scenarios

Scenario Name	Design
State Energy Strategy (SES)	Pace of electrification for buildings and transportation envisioned in the Electrification Scenario from the **2021 WA State Energy Strategy**, which maximizes electrification with potential large impact on electric system
Hybrid	Modified SES scenario assuming existing gas heating that switched to electric heating in the SES all adopt **dual-fuel heat pumps**, aiming at achieving similar emissions reduction but at a lower cost

HVAC Stocks by Technology – SES



HVAC Stocks by Technology - Hybrid



There are multiple ways to serve the incremental peak electric demand driven by heating electrification in Western Washington

- Our results show that the State Energy Strategy Scenario is projected to have peak electric demand in Western WA increase by 8 GW by 2045
- There are multiple ways to serve the incremental peak electric demand:
  1. **Cross-Cascades transmission expansion** to connect to renewables or thermal generation outside of Western WA
  2. **Local Non-GHG Emitting Emissions Resources** such as hydrogen, nuclear SMR or off-shore wind.
     - a. **Clean Firm Resources** such as hydrogen CTs and nuclear SMR meet CETA requirements of 100% clean energy.
     - b. **Off-shore wind** does not provide firm capacity, so nameplate capacity additions to meet winter peaks are very large.
- The next few slides will show results of these **"bookend" alternatives** , i.e. what if incremental peak were served entirely with one resource type. In practice, a portfolio of options could be deployed.

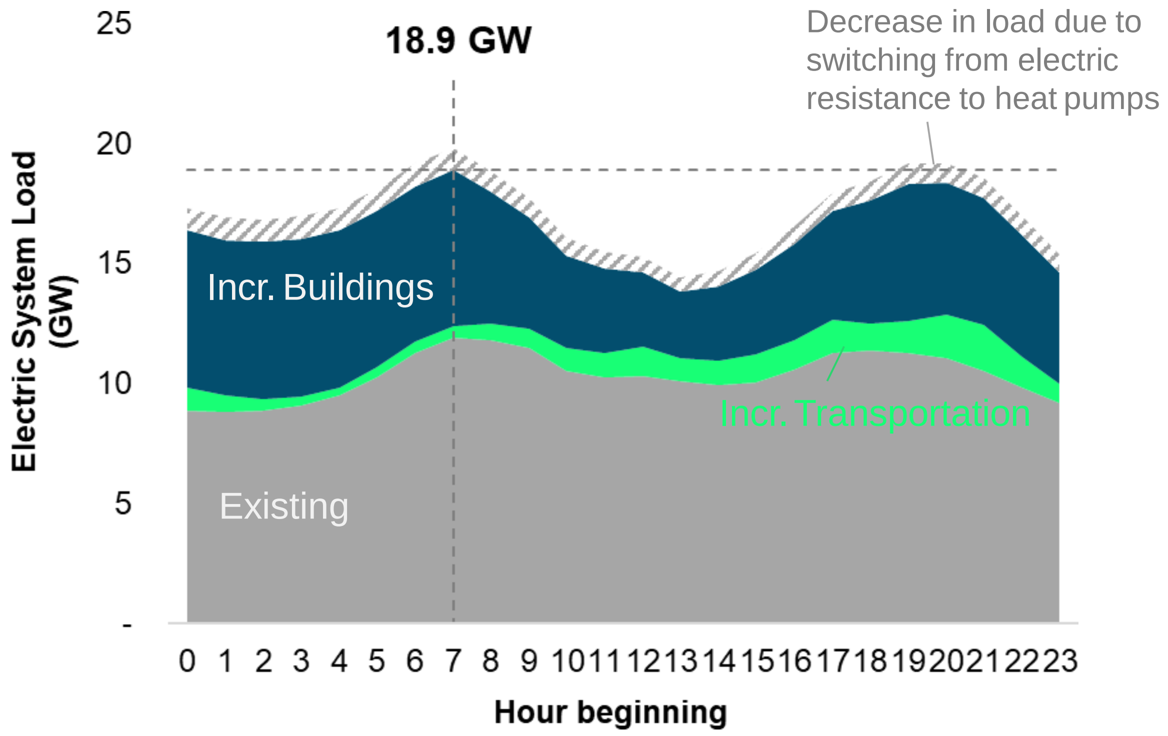
State Energy Strategy Scenario

Electric System 1-in-10 Peak Demand – Western WA

Heating electrification peak demands are sustained over a multi-day periods and could be challenging to serve

Hourly Load on the 1-in-10 Peak Day

State Energy Strategy Scenario (2045)

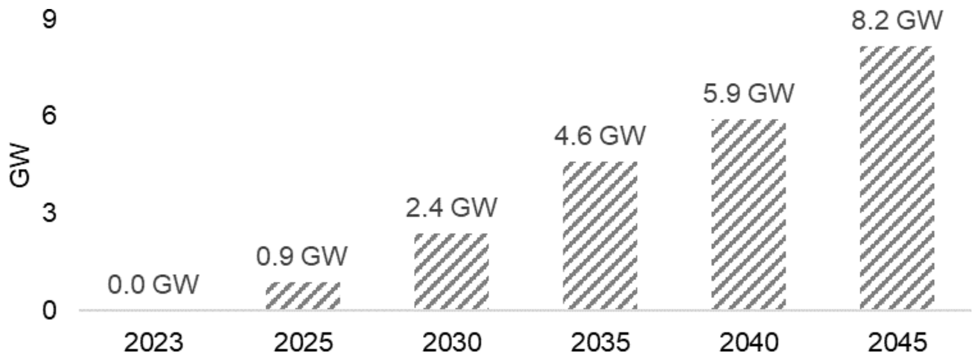


- Heating loads are highest during mornings and evenings, but are also a sustained overnight.
- Given the sustained nature of these loads, opportunities to meet peak demands via commercialized energy storage or load flexibility may be limited.
- An additional challenge is meeting sustained heating loads during periods of low renewable generation.

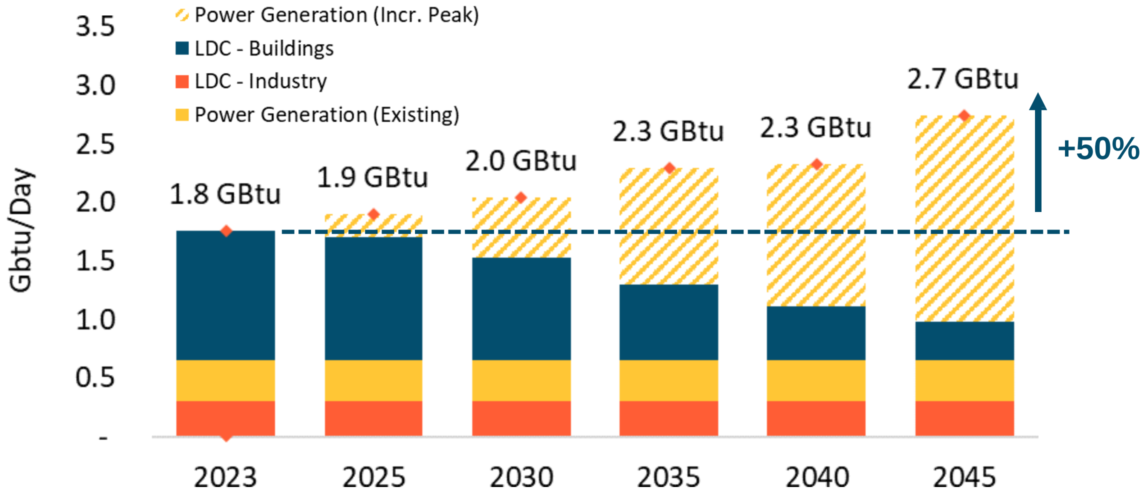
Counterfactual: Building local gas CTs in Western WA

- Serving the incremental peak with local hydrogen-ready CTs would require 8.2 GW additional capacity installed
- The new local hydrogen-ready CTs will result in (1) design day gas throughput increase by 50%, and (2) design day net GHG emissions increase by 52 kTCO2e
- *CAVEAT: Counterfactual scenario may meet the CETA requirement to achieve 100% clean power generation by 2045 if the CTs were powered by zero-carbon fuels*

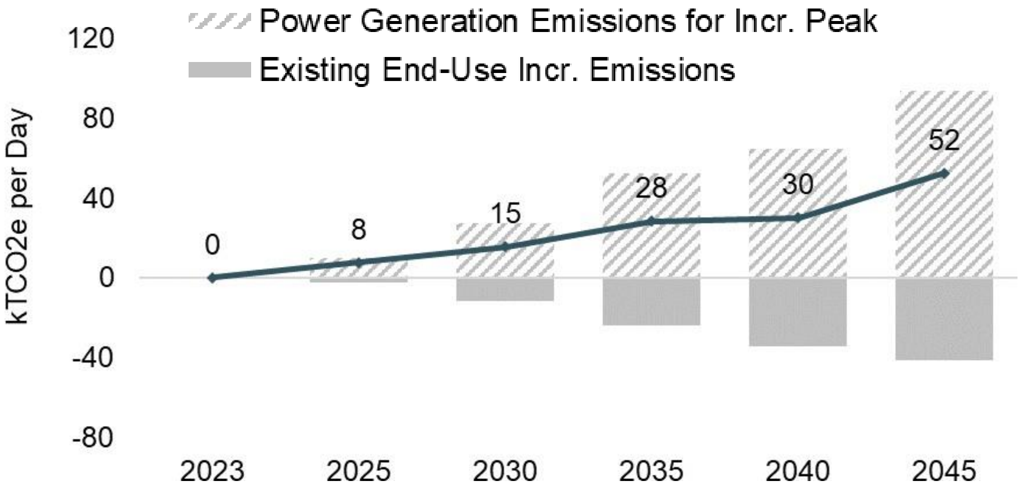
Local Gas CT Capacity to Serve Western WA



Design Day* Gas Throughput in Western WA



Design Day Net Emissions to Serve Western WA

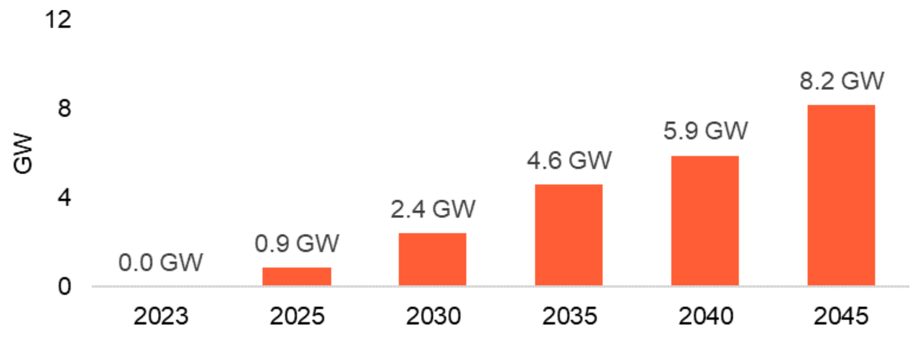


* The gas design day in this analysis is defined based on the most conservative design criteria among gas LDCs in Western Washington. E3 models it as the coldest day with the highest heating degree days (HDDs) from1979-2019.

