UPDATED 2023 DECARBONIZATION STUDY SUMMARY REPORT

January 2025

PUGET SOUND ENERGY

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PUGET SOUND ENERGY

EXECUTIVE SUMMARY

In 2023, Puget Sound Energy (PSE) completed an updated Decarbonization Study (Study) in accordance with the multiparty settlement agreement that was approved by the Washington Utilities and Transportation Commission (Commission) in December 2022 (see Appendix A for the settlement agreement language related to the decarbonization study). The Study seeks to evaluate and identify the potential impacts of four comprehensive building electrification scenarios on both the gas and electric systems and customers served by those systems. These scenarios, which are described in greater detail in Figure 3 of this document, include:

(1) Full electrification with air-source heat pumps (ASHP)

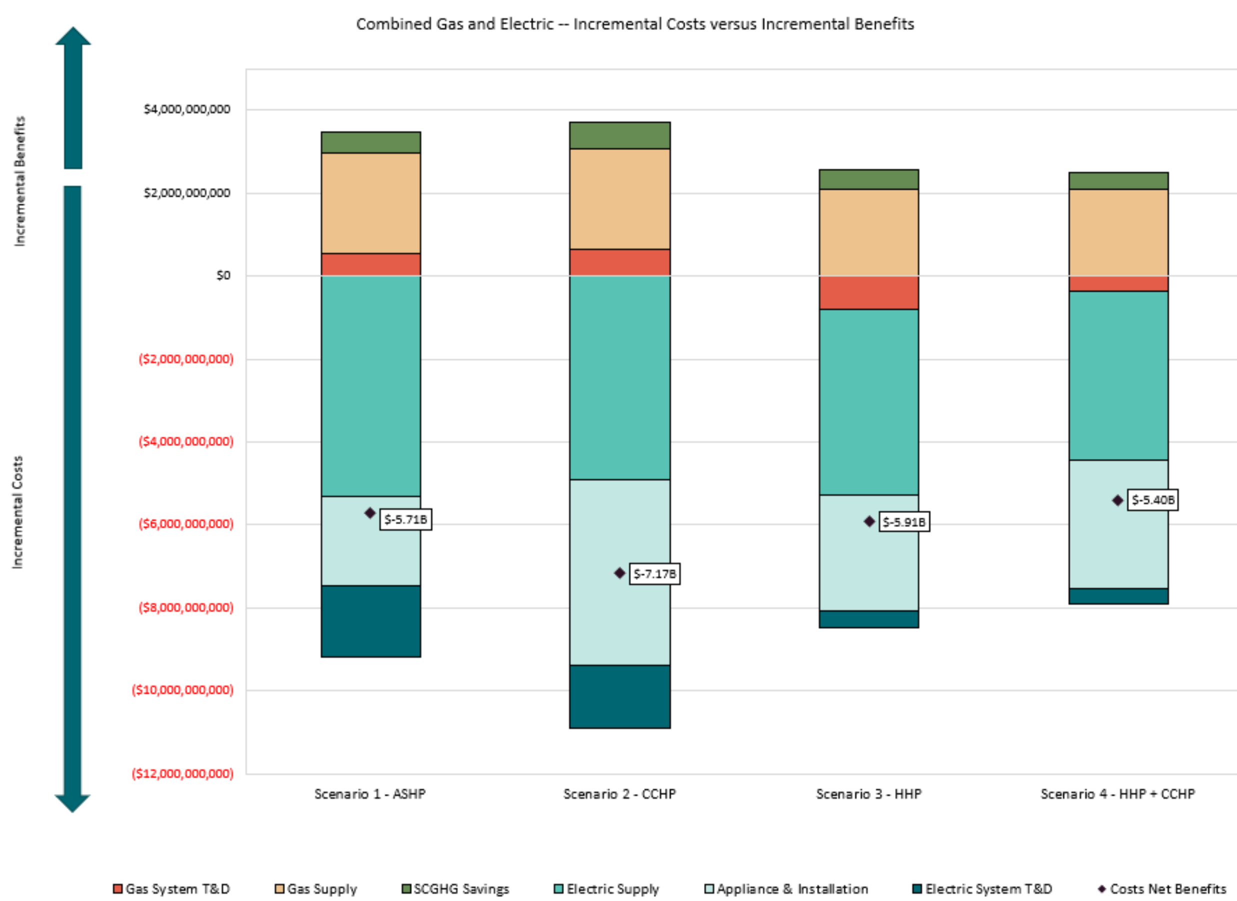
(2) Full electrification with cold-climate heat pumps (CCHP)

(3) Hybrid heat pumps (HHP) with ASHPs

(4) HHPs with ASHPs for existing customers and CCHPs for new customers

Overall, Study results indicate that costs associated with electrification under each of the four Study scenarios outweigh societal benefits at a total system level, as shown in Figure 1.

Figure 1: Summary View of Total System Benefits vs. Costs



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Further, the customer rate impact results indicate that customers who choose to install heat pumps will likely face higher costs across all four scenarios than they would have if they were to replace their existing gas furnace with a new gas furnace to meet their space heating needs in 2030 and 2045. Other summarized takeaways from the Study can be found in Table 1.

Table 1: Summary of Key Findings

TAKEAWAY NUMBER	TOPIC AREA	DESCRIPTION
1	Customer Costs	Total annual heat pump electrification costs incurred by a residential customer are similar across all scenarios and are significantly higher than that of purchasing a new gas furnace.
2	Low-Income Customer Costs	Total annual heat pump electrification costs for low-income customers are close to, but still slightly higher than, the annual costs of purchasing a new gas furnace considering available inflation reduction act (IRA) incentives.
3	Costs / Environmental Impact	The total costs associated with the four study scenarios are currently estimated to be far greater than the societal benefits associated with carbon emission reduction attributed to electrification.
4	Environmental Impact	Electrification from all four scenarios increases carbon emissions in the near term, but carbon emissions decline over time once non-emitting resources are further deployed.
5	Electric & Gas Sales	On average, the four study scenarios resulted in a 25-30% increase in electricity sales and a 75-80% decrease in gas sales in 2050 relative to the reference case forecast depending on the electrification scenario; this includes all sectors analyzed (i.e., including C&I).
6	Technology Performance	Air-source heat pumps (ASHPs) are expected to have the greatest winter peak electricity demand increase of heat pump technologies followed by cold-climate heat pumps (CCHPs); hybrid heat pumps (HHPs) are expected to have near-zero impact on electric demand. This analysis also included electrification of other end uses such as cooking and water heating, these options are all-electric, hybrid solutions are not available. These additional end-uses can also contribute to annual and peak electric demand.
7	Next Steps	Targeted electrification on certain, gas-constrained portions of the system will be further considered within the targeted electrification strategy.

1. STUDY AND REPORT BACKGROUND

1.1. INTRODUCTION

As part of Puget Sound Energy's (PSE) 2022 general rate case (GRC) multiparty settlement agreement approved by the Washington Utilities and Transportation Commission (Commission) in December 2022, PSE agreed to complete an updated Decarbonization Study (Study) within 12 months of the Commission's final order in the case. The Study must build off prior decarbonization analysis prepared for PSE by Energy and Environmental Economics (E3) in 2021, meeting specific requirements outlined in the settlement agreement including the use of updated study assumptions.[1] The purpose of the study is to analyze and present the potential impacts of comprehensive building electrification on both the gas and electric systems and customers served by those systems, with consideration of impacts on infrastructure investments required, emissions, and costs (including customer bill impacts). Its purpose was also to build on the 2021 study with more up-to-date assumptions regarding efficient cold-climate heat pumps (CCHPs).

This summary report provides a high-level overview of the Study, including a consolidation of the analysis and findings for each component of the study completed by PSE, Cadmus, and E3. The findings of this report informed the development of the Targeted Electrification Strategy (Strategy) and are being filed concurrently. Various detailed reports and other documents completed as part of the Study were filed in Dockets UE-220066, UG-220067, and UG-210918 on December 21, 2023.[2] The "Full Decarbonization Study Report" is comprised of this document in combination with the more detailed reports filed on December 21, 2023.

Appendix B in this summary report outlines the specific requirements for the Study, as identified in the 2022 GRC settlement agreement, and identifies the actions PSE took to comply with each requirement.

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[1] The GRC Stipulation Agreement states "PSE's updated decarbonization study will build off the gas decarbonization study prepared for PSE by E3 with more up-to-date assumptions regarding efficient Cold Climate Heat Pumps ("CCHPs") for targeted electrification." The full language of the applicable settlement agreement is located here: https://apiproxy.utc.wa.gov/cases/GetDocument?docID=3216&year=2022&docketNumber=220066.

[2] See documents filed on December 21, 2023 in Docket 220066, for example, located here: https://www.utc.wa.gov/casedocket/2022/220066/docsets.

Appendix C summarizes PSE's engagement with settlement parties throughout the Study to provide updates, present results, and gather feedback.