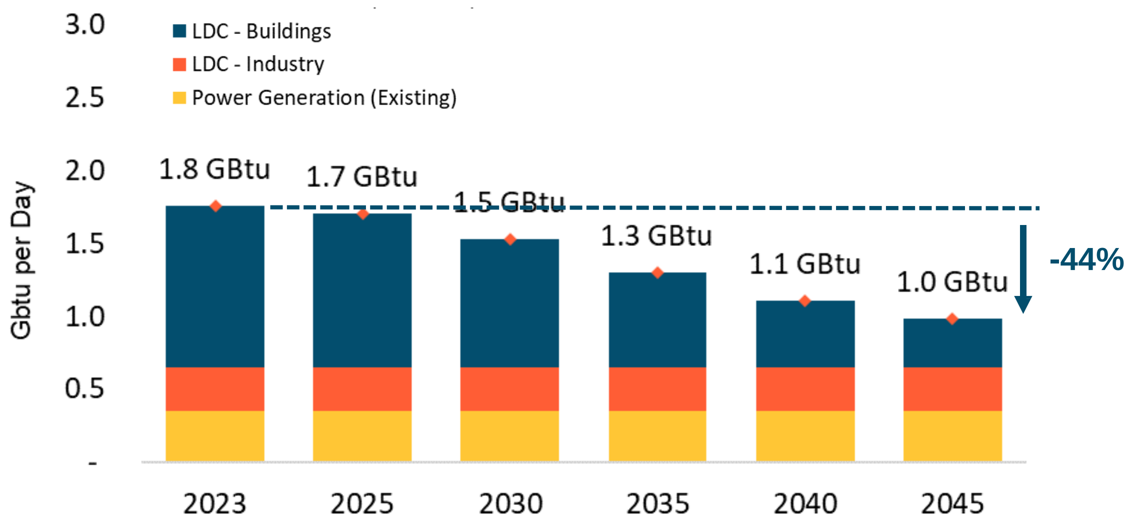
Alternative 1: Expanding cross-Cascades transmission capacity to access clean resources on the east side

- **Serving the incremental peak with non-local gas CTs would require expanding transmission capacity to Western WA by 8.2 GW to access resources on the East-side**
- **Transmission expansion could mitigate the stress on local gas demand on design day**
- **However, it will be challenging to expand or build new transmission capacity crossing the Cascades**
  - Upfront cost of the transmission expansion can be more than $3 Billion based on example project cost estimate from BPA's 2022 Transmission Cluster Study

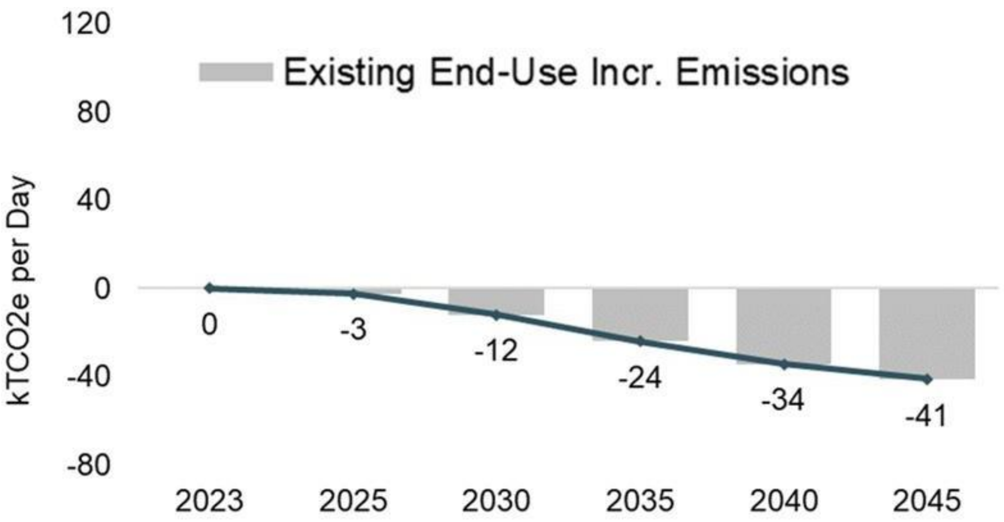
Additional Transmission and East-side Resource Capacity to Serve Western WA



Design Day Gas Throughput in Western WA



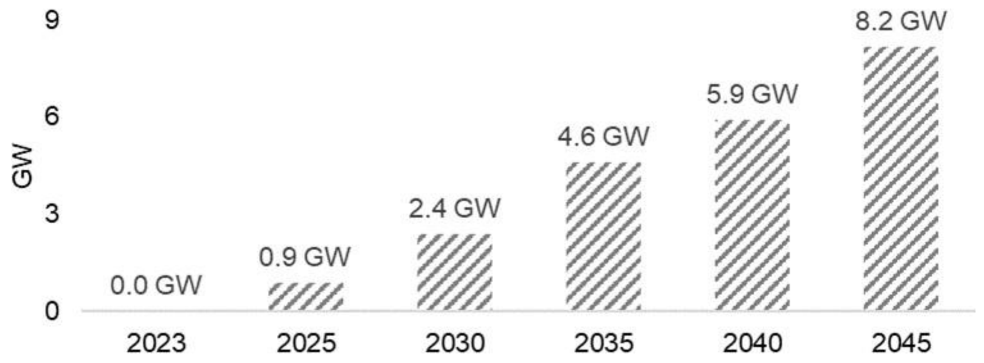
Design Day Net Emissions to Serve Western WA



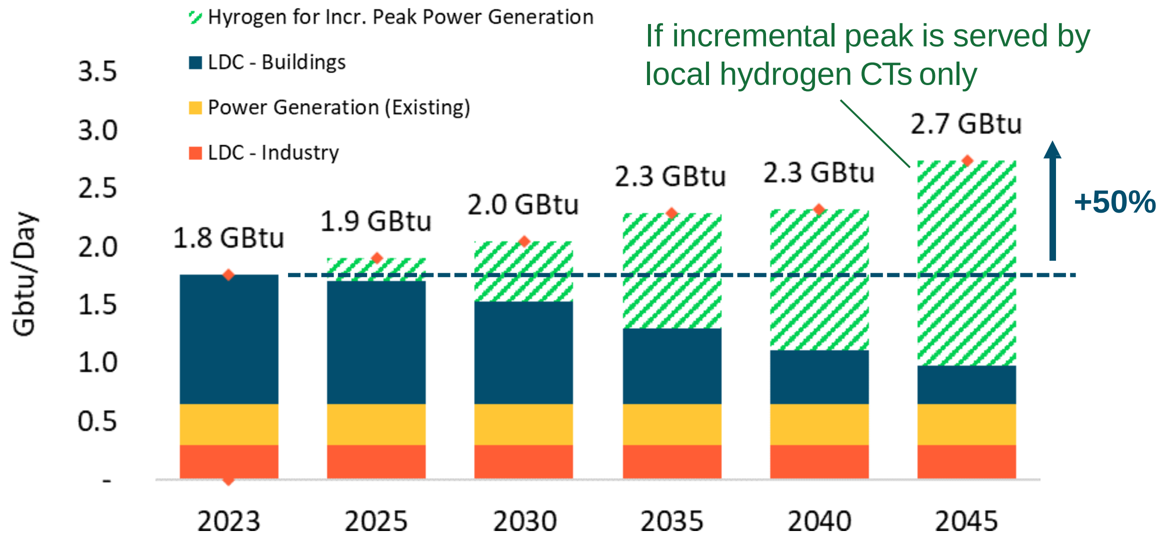
Alternative 2a: Building local clean firm resources in Western WA

- Serving the incremental peak with local clean firm resources would require 8.2 GW additional capacity installed
- Using clean firm resources such as hydrogen-ready CTs and small-modular nuclear to serve the incremental peak will reduce GHG emissions on design day
- However, if all incremental peak demand is served by hydrogen CTs, there will be a big challenge for transporting and storing hydrogen; combined gas and hydrogen demand will be 50% higher than today's gas throughput in Western WA

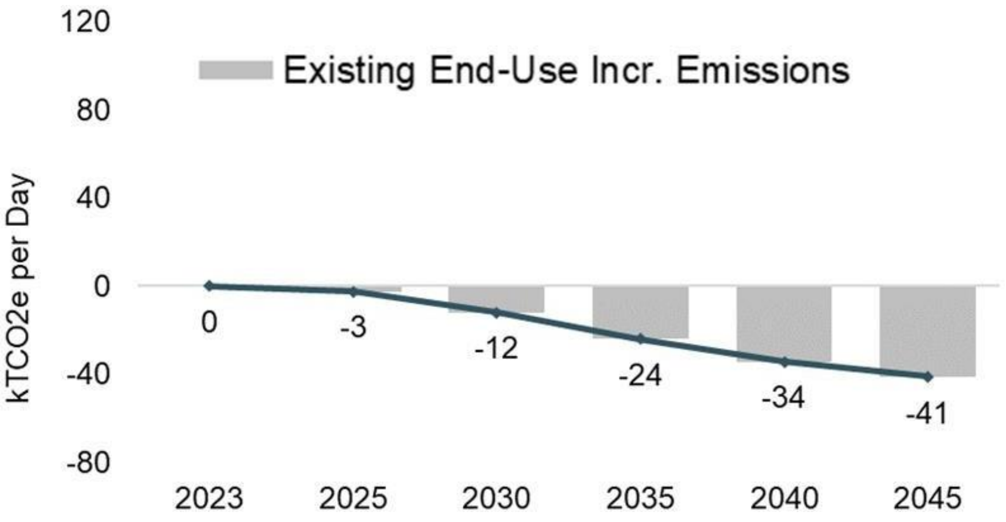
Local Clean Firm Resource Capacity to Serve Western WA



Design Day Gas in Western WA



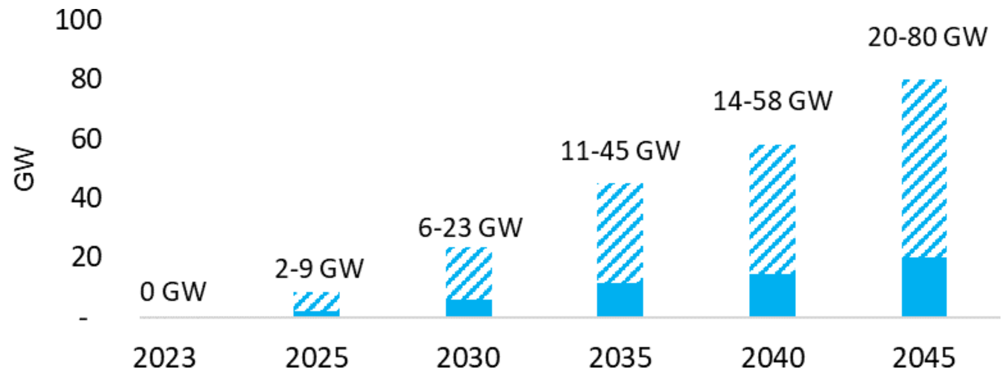
Design Day Net Emissions to Serve Western WA



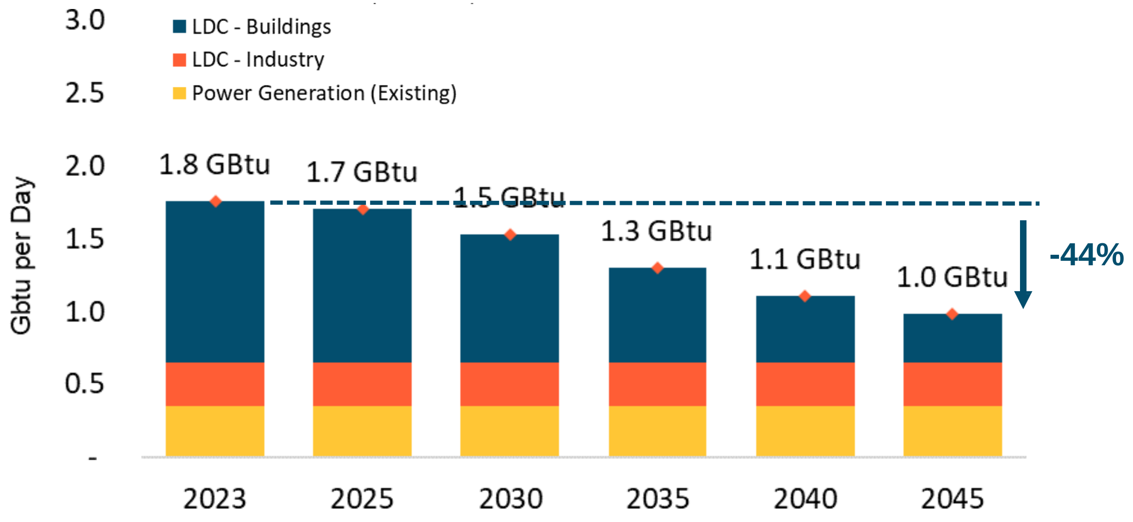
Alternative 2b: Building offshore wind in Western Washington

- **Using only offshore wind to meet the incremental peak will require 20-80 GW in capacity by 2045 and cost $60-370 billion**
  - Effective load carrying capacity (ELCC) of offshore wind is assumed at a wide range 10-40% due to uncertainty; additional research is needed to narrow the range

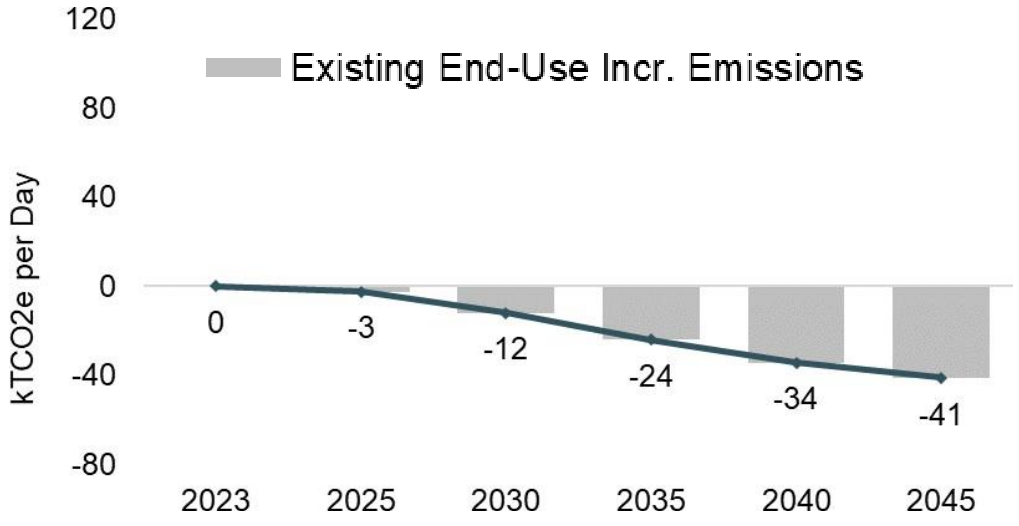
Offshore Wind Capacity to Serve Western WA



Design Day Gas Throughput in Western WA



Design Day Net Emissions to Serve Western WA

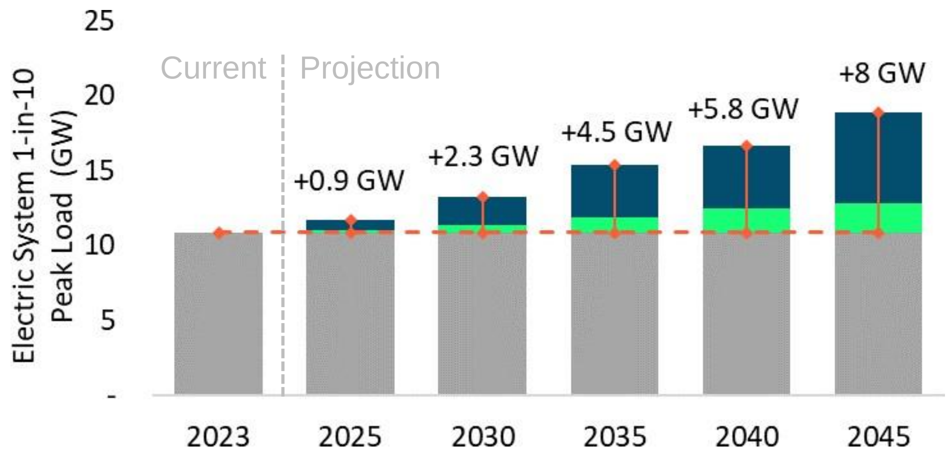


Switching gas heating to dual-fuel heat pumps can significantly reduce peak impact on the electric system

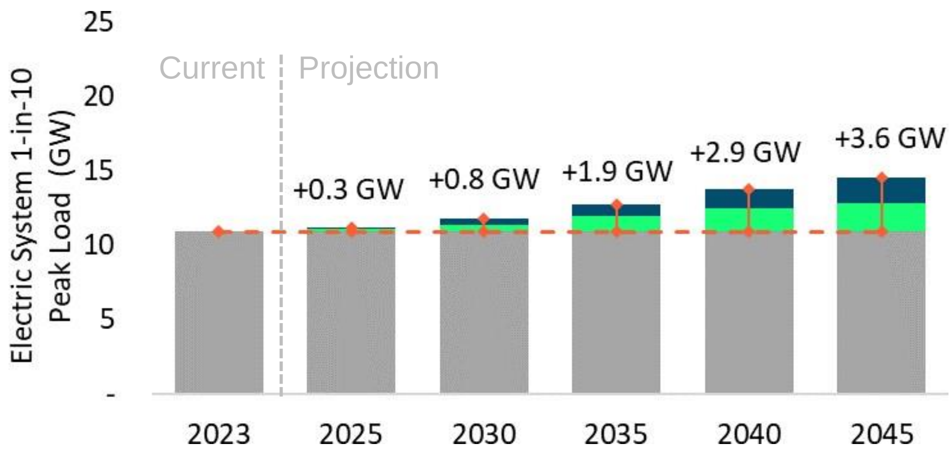
- **Hybrid Scenario** has peak electric demand increase at a much slower pace due to the reliance on the gas system to provide peak heating need during cold spells
- Incremental peak electric demand is **more than halved** in the **Hybrid Scenario** compared to **the State Energy Strategy Scenario**

Electric System 1-in-10 Peak Demand – Western WA

State Energy Strategy Scenario



Hybrid Scenario

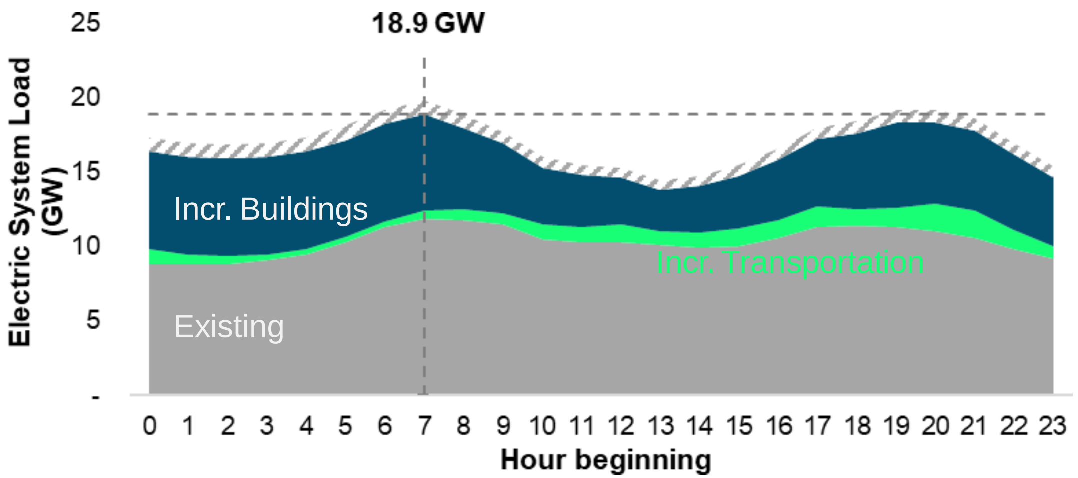


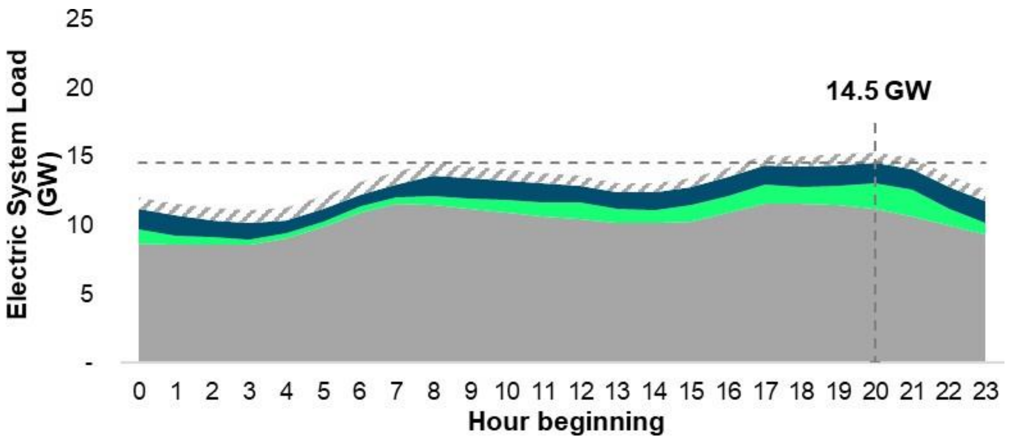
Hybrid Scenario has a much smaller peak impact due to the use of gas backup during the extreme cold event