1.1.1. STUDY METHODOLOGY AND APPROACH

PSE completed the Decarbonization Study using the following four-phased approach depicted in Figure 2:

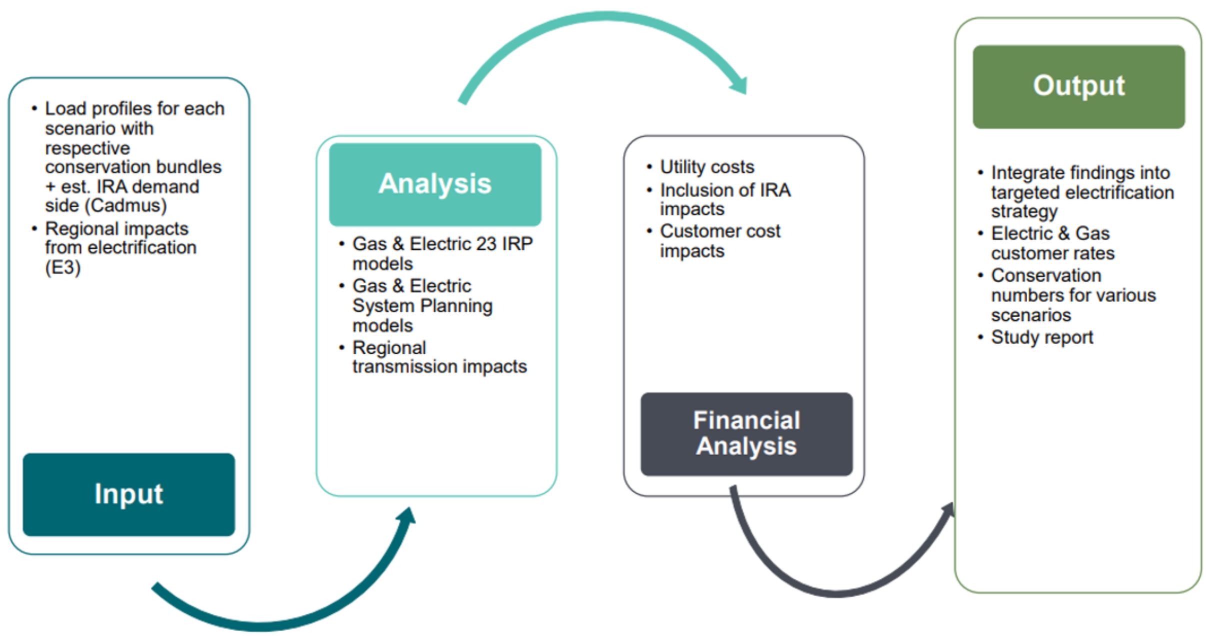
(1) Gathering inputs

(2) Conducting system planning and portfolio analysis

(3) Assessing financial impacts

(4) Compiling outputs

Figure 2: Decarbonization Study Modeling Approach



The Study expanded upon the 2023 Gas Integrated Resource Plan (IRP) and 2023 Electric Progress Report (EPR) reference portfolios. Updates were made based on inputs from E3 and Cadmus as it related to specific data requirements within Stipulation O. Input research included:

- Regional Context – On behalf of PSE, E3 conducted a literature review on decarbonization strategies, focusing primarily on the Pacific Northwest. E3 also completed a regional infrastructure analysis to assess the impacts of heating decarbonization pathways on local electric and gas infrastructure.[3]

- **Cold-climate heat pumps (CCHPs) and Inflation Reduction Act (IRA) Research** – On behalf of PSE, Cadmus evaluated the effectiveness of CCHPs and associated winter peak demand impacts from CCHP adoption. Cadmus also evaluated the potential impact of IRA on heat pump costs for low-income customers.[4]

- **Energy Resource Supply and Costs** – On behalf of PSE, E3 examined non-emitting energy and non-emitting fuel resource availability and costs to update existing assumptions. Resources considered include wind, solar, geothermal, hydropower, offshore wind, biomethane, and synthetic fuels.[5]

Similarly, as an input to analysis, PSE worked with Cadmus to construct four scenarios for space heating electrification for the Study, as defined in Figure 3. Scenarios differ based on the heat pump technology considered for natural gas-to-electric conversions and are compared against a reference case that is based on data and assumptions from the 2023 EPR and the 2023 Gas IRP.[6] There is a significant emphasis on the residential segment within the Study, but standardized assumptions around commercial and industrial (C&I) electrification were considered across all four scenarios as well.[7]

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[3] See Attachments C and D to the Decarbonization Study filing made on December 21, 2023 in Docket 220066, located here: https://www.utc.wa.gov/casedocket/2022/220066/docsets.

[4] See Attachment B to the Decarbonization Study filing made on December 21, 2023 in Docket 220066, located here: https://www.utc.wa.gov/casedocket/2022/220066/docsets.

[5] See pages 50-52 of Attachment A to the Decarbonization Study filing made on December 21, 2023 in Docket 220066, located here: https://www.utc.wa.gov/casedocket/2022/220066/docsets.

[6] Additional detail is included in the 2023 Gas IRP and EPR, located here: https://www.pse.com/en/IRP/Past-IRPs/2023-IRP

[7] These assumptions can be found in the detailed Cadmus report, located here: https://apiproxy.utc.wa.gov/cases/GetDocument?docID=3616&year=2022&docketNumber=220066

Figure 3: Decarbonization Study Electrification Scenario Definitions

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.

Additionally, for the residential and commercial sectors, water heating, cooking, and clothes dryer end uses were considered in the electrification impact analysis for the Study. For industrial segments, PSE used the same methodology as the 2023 IRP Conservation Potential Assessment (CPA) by converting approximately 30% of natural gas loads to electric.

Following establishment of Study scenario definitions, Cadmus (on behalf of PSE) developed equipment adoption forecasts and load profiles for each scenario to determine annual gas and electricity consumption and winter peak electric demand impacts.[8] These outputs from Cadmus were then used as inputs for PSE's modeling of electric and gas portfolio (i.e., energy resources) and system (i.e., infrastructure) impacts. The outputs from PSE's modeling include gas and electric resource portfolio bundles and associated costs, systemwide emissions based on Clean Energy Transformation Act (CETA) and Western Electricity Coordinating Council (WECC) market emission rates, and gas and electric system infrastructure impacts (including impacts on gas capacity-constrained areas). PSE then calculated the societal benefit of each scenario's emissions reduction over the Study's timeframe considering the social cost of greenhouse gases (SCGHG) and the net present value of costs associated with the scenario. Ultimately, the net portfolio costs, net system costs, and societal benefits of each scenario were compared against the reference case to determine the viability and economic impact of each electrification scenario within PSE's service territory. Further, the Study analyzed the impacts of these scenarios and their costs on customer bills with a primary focus on residential and low-income customers, but also presenting bill impacts for a few specific C&I rates.

Further information on the assumptions and methods used for the Study is provided in

[8] See Attachment B to the Decarbonization Study filing made on December 21, 2023 in Docket 220066 for further information, located here: https://www.utc.wa.gov/casedocket/2022/220066/docsets.

Appendix D to this summary report.

2. STUDY RESULTS

This section describes the core results from the Study. Given the many components to the Study, some of the analysis that was primarily used to guide the core analytical steps is not discussed here. This includes the initial steps taken to inform modeling inputs as described at the beginning of Section 1 of this summary report.

Appendix E provides a summary table of documents filed for the Study on December 21, 2023, should the reader of this summary report be interested in reviewing the more detailed information.

2.1. IMPACT OF SCENARIOS ON ELECTRIC AND NATURAL GAS DEMAND

Across all four Study scenarios, annual natural gas consumption decreases and annual electricity sales increase, as illustrated in Figure 4 and Figure 5.

Figure 4: Annual Natural Gas Consumption – All Sectors and End Uses

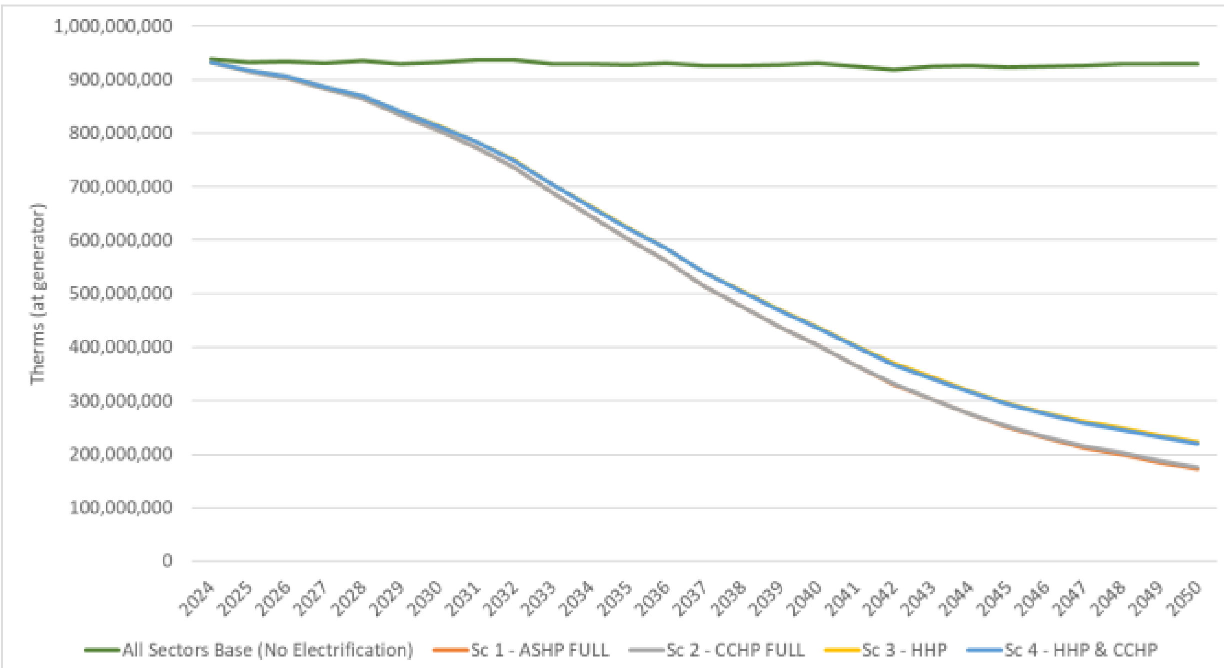
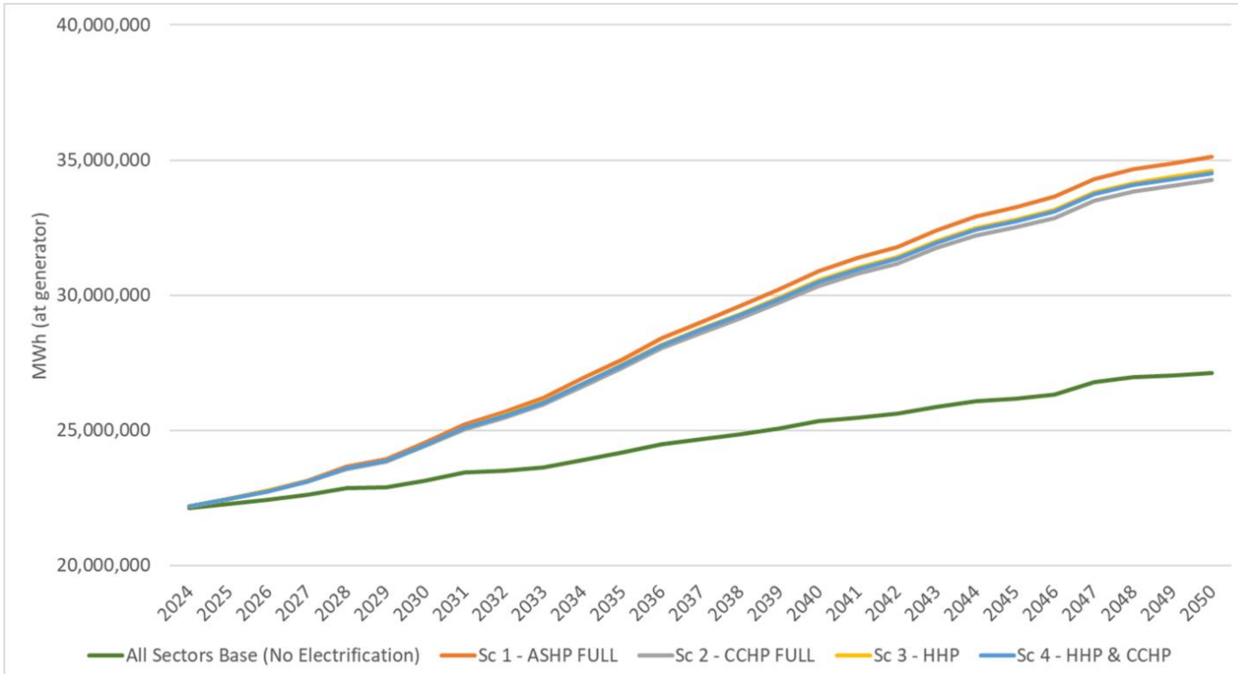


Figure 5: Annual Electricity Sales – All Sectors and End Uses



By 2050, these impacts result in significant differences when compared with the reference case. While results vary by scenario, natural gas sales (all sectors) are expected to decrease by approximately 75-80% and electricity sales (all sectors) is expected to increase by about 25-30% across the four Study scenarios. Air Source Heat Pump (ASHP) Full and CCHP Full scenarios yield the largest decrease in natural gas sales because they both fully replace gas space heating while the other scenarios do not. ASHP Full yields the largest increase in electricity sales because ASHPs are less efficient than CCHPs when operating at relatively low temperatures. The CCHP Full scenario results in the smallest increase in electricity sales due to the relatively higher efficiency of this type of heating system. Table 2 provides a summary of these results for residential and all sectors.

Table 2: Percentage Change in Sales in 2050 Relative to Reference Case

SCENARIOS	RESIDENTIAL SALES ONLY		ALL RESIDENTIAL AND C&I SALES	
	% DECREASE IN NATURAL GAS SALES	% INCREASE IN ELECTRIC SALES	% DECREASE IN NATURAL GAS SALES	% INCREASE IN ELECTRIC SALES
S1 – ASHP Full	89%	40%	81%	29%
S2 – CCHP Full	89%	35%	81%	26%
S3 – HHP	82%	37%	76%	28%
S4 – HHP&CCHP	82%	36%	76%	27%

Scenarios 1 and 2 of the Study have significant impacts on winter peak electricity demand. The ASHP Full scenario results in the largest electricity peak demand impact of the scenarios, reaching approximately 2,900 megawatts (MW) of incremental system peak over the reference case by 2050. In comparison, hybrid heat pump (HHP) and HHP&CCHP scenarios have lower electricity peak demand impacts at approximately 580 MW and 650 MW, respectively, by 2050. The vast majority of the winter peak electricity demand in the HHP scenario is associated with non-space heating load (i.e., water heating, cooking, clothes dryers) since nearly all heating load is expected to be served by the gas furnace component of the HHP system at the time of winter peak electricity demand. Figure 6 shows the incremental winter peak electricity demand across all sectors and end uses for each Study scenario. Table 3 shows the percentage change in winter peak electricity demand relative to the ASHP Full scenario for both residential only and all sectors.

Figure 6: Incremental Winter Peak Demand – All Sectors and End Uses

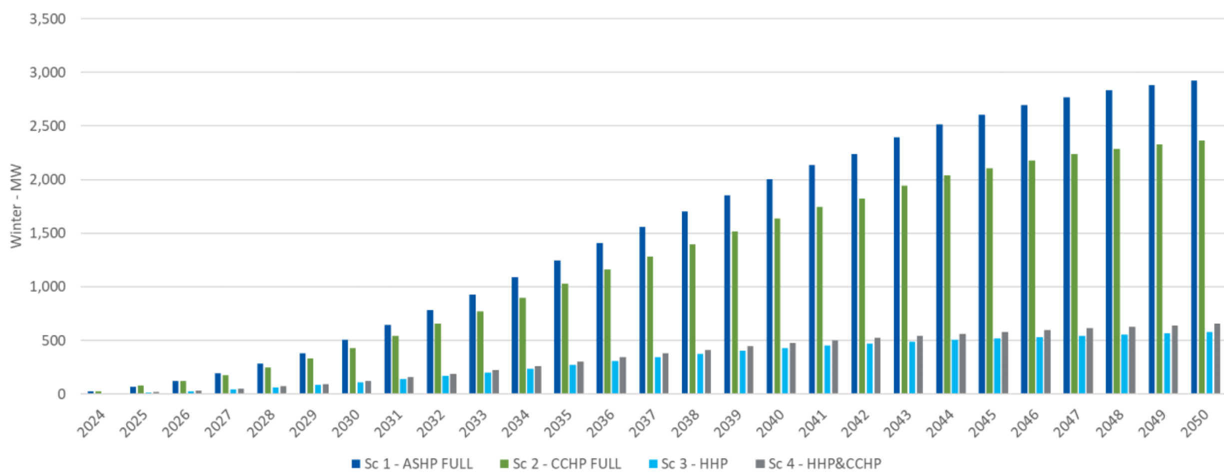


Table 3: Significance of Winter Peak Demand When Compared with ASHP Full in 2050

SCENARIOS	CHANGE IN ELECTRIC PEAK DEMAND AS PERCENT OF PEAK DEMAND: SCENARIO 1	
	RESIDENTIAL ONLY	ALL SECTORS
S1 – ASHP Full	100%	100%
S2 – CCHP Full	79%	81%
S3 – HHP	14%	20%
S4 – HHP&CCHP	17%	22%

2.2. ELECTRIC PORTFOLIO MODELING

As described in the prior subsection, there is significant incremental annual and peak electricity demand associated with the four Study scenarios in the long-term. PSE's electric portfolio modeling identified the need for approximately 1,100-3,100 MW of incremental total electricity resource additions, depending on scenario, relative to the reference case portfolio from the 2023 EPR. Figure 7 shows the resource builds that PSE's portfolio model identified to meet the required additional demand by Study scenario.