+ **Switching the electrified gas heating in the SES to dual-fuel heat pumps reduces peak impact by ~4.4 GW during the extreme event in 2045**

Hourly Load on the 1-in-10 Peak Day

State Energy Strategy Scenario (2045)	Hybrid Scenario (2045)



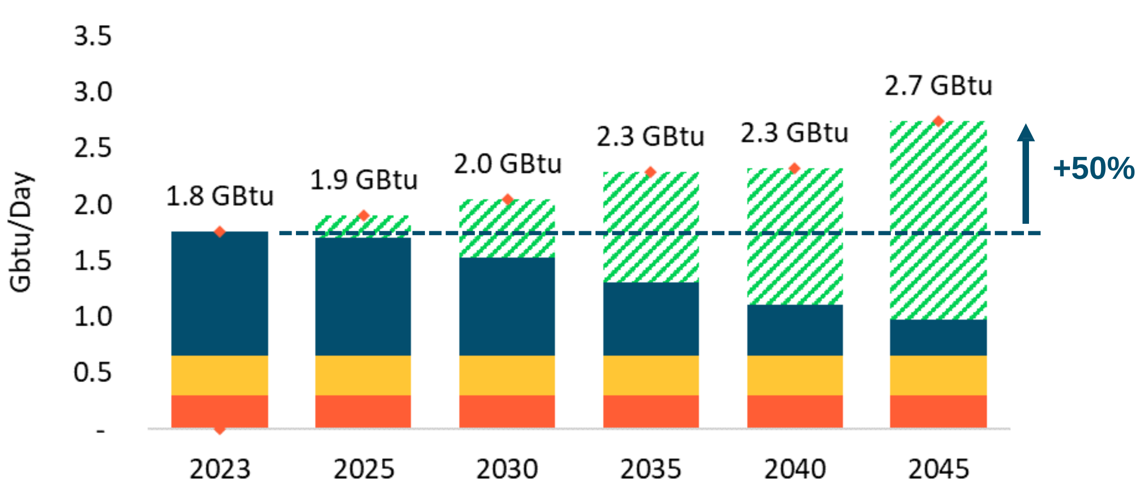


Switching gas heating to dual-fuel heat pumps can alleviate the impact on design day gas throughput

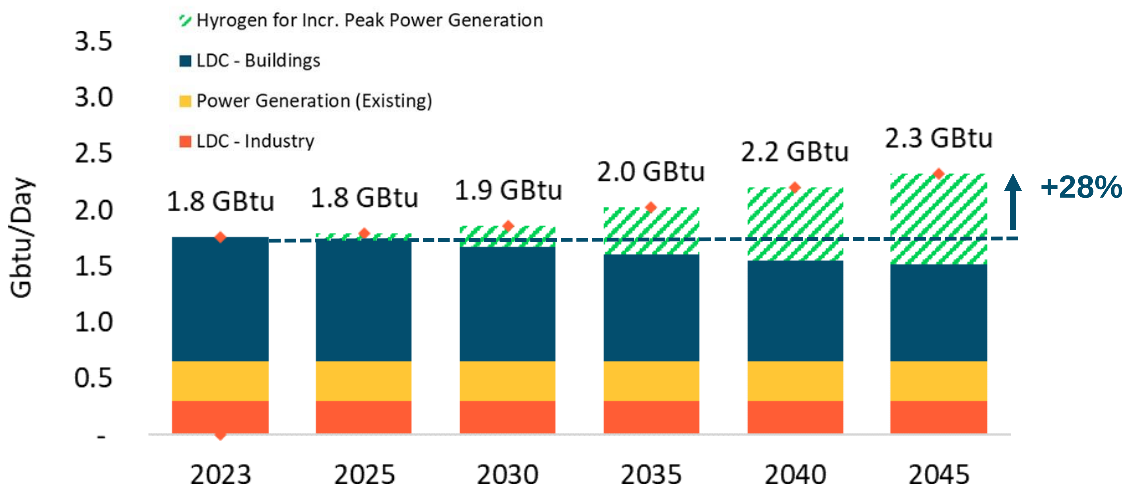
+ In the Hybrid gas, design day total gas throughput for existing end-uses largely remains at today's scale since dual-fuel heating systems will rely on back-up gas heating during cold spell
+ Hybrid Scenario will need less than half of the hydrogen in the SES scenario to serve incremental electric demand in Western WA using local hydrogen-ready gas CTs

Design Day Gas and Hydrogen Throughput in Western WA

State Energy Strategy Scenario



Hybrid Scenario



Emissions Impact "Bookend" Alternatives in 2045 by World View

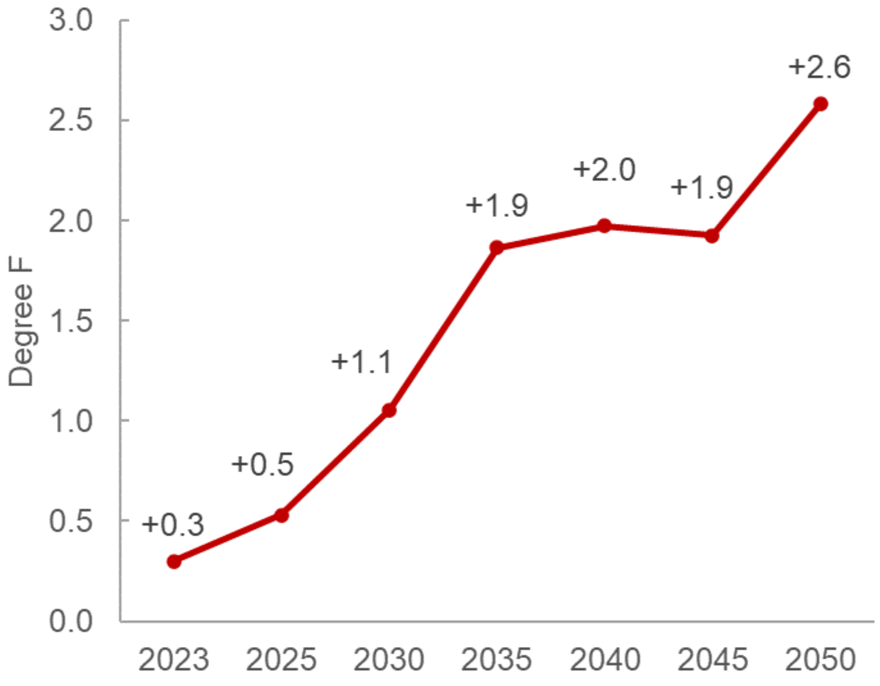
Scenario	Counterfactual Scenario	Clean Resources (clean firm resources, offshore wind, etc.)
***Gas Design Day Net Emissions** from Serving Heating Demand in Western WA*		
State Energy Strategy	+52 ktCO2e/day	-41 ktCO2e/day
Hybrid	+30 ktCO2e/day	-13 ktCO2e/day
Annual Net Emissions from Serving Heating Demand in Western WA relative to 2020*		
State Energy Strategy	N/A (Not CETA-Compliant)	-6 MMT CO2e/year
Hybrid	N/A (Not CETA-Compliant)	-5.6 to -6 MMT CO2e/year

* Local Gas CTs is a counterfactual scenario focusing on gas design day impact only. Annual emissions impact does not apply as this scenario will not be CETA-compliant
** Annual net emissions in 2045 is from LDC gas combustion assuming all natural gas. Electric sector emissions in 2045 are assumed to be zero in compliance with CETA.

Approach to Model Climate Impact

- **E3 leveraged historical temperature data and projected future temperatures from climate models provided by PSE for its service territory**
- **We first calculate the change in average winter daily minimum temperature throughout all winter months (i.e. December, January and February) in four steps:**
  1. Find minimum daily temperature in all winter months of future years from the climate model results
  2. Find average winter daily minimum temperature for every historical year
  3. Take an 11-year rolling average to smooth out data over time, with each model year as the center of the rolling average window
  4. Calculate change in average winter daily minimum temperature of all future years from 2018
- **We find the new 1-in-10 peak based on the increase in average winter daily minimum temperature relative to the temperature associated with the historical 1-in-10 peak modeled in RESHAPE**

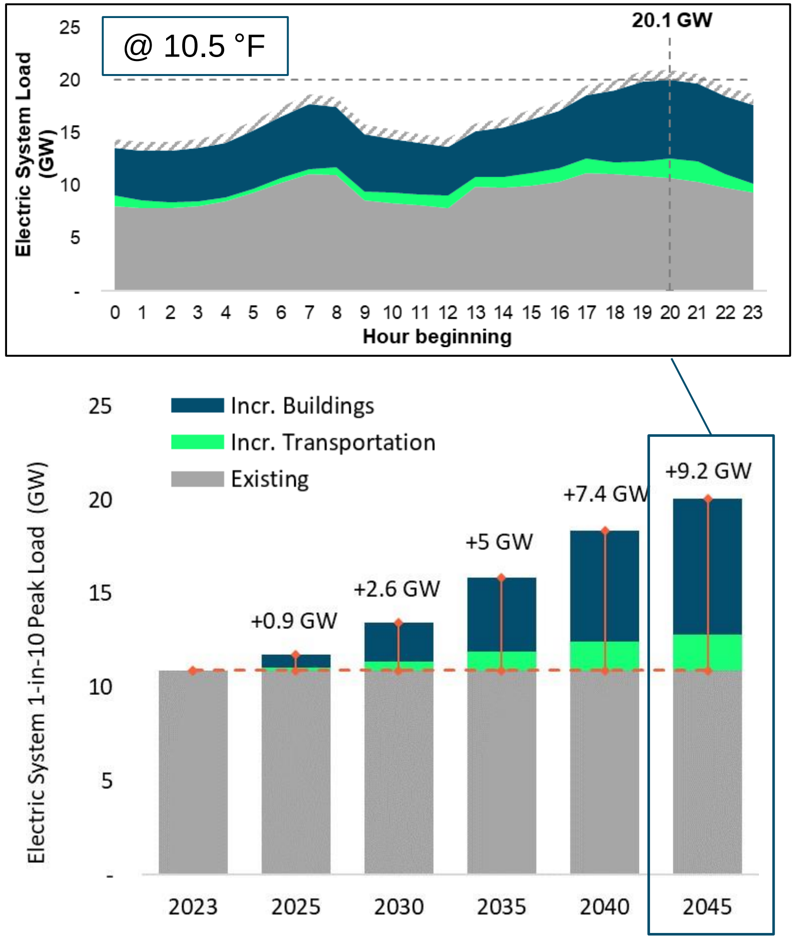
Change in Average Winter Daily Minimum Temperature Relative to Today