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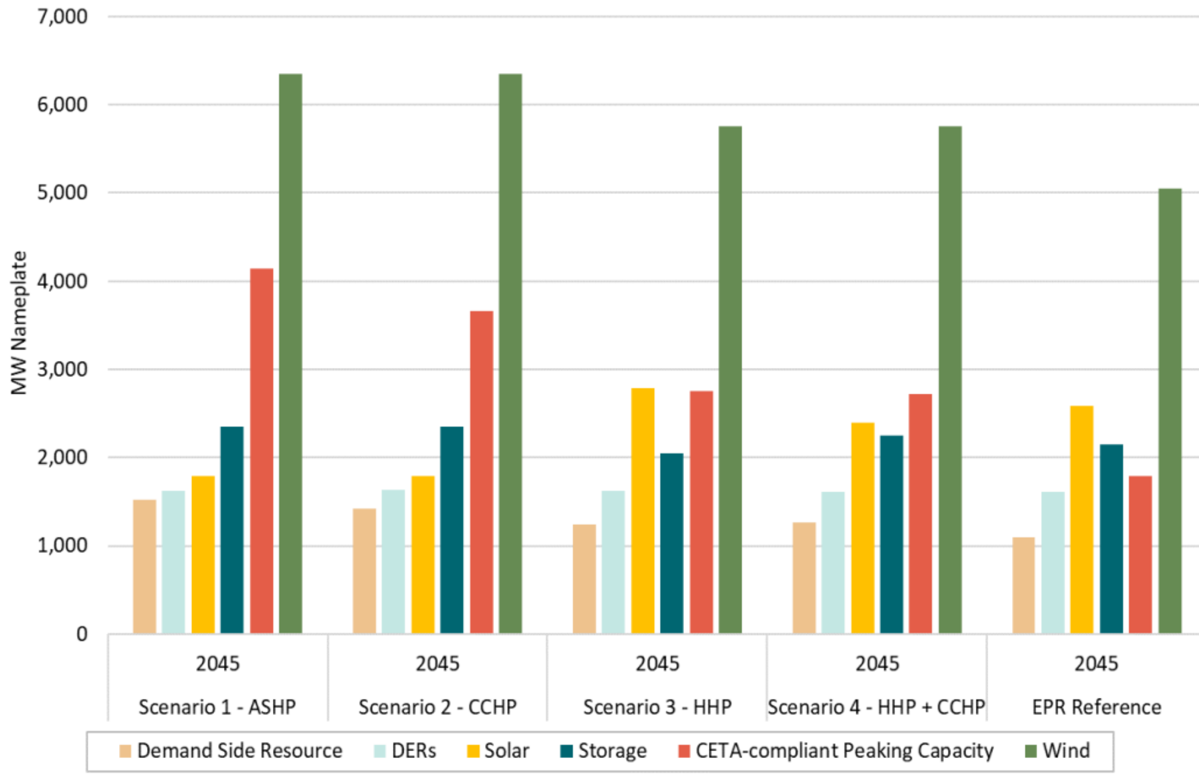
Figure 7: Optimal Electric Portfolio Builds by Study Scenario



It is important to consider the impacts of these portfolios from the perspective of Washington clean energy policy. In 2019, Governor Jay Inslee signed into law CETA, which commits Washington to supply 100% clean electricity, free of greenhouse gases (GHG), by 2045 with no provision for GHG offsets. As an interim step, CETA requires generation portfolios to be carbon neutral (allowing for GHG offsets) by 2030.[9] PSE's electric portfolio build within the 2023 EPR reference case surpasses 100% of the CETA targets in 2030 and 2045, and all resource builds for the four Study scenarios enable PSE to meet targets in both years, as well. In 2030, the HHP scenario reaches 95% of the CETA target through supply-side resources, while the ASHP Full, CCHP Full, and HHP&CCHP scenarios achieve 85% of the target through supply-side resources. The remainder of the target is achieved through the use of GHG offsets.

2.3. GAS PORTFOLIO MODELING

In contrast, the Study scenarios all reduce peak and annual gas system demand due to electric-to-gas conversions, as shown in Figure 8 and Figure 9, respectively.

[9] "Clean Energy Transformation Act." Washington State Department of Commerce, Nov. 2024, https://www.commerce.wa.gov/growing-the-economy/energy/ceta/ceta-overview/

Figure 8: Peak Day Impacts of Study Scenarios

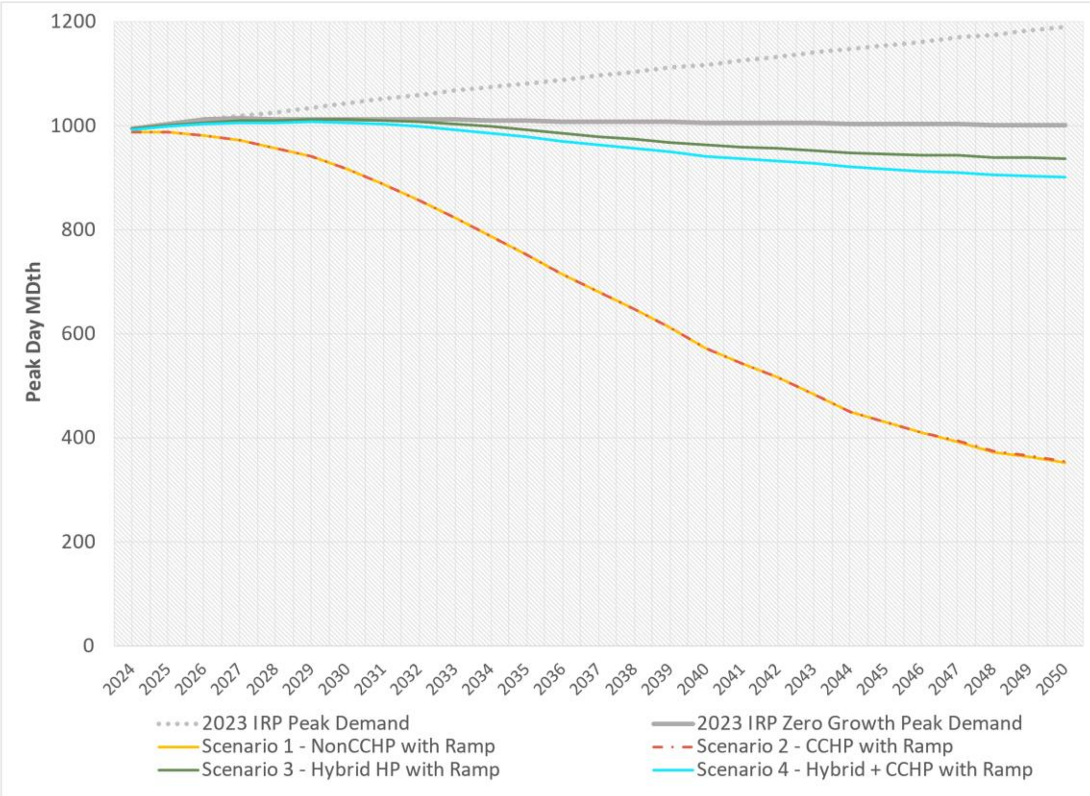
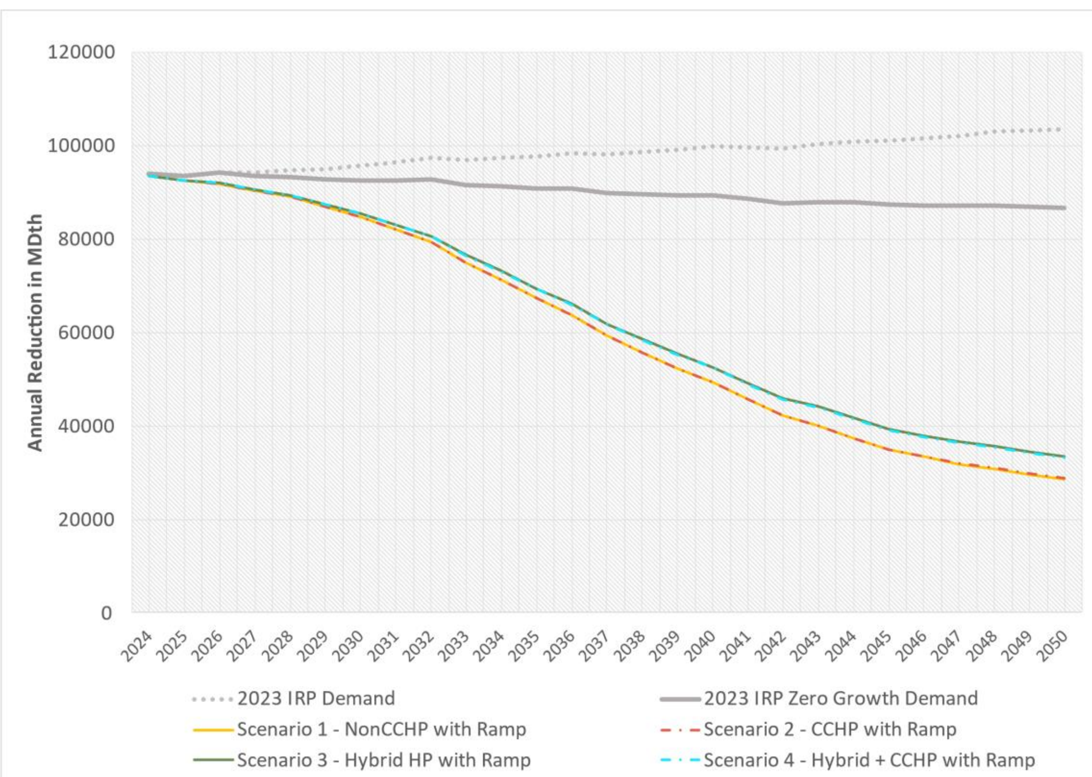