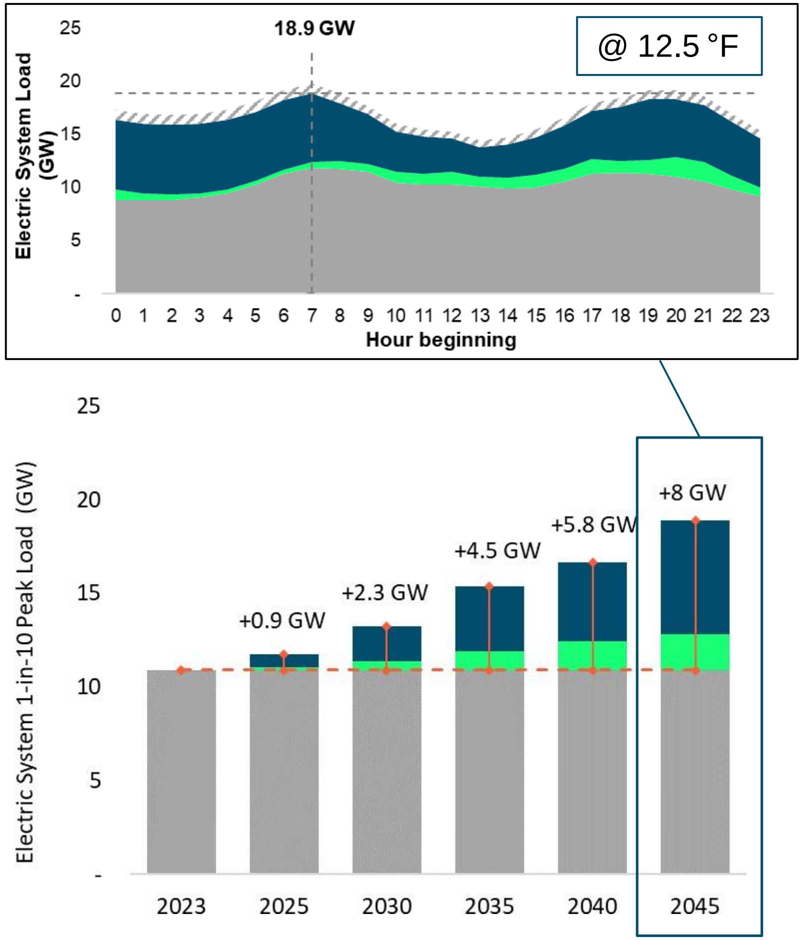
With Climate Impact, 1-in-10 peak load impact in the SES scenario is reduced by 1.2 GW in 2045

- Climate impact on the peak load increases over time as higher levels of heating electrification takes place
- There is almost no 1-in-10 peak impact on the Hybrid scenario as backup gas furnaces provide heating during the extreme cold events

1-in-10 Peak Load, SES Scenario
No Climate Impact



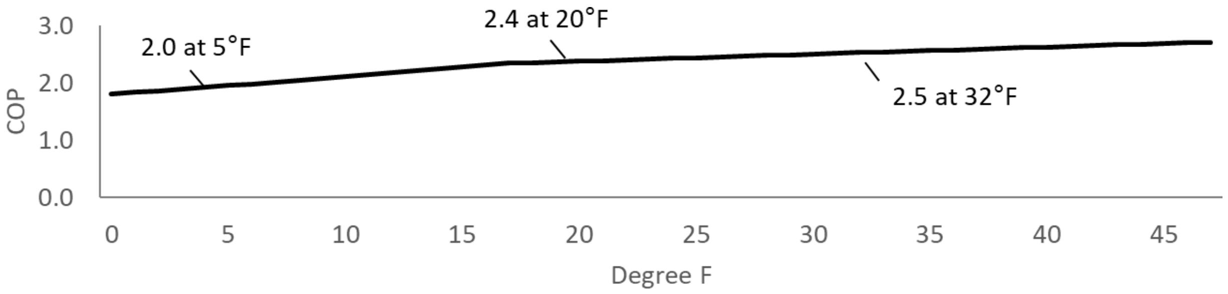
1-in-10 Peak Load, SES Scenario
With Climate Impact



Heat Pump Configurations

- E3 models a cold-climate all-electric heat pump in this analysis, sized to serve full heating load at 20°F with an average annual coefficient of performance (COP) at 2.6
- A dual-fuel heat pump is also modeled assuming gas backup will provide full heating load below 30°F, serving about 15% of the annual heating demand
- Heat pump efficiencies and configurations are aligned with those modeled by Cadmus in the updated gas decarbonization study

Heat Pump COPs Modeled at Different Outdoor Temperatures



Heat Pump Sizing Criteria and Achieved Performance in Western WA

Heat Pump	Sizing Criteria	Percent of Heating Demand Met by Gas Backup	Achieved Annual Average COP
All-electric ASHP (electric resistance backup)	**~20F** (99% of heating hours)	**0%**	**2.6** (*Performance Curve Aligned with Cadmus*)
Dual-fuel HP (gas backup)	**30F** (~90% of heating hours)	**15%**	**2.7** (*Performance Curve Aligned with Cadmus*)

Renewable Fuels Supply and Costs

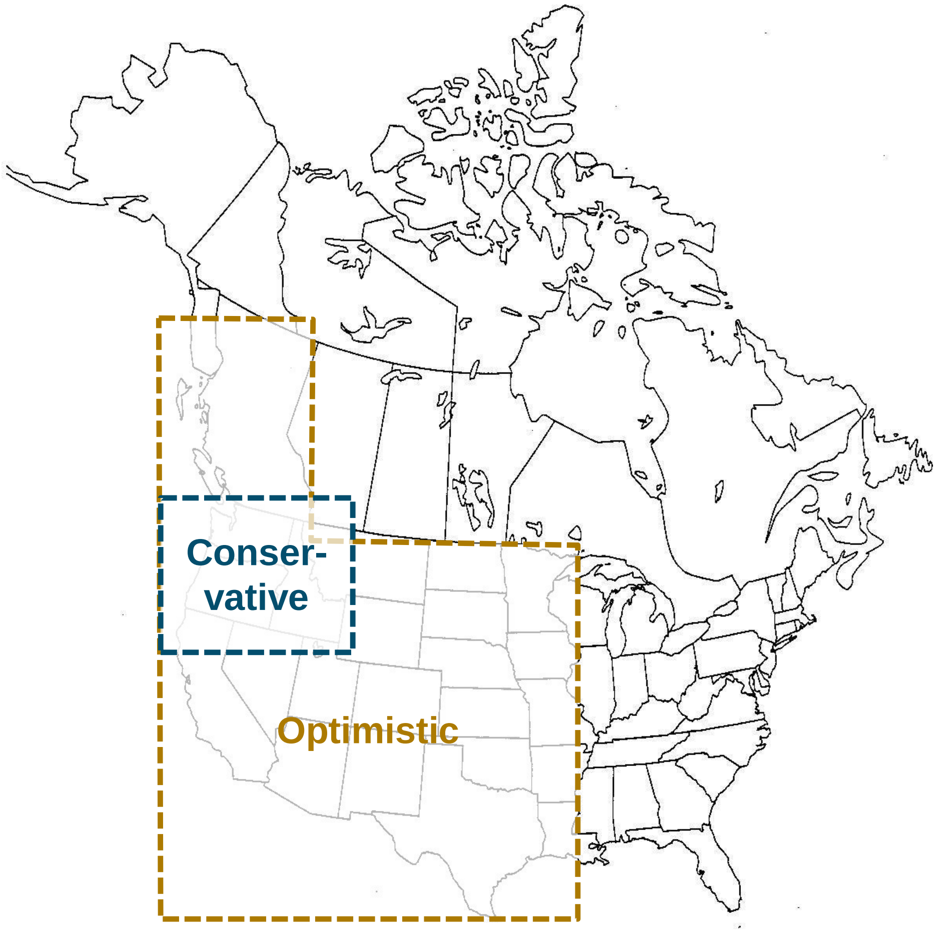
Energy+Environmental Economics

Biofuels Modeling

Energy+Environmental Economics

Biofuels Modeling Assumptions
Geography

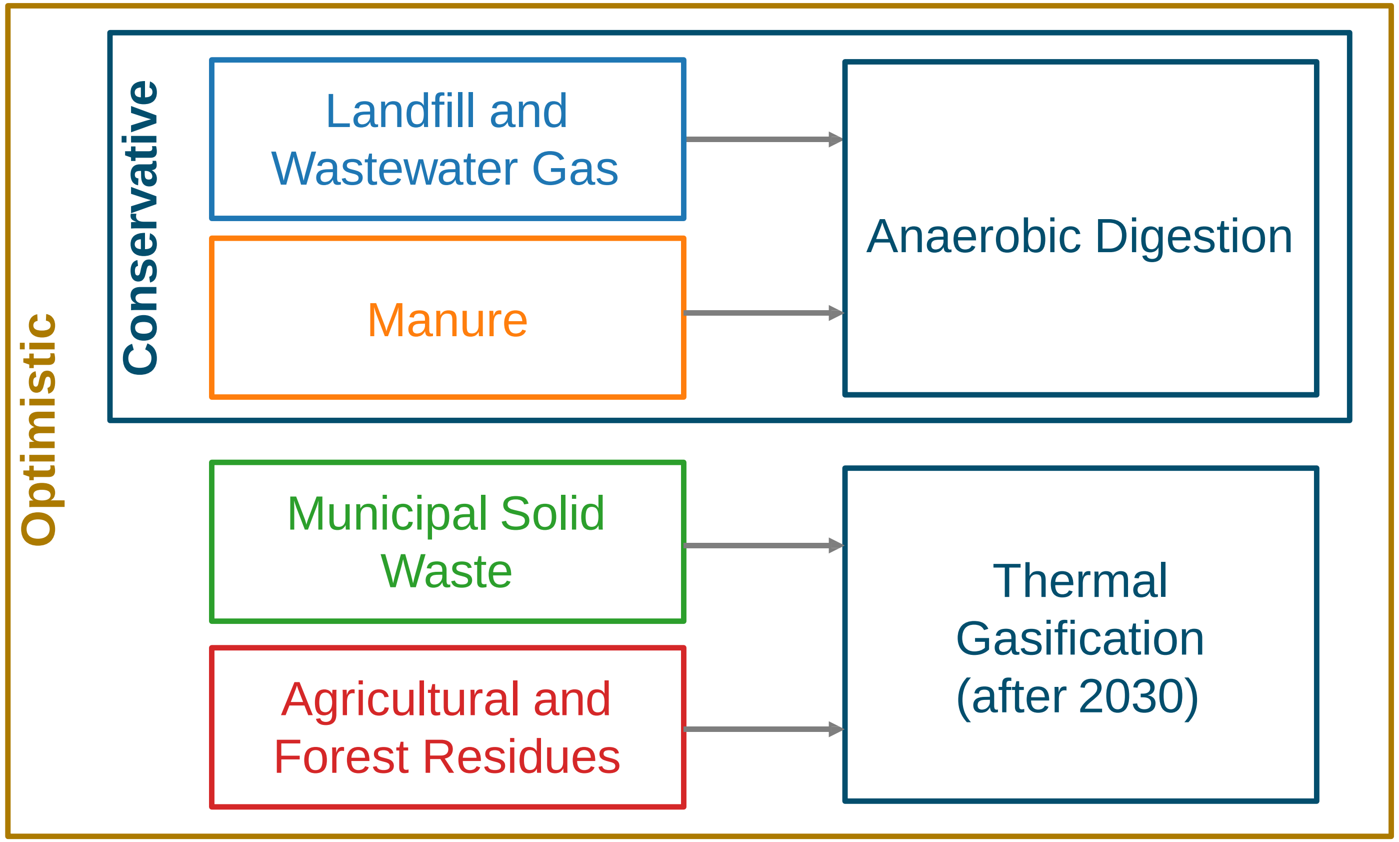
- **E3 has modeled multiple optimistic and conservative "worldviews" of biomethane availability and cost, representing uncertainty around:**
  - Feedstock availability driven by location
  - Possible future ranges of feedstock availability within given locations
  - Availability of conversion pathways to biomethane
  - Demand for competing low-carbon fuels, such as renewable diesel
  - Competition with low-carbon fuel standards in other parts of the US
- **Conservative: Biomethane only sourced from WA/OR/ID as a part of a regional market**
- **Optimistic: National market, based on gas "deliverability"**