Figure 9: Gas Load Impacts of Study Scenarios



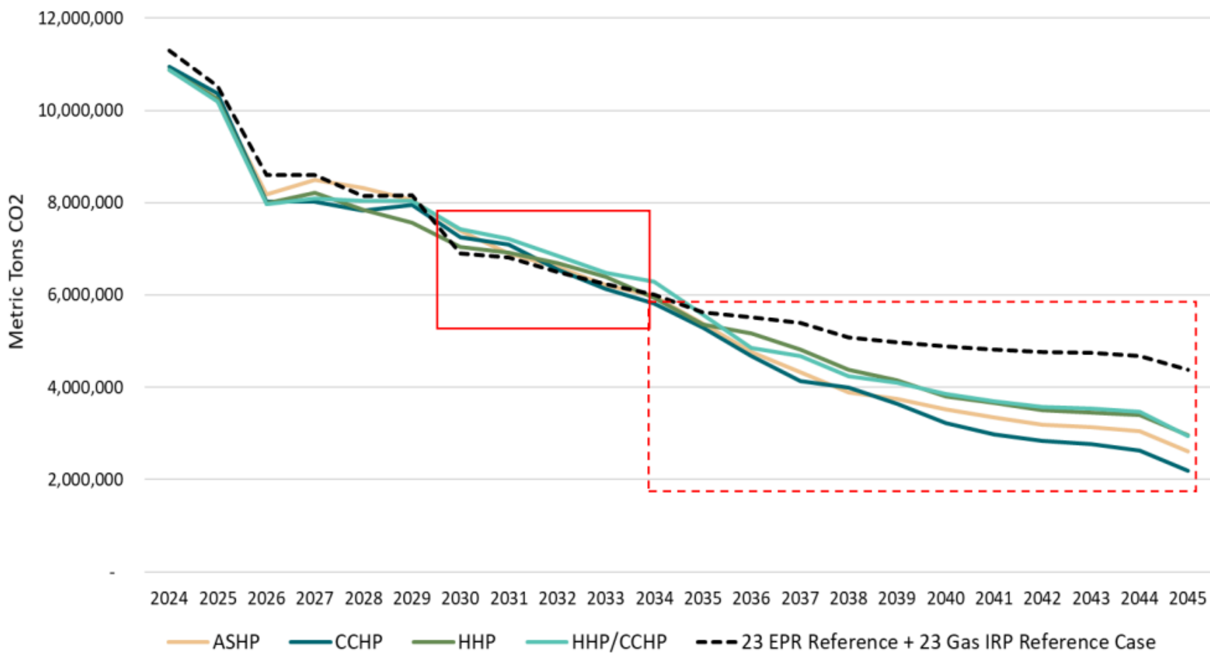
All four Study scenarios drastically reduce the volume of annual gas consumption on a similar order of magnitude, ranging from approximately 65-70% compared to the 2023 Gas IRP reference case by 2050. Reductions in winter peak gas demand are far greater for the ASHP Full and CCHP Full scenarios, at approximately 70% reduction by 2050, when compared to the HHP and HHP&CCHP scenarios, which show approximately a 20-25% reduction by 2050. In the Study scenarios with HHPs, most of the space heating load during the design day is expected to be met by the gas furnace portion of the hybrid system, so peak day impact reduction for these scenarios is primarily driven by other equipment that has been electrified (i.e., water heating, cooking, and clothes dryers).

2.4. EMISSIONS REDUCTION

To determine the net emissions impact for each of the Study scenarios, PSE modeled both the emissions reduction from decreased gas consumption and the emissions increase from additional electricity usage. This is relatively straightforward from the gas perspective, as the emissions intensity of natural gas remains relatively static regardless of the time or year of consumption. Emissions calculations on the electric system are more complex, however, since the emissions intensity of electricity varies based on the time of day the electricity is consumed. Further, over time, the penetration of non-emitting energy as a percentage of electricity production is expected to increase and drive down the emissions intensity of electricity and, as a result, also drive down total emissions from the electric system. However, in the near-term, electric system emissions may rise due to the increased load on the electric system. To account for these considerations, PSE evaluated the electric portfolio emissions using two different approaches. The first and simpler method assumes a static 0.437 metric tons per megawatt-hour (mt/MWh) emission rate for unspecified market purchases as is required by CETA. The second method uses a PSE-forecasted electricity market emission rate for the WECC extracted from the 2023 EPR power price model. This value declines from 0.25 mt/MWh in 2024 to 0.10 mt/MWh in 2045 to better represent the expected deployment of non-emitting energy over time to meet policy goals.

PSE ultimately applied the second method's market emissions rate for the WECC to generate the net emissions results shown in Figure 10. Even though this value is lower than the alternative emission rate for CETA, PSE's modeling indicates that total emissions would increase over the reference case for all four scenarios in the short term. The CCHP scenario results in the greatest increase in total emissions in 2030 at approximately 5%. In the near term, the increased dispatch of existing fossil-based electricity generation required to meet increased electricity demand outweighs the emissions reduction associated with less consumption of natural gas for building energy use. As the generation mix for electricity becomes increasingly comprised of non-emitting energy and more customers convert their gas appliances to electric appliances, total emissions are expected to go down significantly. Emission reductions in 2045 are estimated to range from 30-50% below the reference case, with the CCHP Full and HHP scenarios representing the lower and upper bound. Figure 10 illustrates the total emissions observed across the scenarios in greater detail.

Figure 10: PSE Gas and Electric Emissions Projections[10]



2.5. ELECTRIC SYSTEM MODELING

PSE modeled the impacts of the four Study scenarios on electric infrastructure needs using planner-level estimates based on historical costs and making assumptions based on $/MW peak added in Microsoft Excel. Costs are shown in nominal dollars and include the following types of infrastructure additions: 115/230 kilovolt (kV) transmission lines, bulk 115/230 kV transformers, transmission switching stations, distribution substation transformers, distribution feeders, and distribution service transformers.

PSE projected infrastructure costs for 2030 and 2045, but the 2030 values are relatively minimal compared to costs in 2045 since only distribution system expenditures are needed by 2030. Increased electric infrastructure for all types of infrastructure additions listed above was found to be needed across all four Study scenarios by 2045, however, with projected costs being six times higher than the 2030 estimates. Table 4 summarizes the cumulative infrastructure capacity and costs estimates for each Study scenario by 2030 and 2045, respectively.

Table 4: Electric System Modeling Summary Outputs

SCENARIO	2030 MW	2030 $M	2045 MW	2045 $M
S1 – ASHP Full	431	649	2,027	4,283
S2 – CCHP Full	387	583	1,731	3,665

[10] This represents gas and electric emissions attributed to PSE customers. This does not include any change in gas emissions in areas where PSE is only the electric provider. Conversely, this does not include any change in electric emissions in areas where PSE is only the gas provider.

SCENARIO	2030 MW	2030 $M	2045 MW	2045 $M
S3 – HHP	94	156	435	960
S4 – HHP&CCHP	89	135	390	865

2.6. GAS SYSTEM MODELING

To analyze gas system capital cost impacts, PSE evaluated each scenario using load and customer counts provided by Cadmus and forecasted fuel heat content from the 2023 IRP based on thermal modeling. Gas capital costs for the IRP reference case are higher than the Study scenarios, with the costs for the HHP and HHP+CCHP scenarios closely behind because of the continued use of a gas furnace at low temperatures. Further, gas infrastructure requirements are driven primarily by miles of pipeline and number of customers rather than volume of gas delivered, and hybrid heat pump systems will still require gas to be distributed during the coldest temperatures coinciding with winter peak demand. Since both the ASHP and CCHP scenarios fully convert customer space heating from gas to electric, the gas infrastructure expenditure is relatively lower for these Study scenarios. However, it is worth noting that under the ASHP and CCHP scenario conditions there are still 40% of gas customer remaining on the gas system in 2045. Figure 11 and Figure 12 show the projected annual gas system capital costs and cumulative capital costs for these scenarios, respectively.

Figure 11: Annual Gas Capital Costs by Study Scenario

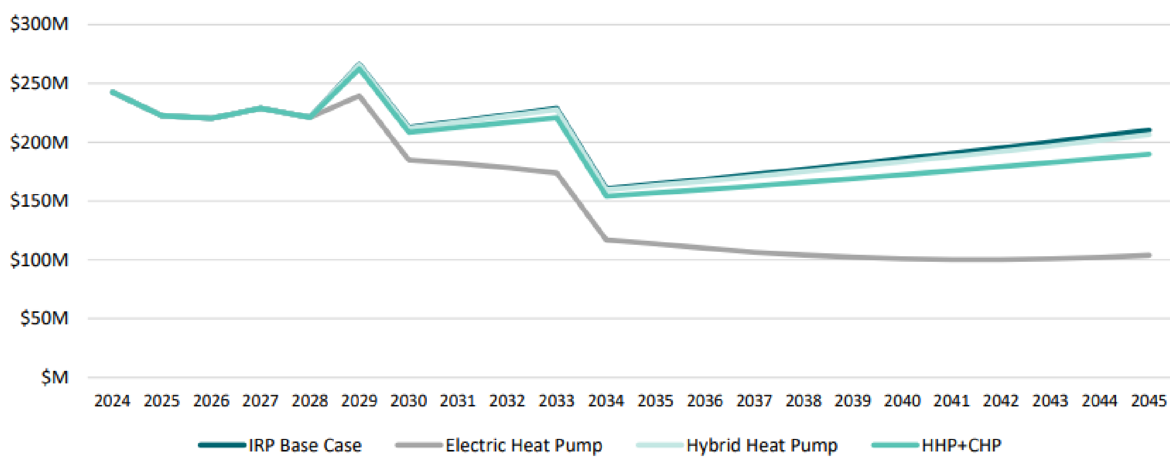
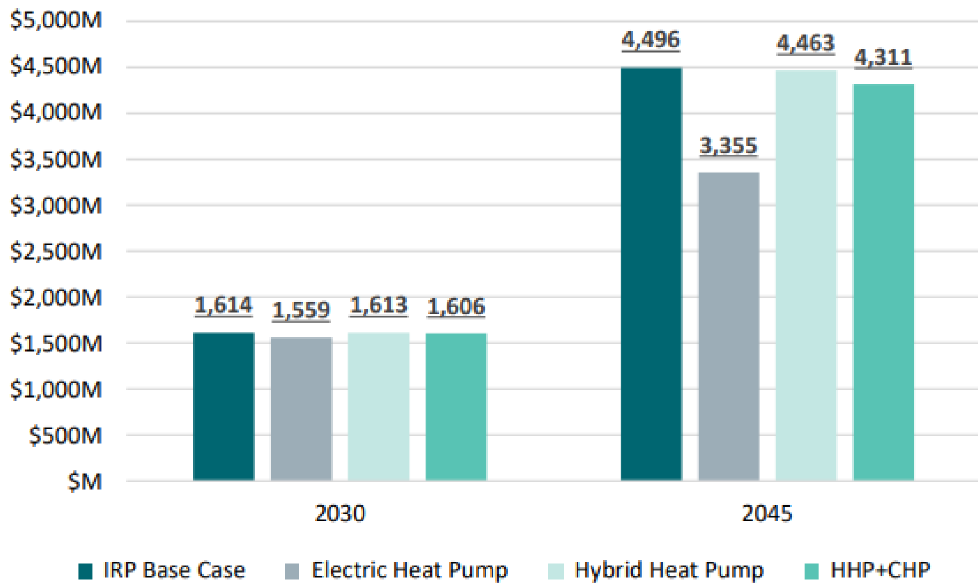


Figure 12: Cumulative Gas Capital Costs by Study Scenario



PSE also assessed the impact of the Study scenarios on addressing gas capacity-constrained areas of its system. A constrained area is defined as a specific section of the gas delivery system that is unable to serve peak customer demand without manual intervention when heating degree days (HDD) exceed 52 within a one-day period.[11] Dependence on manual intervention to maintain gas service during peak load conditions presents an outage risk and safety concerns. PSE currently has four capacity-constrained areas with project needs identified and solutions being considered. Peak load constraints total 472,000 standard cubic feet per hour (scf/hr) of natural gas (NG). Under the base case, existing gas capacity-constrained areas will become more challenging to mitigate if left unaddressed, and PSE anticipates the emergence of a fifth constrained area and growth of total peak load constraint to 519,000 scf/hr by 2032, assuming a supply of 100% NG. This constraint becomes even greater if 100% non-emitting natural gas (RNG) is delivered by the system, reaching 642,000 scf/hr. This difference is due to the lower heat content of RNG compared to NG, resulting in a greater amount of RNG required to meet the same heating demand as NG.

The ASHP Full and CCHP Full scenarios have a meaningful impact on lowering total peak load constraint of gas capacity-constrained areas because customers are assumed to fully electrify their space heating equipment. By 2032, the total peak load constraint in gas capacity-constrained areas decreases to 322,000 scf/hr under both full electrification scenarios.[12] HHPs do not address the total peak load constraint when compared to the base case because customers' backup gas furnaces are deployed at lower temperatures correlating with the system peak. As such, the HHP and HHP+CCHP scenarios result in no and minimal reductions to the total peak load constraint, respectively. However, from a gas capacity-constrained area perspective, these scenarios (HHP and HHP+CCHP) do provide

[11] A degree day compares the daily outdoor temperature mean (high temperature plus low temperature divided by two) to a standard base temperature (65°F). A 52 Heating Degree Day (HDD) would occur with an average outdoor temperature of 13°F. (US Energy Information Administration, Degree-days - U.S. Energy Information Administration (EIA))

[12] This value would be even less if not for an assumed transition to 100% RNG.

some benefit over the base case in 2032 by reducing the outdoor temperature below which cold weather actions are required, thereby lowering the number of such actions needed throughout a heating season.

Cold weather actions such as manual bypass of regulator stations or injection of gas to maintain pipeline pressure, delivered in the form of compressed natural gas (CNG) or liquefied natural gas (LNG), supplement the existing gas delivery system without needing to build additional infrastructure. For example, PSE begins cold weather action with LNG injection when outdoor air temperature drops to 38°F for one gas capacity-constrained area. While HHP systems use the gas furnace backup during times that correspond with the system peak, they are expected to use the heat pump during less-extreme conditions and would offset or delay the need to for PSE to take some cold weather actions. Deferring cold weather actions provides value to PSE through avoided costs and alleviates worker safety concerns associated with performing these actions in very cold temperatures, often during inclement weather conditions.

Table 5 provides greater detail on aggregate gas capacity-constrained area impacts under each Study scenario, specifically highlighting the total peak load constraint of each scenario in 2032 compared with the base case. Table 5 also describes the number of residential space heating end-use conversions that would be required to alleviate the total peak load constraint as well as the estimated cost of these conversions.

Table 5: Gas Capacity-Constrained Area Analysis

SCENARIO	TIME PERIOD	FUEL BLEND[13]	TOTAL PEAK LOAD CONSTRAINT[14]	# OF CONVER-SIONS[15]	EST. COST TO CONVERT[16]	BENEFITS/ OPPORTUNITIES
Base Case – 100% NG	Current	100% NG (1046BTU)	472,000 scf/hr	11,800	$177M	N/A
Base Case – 100% NG	2032	100% NG (1046BTU)	519,000 scf/hr	13,000	$195M	N/A
Base Case	2032	100% RNG	642,000 scf/hr	16,050	$241M	N/A
S1 – ASHP Full	2032	100% RNG	322,000 scf/hr	6,600	$99M	Reduces constrained areas on system occurring with lower carbon fuel

[13] The fuel blend is a key determinant in determining the total load constraint value as non-emitting natural gas (RNG) has a lower heat content than natural gas and thus at 100% RNG v. 100% natural gas (NG), therefore approximately 10% more fuel is required to serve the same customers.

[14] This represents the remaining level of the gas constraint after accounting for fuel blend and level of electrification assumed in the scenario.

[15] This is the number of residential customer space heating end use conversions from gas to electric required to alleviate the total peak load constraint of the Study scenario.

[16] This uses a simple assumption of $15,000 per residential customer to convert space heating from gas to electric.

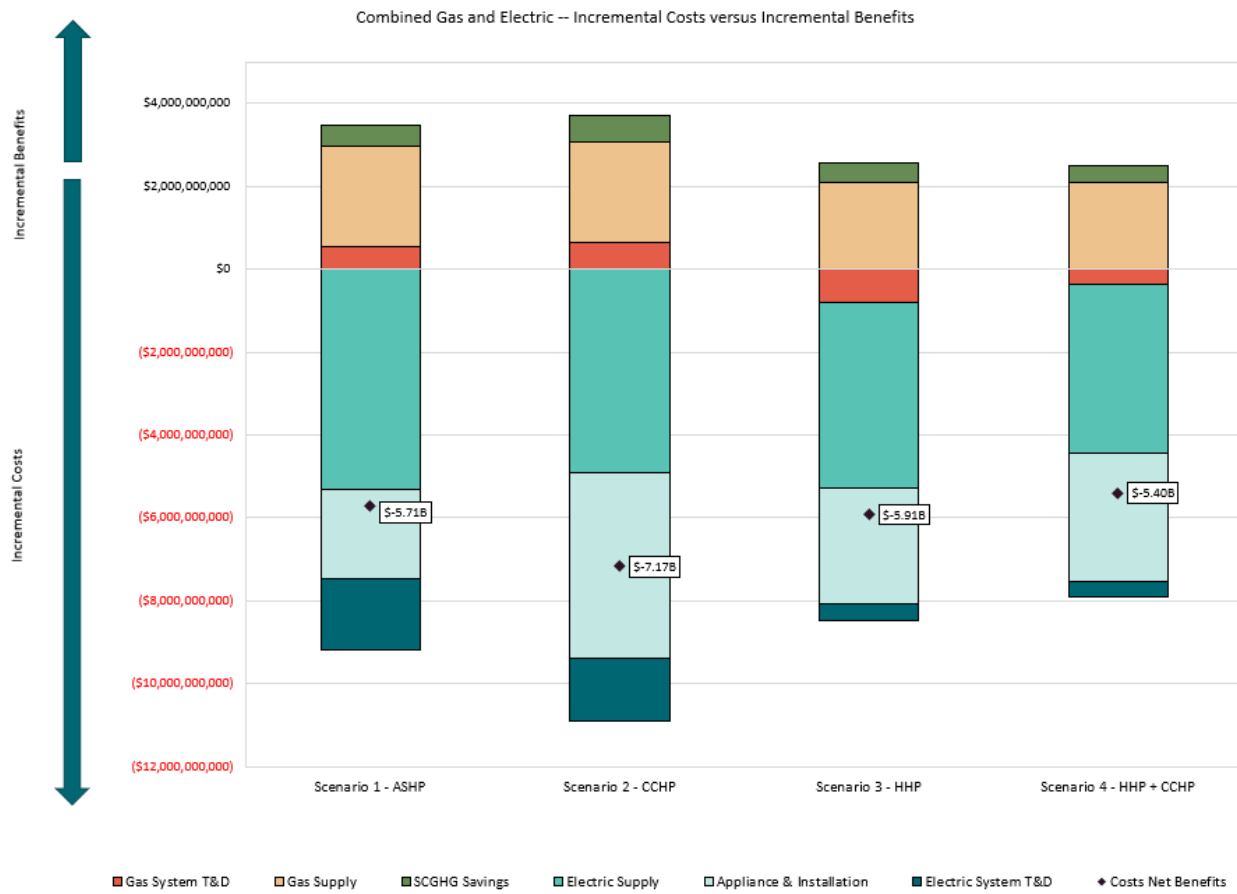
SCENARIO	TIME PERIOD	FUEL BLEND[13]	TOTAL PEAK LOAD CONSTRAINT[14]	# OF CONVER-SIONS[15]	EST. COST TO CONVERT[16]	BENEFITS/ OPPORTUNITIES
S2 – CCHP Full	2032	100% RNG	322,000 scf/hr	6,600	$99M	Reduces constrained areas on system occurring with lower carbon fuel
S3 – HHP	2032	100% RNG	642,000 scf/hr	16,050	$240M	Reduces temperature where cold weather actions are needed
S4 – HHP&CCHP	2032	100% RNG	610,000 scf/hr	15,250	$228M	Reduces temperature where cold weather actions are needed