Biofuels Modeling Assumptions
Feedstocks and Conversion Pathways

+ E3 restricted the types of conversion pathways to biomethane and the availability of certain feedstocks

- Conservative: Low amounts of landfill gas, wastewater treatment gas, and manure gas; only anaerobic digestion
- Optimistic: High amounts of LFG, WWTP, manure; anaerobic digestion always + thermal gasification after 2030



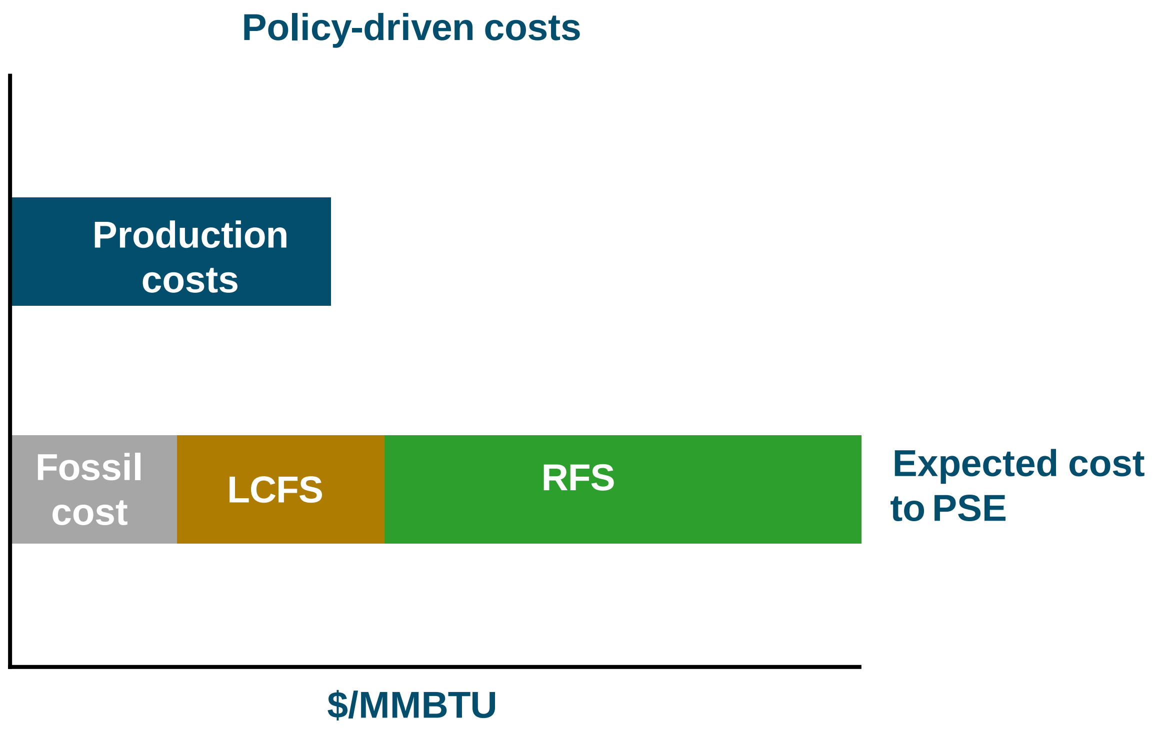
Feedstock	Source
Landfill and Wastewater Gas	ICF Report[1], Fortis BC[3] (optimistic only)
Manure	ICF Report[1], Billion Ton Report[2], Fortis BC[3] (optimistic only)
Municipal Solid Waste	BTR[2]
Ag and Forest Residues	BTR[2]

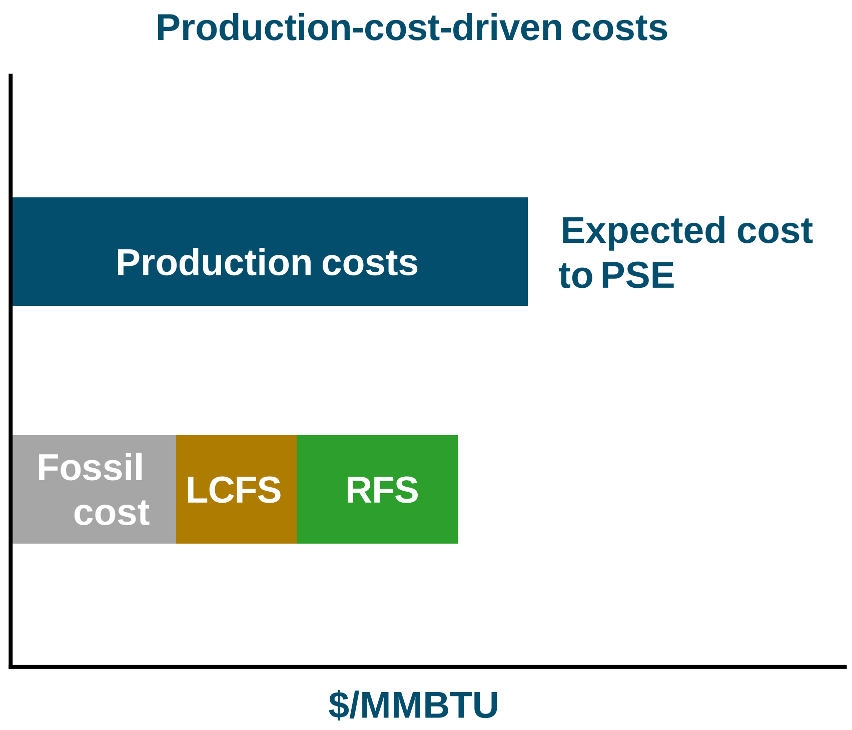
Energy+Environmental Economics

1. "Net Zero Emissions Opportunities for Gas Utilities." AGF prepared by ICF. 2021.
2. "2016 Billion-Ton Report: Advancing Domestic Resources for a Thriving Bioeconomy." US. DOE. 2016.
3. "BC Renewable and Low Carbon Gas Supply Potential Study." Fortis BC, BC Bioenergy Network, Province of BC. 2022

Biofuels Modeling Assumptions
Inter-Market Competition and Costs

+ The cost for biomethane may be influenced by transportation sector policies that produce markets for renewable fuel attributes, such as state-level LCFS and US RFS policies. PSE may need to match these expected policy-driven revenues to purchase these fuels.
+ Alternatively, revenues from attribute markets may be too low. As a result, PSE may need to purchase biomethane at least at the cost of production.





Biofuels Modeling Assumptions
Inter-Market Competition and Costs

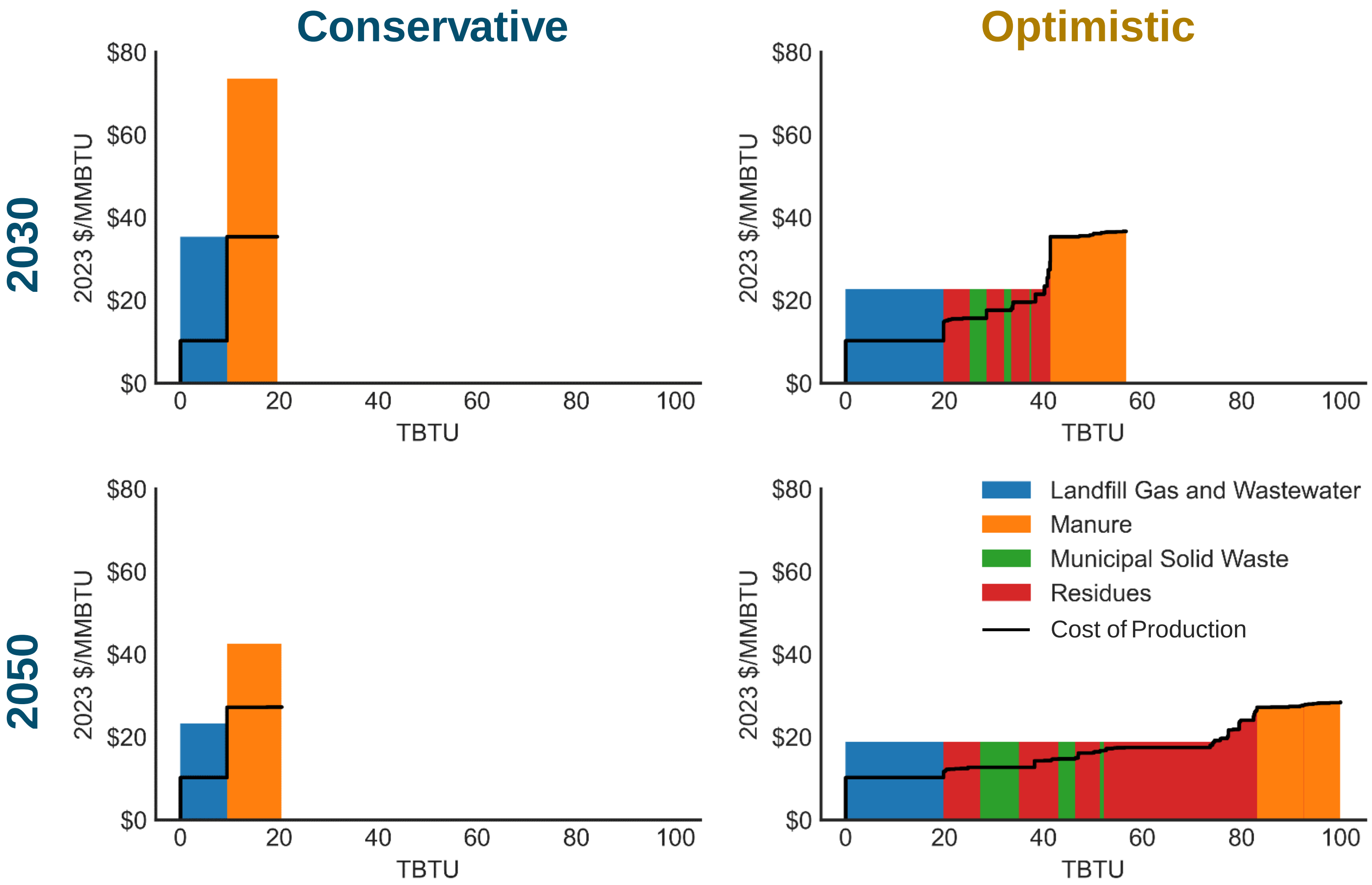
+ **To construct conservative and optimistic worldviews, E3 evaluated cost bounds in terms of producer access to the RFS and LCFS markets**
  - Under the conservative worldview, all fuel producers can directly access the LCFS and RFS markets. As a result, their expectation for revenue will be based around internalizing the full LCFS and RFS credits for their fuel
  - Under the optimistic worldview, market access is restricted for all fuel producers
    1. Producers would access the RFS market indirectly through a fuel wholesaler, who will internalize a percentage of the RFS credit
    2. Transportation electrification drives a reduction in demand for RNG, thereby locking out new RNG producers from the LCFS market entirely
+ **If the fuel is evaluated to be uneconomic within the context of the LCFS and RFS, their cost to PSE is the cost of production**