These Study scenarios evaluate benefits from targeted electrification focused in specific geographic areas where targeted electrification may be a cost-effective alternative to gas pipeline upgrades, or at least be effective in reducing the scale of upgrades required. This is a concept commonly referred to as non-pipe alternatives (NPAs). Conversely, the application of broad system-wide electrification, without a focus on capacity-constrained areas, is unlikely to prevent gas infrastructure investments in a way that is cost-effective.

2.7. FINANCIAL ANALYSIS AND IMPACTS ON CUSTOMERS

PSE conducted financial analysis of each Study scenario by first evaluating the total cost impact on the combined electric and gas systems to determine the average electric and gas customer cost impact. From the combined system view, the total costs for each of the four Study scenarios far exceed the societal benefits attributed to carbon emission reduction achieved for the corresponding scenario. Figure 13 shows the costs and societal benefits detail net of the 2023 Reference Case for each of the four Study scenarios.

Figure 13: Combined Gas and Electric Scenario Benefits vs. Costs



From a customer perspective, cost impacts are similar across all four scenarios, with the CCHP Full scenario estimated to cost the average residential customer slightly more than any of the other scenarios. This means that under current market and available technology assumptions regardless of heat pump technology customers are not likely to convert from gas to electric for space heating, and possibly other end uses, absent substantial financial incentives (e.g., tax credits and/or utility rebates or other forms of incentives) or policy intervention (e.g., legislative changes) to significantly raise gas prices. While the assumptions used in this study (e.g., assumed costs) may change in the coming years as technology progresses, adoption increases, and policies change, at this time residential customers are not motivated to switch to an electric heat pump from a purely economic perspective. Figure 14 and Figure 15 show the costs for heat pump conversion compared with installation of a new gas-fired heating system for all scenarios compared with the reference case in 2030 and 2045, respectively.

Figure 14: Annual Residential Costs of Heat Pump Conversion vs. New Gas System in 2030

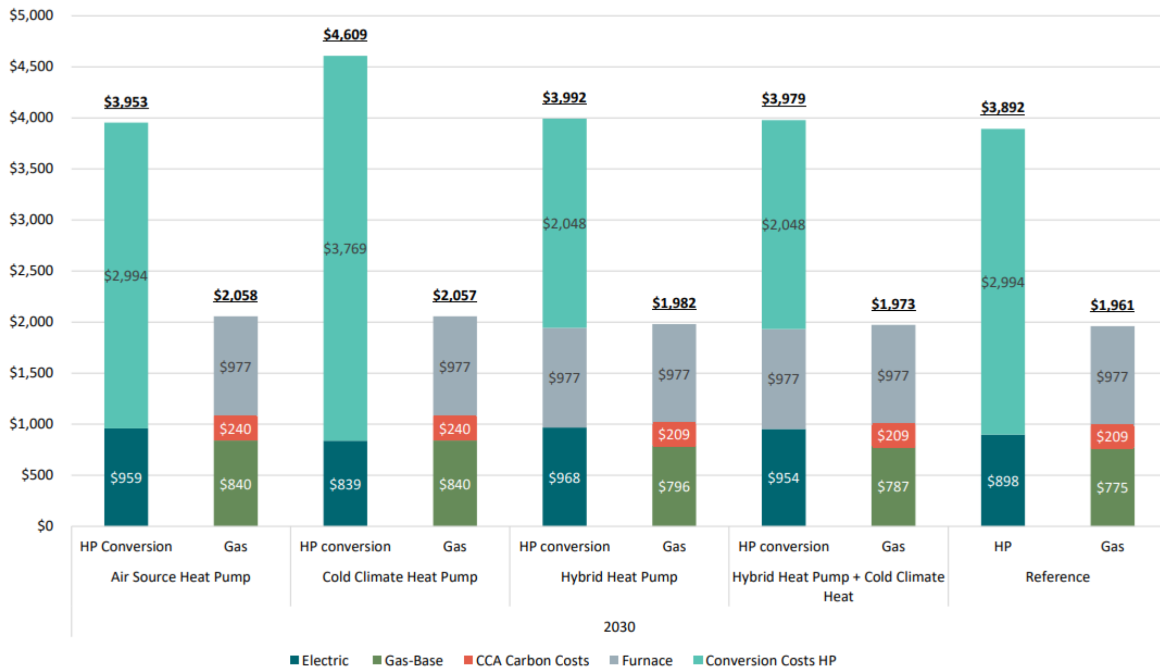
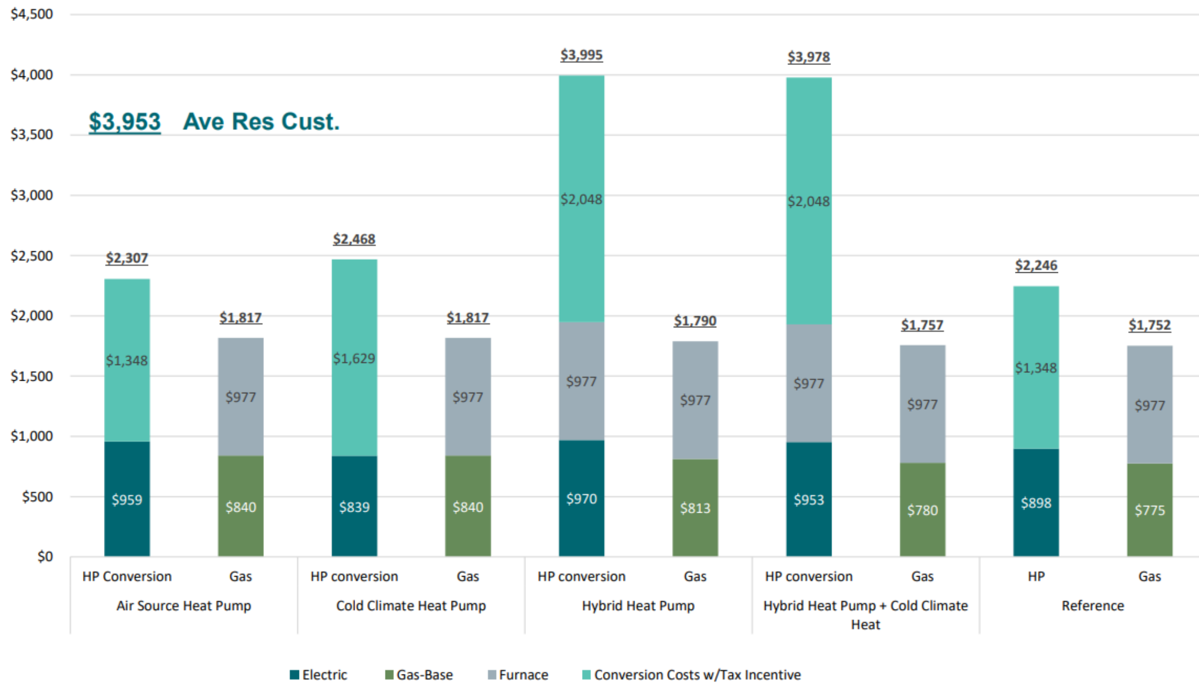


Figure 15: Annual Residential Costs of Heat Pump Conversion vs. New Gas System in 2045

While not all customers are eligible for state and federal incentives and rebates for heat pumps, low-income customers are generally eligible for incentives and rebates that can help offset all or a portion of the costs of a heat pump. Low-income customers earning less than 80% of the area median income (AMI) are eligible to receive $8,000 for qualifying heat pumps through IRA funding, as well as additional tax credits of up to $2,000 through the energy efficient home improvement federal tax credit.[17] When these financial incentives are applied, the cost of heat pump conversion is reduced significantly for eligible customers. Thus, even though price signals make gas-to-electric conversions more financially attractive to low-income customers than other residential customers, there is still no clear financial motivation for them to convert to heat pumps by 2030, as shown in Figure 16.