Worldview	RFS Market Revenues	LCFS Market Revenues
Conservative	100% of credit $12-$31/MMBTU	100% of credit $0-$36/MMBTU
Optimistic	70% of credit $8-$22/MMBTU	0% of credit $0/MMBTU

Summary of Biofuels Modeling Worldviews & Assumptions

	Conservative	Optimistic
Feedstock Availability	Biomethane only sourced from **WA/OR/ID** as a part of a **regional market**	**National market** with access to resources **in all states west of Mississippi River + British Columbia**, based on gas "deliverability"
Conversion Pathways	**Anaerobic digestion** using landfill & wastewater gas, and manure	**+ Thermal gasification** after 2030 using municipal solid waste, and agricultural & forest residues
Access to clean fuels markets	**Direct access to the LCFS and RFS markets**, with full credits from the two markets internalized in fuel cost	**Restricted market access** assuming: • Producers would access the RFS market indirectly through a fuel wholesaler, who will internalize a percentage of the RFS credit • Transportation electrification drives a reduction in demand for RNG, thereby locking out new RNG producers from the LCFS market entirely

Biofuels – Availability and Cost
Washington's Share of Produced Biomethane



+ **RNG costs are higher across most feedstocks and worldviews**
+ **Under a conservative worldview, the LCFS + RFS represent 50-60% of revenues for producers**
+ **Under an optimistic worldview, manure gas producers will only be able to sell at their cost of production**
+ **BC contributes a small proportion of total landfill, wastewater, and manure gas in the optimistic worldview**

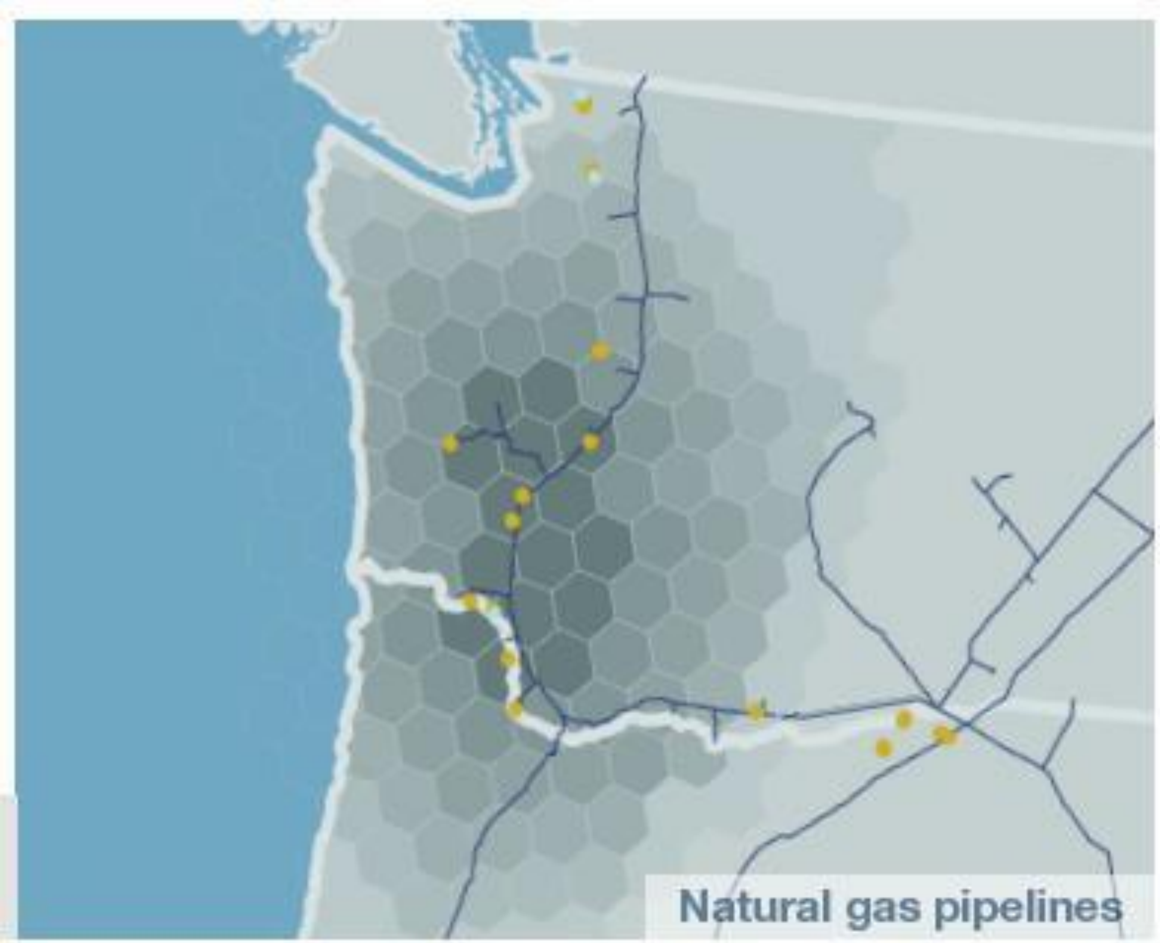
BC Feedstocks	TBTU	Percent of Total
Landfill + wastewater gas	0.08	0.4%
Hog and cow manure	0.03	0.2%

Synthetic Fuels Modeling

Energy+Environmental Economics

Synthetic Fuels Assumptions

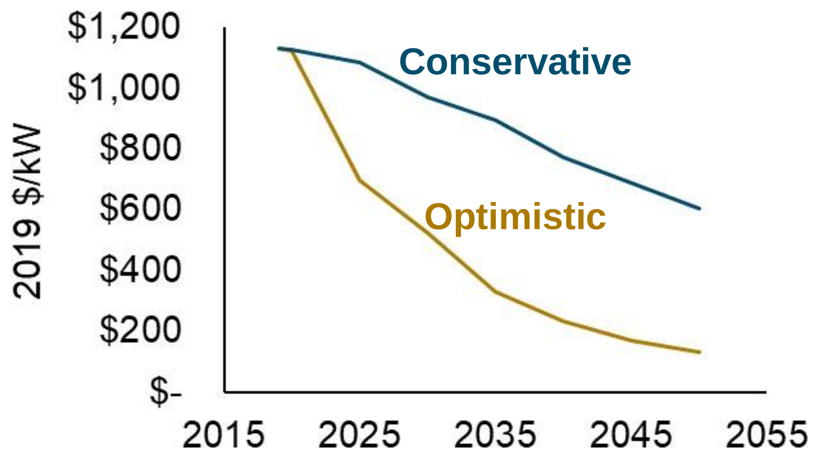
Geography



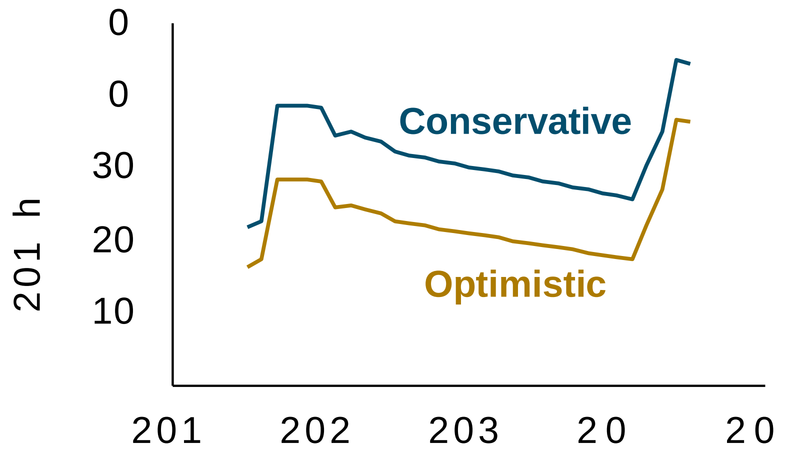
- **PSE could feasibly source synthetic fuels from multiple in- and out-of-state sources**
- **In-state**
  - Eastern wind or grid-based production in any part of the state
  - No potential for storage
  - Low or no cost of transportation
- **Out-of-state**
  - British Columbia or Wyoming
  - In the case of Wyoming, trade off potentially high-quality wind and ability to store hydrogen with longer transportation distances
- **Hydrogen transportation is built to the west of the state where:**
  - Industrial facilities need high-temperature heat
  - Existing natural gas right-of-ways are repurposed

Synthetic Fuel Assumptions
Electrolyzer, Renewable Costs and IRA 45V Tax Credit

Electrolyzer Capital Costs



Onshore Wind LCOE – Eastern WA



- **Alkaline electrolysis cell (AEC) electrolyzers were modeled as the primary production pathway for green hydrogen**
  - E3 assumed slow or fast learning rates to produce conservative and optimistic capital costs
  - PEM and SOEC electrolyzers are available for modeling but tend to be significantly more expensive
- **Dedicated onshore wind from eastern WA or western WY was assumed as a source of renewable electricity**
  - Short-term wind costs are driven up by inflation arising from supply constraints and other factors
  - Wind PTC drives down costs in mid-term through the mid-2040s, after which they rise once the PTC expires
  - The full $3/kg 45V tax credit was applied to the first ten years of hydrogen production
- **Alternatively, local grid electricity could be used as a source of electricity**
  - Coal is on the margin in the short-term, while natural gas is expected to be on the margin in the long-term
  - Modeled to receive either all or none of the 45V tax credit to test the full range of possible costs

Synthetic Fuel Assumptions
SNG-Specific Assumptions

+ **Two sources of CO_2 to produce SNG were modeled**
  - CO_2 produced by post-biomethane-production CO_2 capture – limited in potential but lower cost (**SNG-Bio**)
  - Collocated direct air capture – potential effectively limited by land use availability or other policy constraints (**SNG-DAC**)

+ **Both forms of SNG are assumed to depend on collocated green hydrogen production with dedicated renewables**
  - They are assumed to be available later than hydrogen
  - They receive the benefit of the 45V tax credit if they are powered by dedicated wind; a range is evaluated if powered by grid electricity

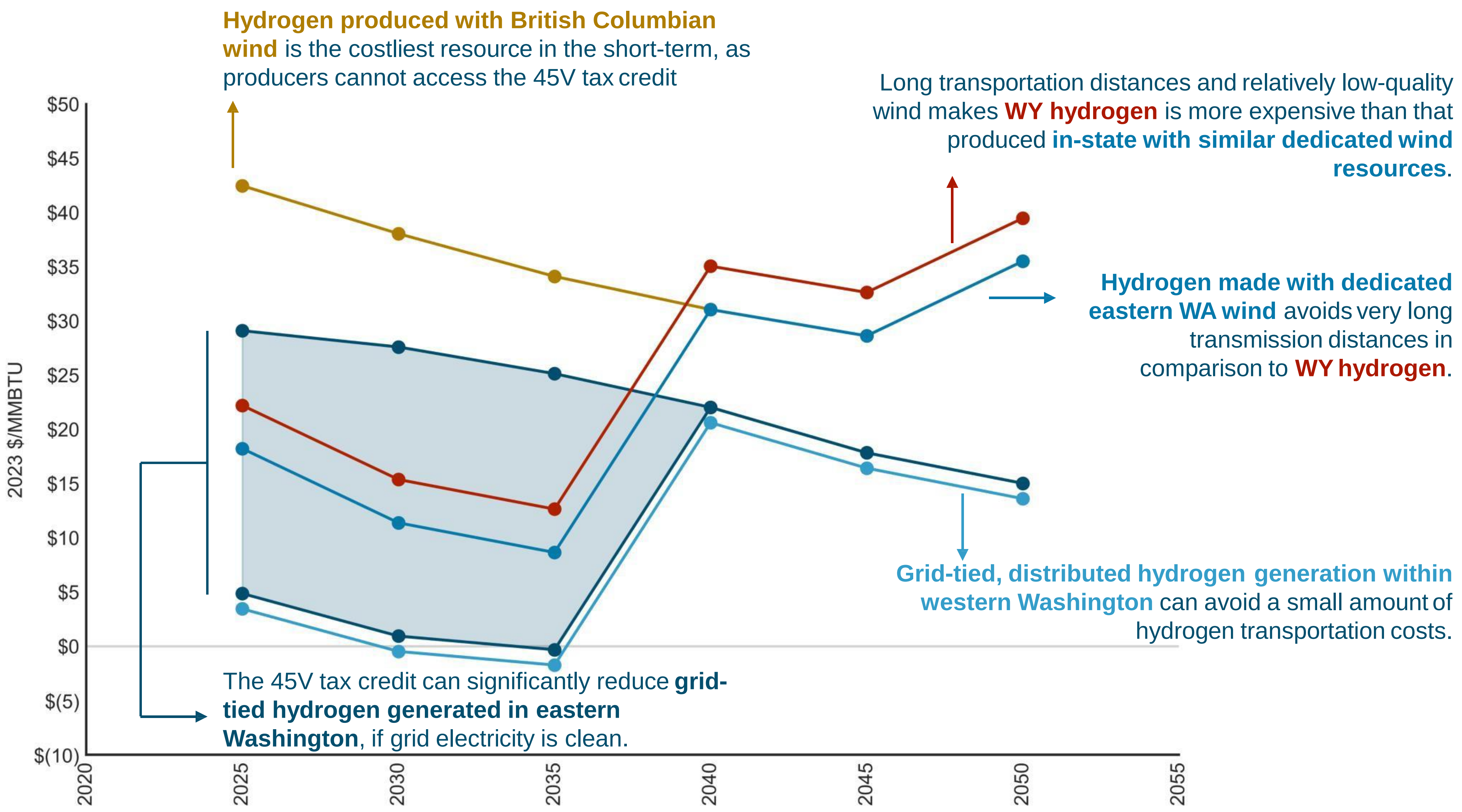
Synthetic Fuel Assumptions
Parameter Summary

+ Key Questions

- Can synthetic fuels created with dedicated renewable fuels compete with grid-tied synthetic fuel production?
- When is it cost-effective to purchase synthetic fuels produced far away from western WA?
- What does distributed synthetic fuel production in western Washington cost if new hydrogen pipelines cannot be built in the future?

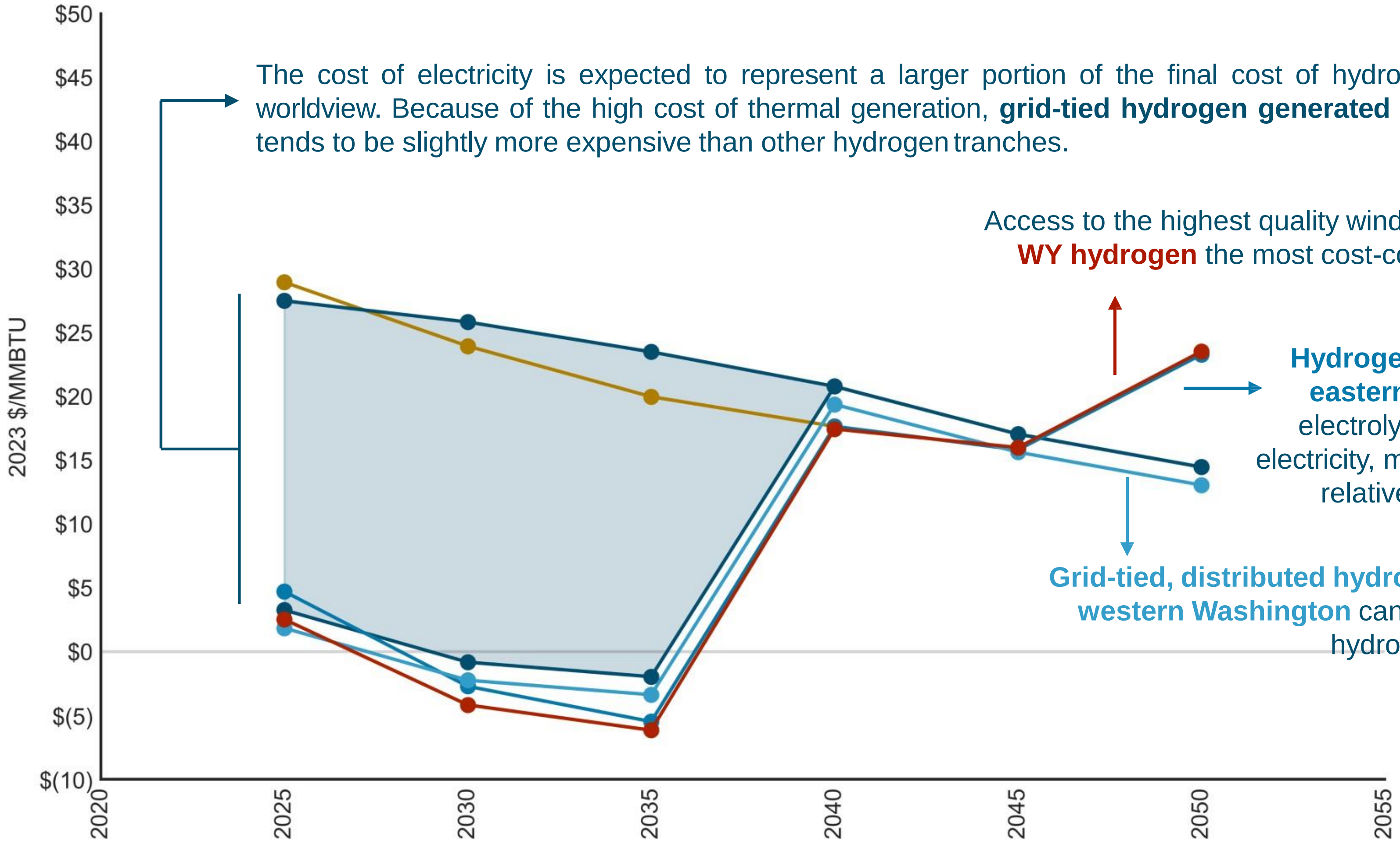
Location	Electricity Source	New Storage	New Pipeline	45V Tax Credit
Eastern Washington	Grid	☒	☑	☑
Eastern Washington	Grid	☒	☑	☒
British Columbia	Dedicated Wind	☒	☑	☒
Wyoming	Dedicated Wind	☑	☑	☑
Eastern Washington	Dedicated Wind	☒	☑	☑
Western Washington	Grid	☒	☒	☑

Synthetic Fuel Costs
Hydrogen under a Conservative Worldview



Synthetic Fuel Costs

Hydrogen under an Optimistic Worldview



The cost of electricity is expected to represent a larger portion of the final cost of hydrogen under an optimistic worldview. Because of the high cost of thermal generation, **grid-tied hydrogen generated in eastern Washington** tends to be slightly more expensive than other hydrogen tranches.

Access to the highest quality wind resources in WY makes **WY hydrogen** the most cost-competitive in most years.

Hydrogen made with dedicated eastern WA wind offsets its low electrolyzer utilization with cheap electricity, making it cost-competitive relative to **grid-tied hydrogen**.

Grid-tied, distributed hydrogen generation within western Washington can avoid a small amount of hydrogen transportation costs.

Synthetic Fuels Costs
Synthetic Natural Gas

- **SNG is assumed to be available after hydrogen infrastructure is built**
- **The parameters that govern hydrogen costs under both worldviews similarly impact SNG costs**
  - No new pipelines must be built for SNG, so **WY SNG** is significantly cheaper
- **No BC SNG was considered**