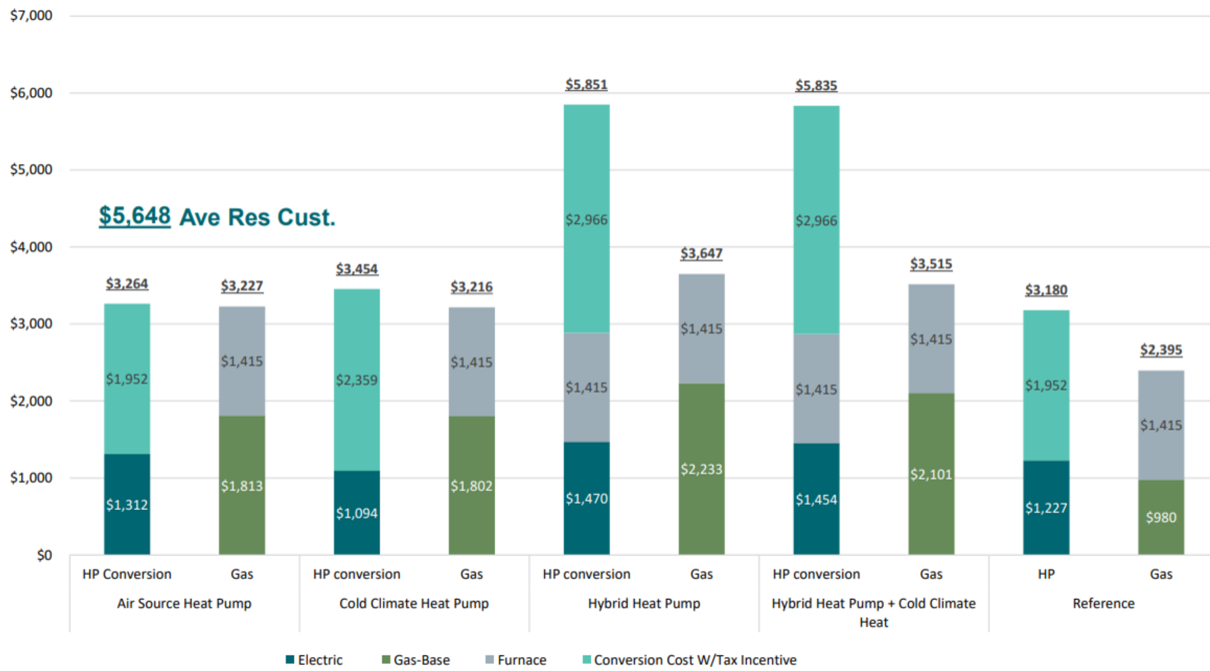
Figure 16: Annual Low-Income Customer Costs of Heat Pump Conversion vs. New Gas System in 2030



However, as is observed in Figure 17, the ASHP and CCHP scenarios in 2045 do nearly reach the tipping point for heat pump conversion to be financially justifiable.

[17] Further details on IRA funding can be found in Attachment B of Appendix B, located here: https://apiproxy.utc.wa.gov/cases/GetDocument?docID=3616&year=2022&docketNumber=220066

Figure 17: Annual Low-Income Customer Costs of Heat Pump Conversion vs. New Gas System in 2045



3. CONCLUSION

Study results indicate that costs associated with electrification under each of the four Study scenarios outweigh societal benefits at a total system level. Further, the customer rate impact results indicate that customers who choose to install heat pumps will likely face higher costs across all four scenarios than they would have if they were to replace their existing gas furnace with a new gas furnace to meet their space heating needs in 2030 and 2045. Table 6 lists these and other key takeaways from the Study.

Table 6: Key Study Takeaways

TAKEAWAY NUMBER	TOPIC AREA	DESCRIPTION
1	Customer Costs	**Heat Pump Electrification Costs for Residential Customers** – for an average residential customer, annual incremental costs of electrification are similar across all study scenarios with all study scenarios resulting in higher annual costs for residential customers that convert to heat pump systems.
2	Low-Income Customer Costs	**Heat Pump Electrification Costs for Low-Income Customers** – all study scenarios also show increased costs for low-income customers that convert to heat pump systems in the near term, even when additional low-income customer financial incentives are considered. The cost of converting to an electric heat pump for low-income customers for the ASHP Full and CCHP Full scenarios with financial incentives included is close to the annual cost of a new gas system, but still doesn't reach the tipping point that would motivate a customer to switch from a financial perspective.
3	Costs / Environmental Impact	**Total Costs Vs. Environmental Benefit** – the total costs associated with the four study scenarios are currently estimated to be far greater than the societal benefits associated with carbon emission reduction attributed to electrification. This is consistent with the

		finding from PSE's 2023 gas IRP when building electrification was determined to be too costly for inclusion in PSE's IRP relative to other planning solutions.
4	Environmental Impact	**Total Emissions Reduction** – using the WECC market emission rate, accelerated electrification increases carbon emissions in the near term, but carbon emissions decline over time should sufficient non-emitting resources be added to the generation mix to lower electric emissions intensity.
5	Energy Consumption	**Changes In Electricity and Gas Consumption** – on average, the four study scenarios resulted in a 25-30% increase in electricity consumption and a 75-80% decrease in gas consumption in 2050 relative to the reference case forecast.
6	Technology Performance	**Efficiency by Heat Pump Technology Type** – CCHPs are expected to have lower winter peak electricity demand impact than ASHPs given their higher efficiency at low temperatures. HHPs are expected to have near-zero winter peak electricity demand impact given that a hybrid system intends to use its gas backup system for heating during the winter peak.
7	Next Steps	**Targeted Electrification Considerations** – there are additional benefits to targeted electrification on certain, gas-constrained portions of the system. These benefits will be further considered within the targeted electrification strategy.

While PSE's analysis indicates that electrification at scale is neither cost-effective today nor a viable strategy for the entirety of their customer base, targeted electrification in gas capacity-constrained areas may prove to be cost effective given the greater potential for avoided costs.

APPENDIX A. DECARBONIZATION STUDY SETTLEMENT AGREEMENT LANGUAGE

Provisions of Stipulation Agreement Provision O related to Comprehensive Decarbonization Study.

65. Overview. The Settling Parties agree that PSE will (1) conduct an updated decarbonization study aimed at maximizing carbon reductions with more up-to-date assumptions on targeted electrification…

66. Decarbonization Study. PSE's updated decarbonization study will build off the gas decarbonization study prepared for PSE by E3 with more up-to-date assumptions regarding efficient Cold Climate Heat Pumps ("CCHPs") for targeted electrification. Measures and scenarios evaluated in the study must include but are not limited to comparisons of cost to ratepayers and GHG emissions associated with installing all electric vs. dual fuel systems for new customers and for existing gas customers, DERs, and decarbonized fuels. This decarbonization study will also include an evaluation of the impacts of all electric heat pumps, hybrid systems, and reducing and decarbonizing gas throughput. The study will be provided within 12 months of the Commission's final order in this case, and should include but not be limited to the following elements:

a. A more up-to-date electrification scenario that takes into account recent performance trends of CCHPs.
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.
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.
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.
e. Updated unit costs, including the incentives provided by the Inflation Reduction Act.
f. Study the impacts and benefits of electric heat pump technologies on PSE's gas constrained delivery systems.
g. Collaborate with adjacent consumer-owned utility electric service providers to conduct coordinated electric delivery system and gas delivery system studies or pilots.
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.
i. Include regional forecasted load and market price sensitivities that reflect regional electrification.
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.
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.

APPENDIX B. REQUIRED STEPS

STIPULATION O REQUIREMENT	PSE ACTION(S) TO ADDRESS
(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.	PSE publicly filed the detailed decarbonization study on December 21, 2023 with no designations of confidentiality. This filing included numerous document that describe study inputs, outputs, analysis, and findings. PSE has similarly published results and relevant documents for the Targeted Electrification Pilot (Pilot). The following reports are filed as separate documents: Decarbonization study summary report, targeted electrification pilot summary report and targeted electrification strategy report.
A. A more up-to-date electrification scenario that takes into account recent performance trends of CCHPS	PSE generation and transmission and distribution (T&D) system impact results were shared with parties on September 28, 2023. Cadmus reviewed load results in a meeting with parties 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	Near and long-term PSE generation and T&D system impact results were shared with parties on September 28, 2023. Updates were provided to parties at 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 emissions reduction	PSE generation and T&D system impact results were shared with parties on September 28, 2023. Cadmus reviewed load results in a meeting with parties 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 and T&D system impact results were shared with parties on September 28, 2023.
E. Updated unit costs, including the incentives provided by the IRA	See Cadmus presentation to parties on August 10, 2023.
F. Study the impacts and benefits of electric heat pump technologies on PSE's gas constrained delivery systems	See PSE presentation to parties 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 requirement is being met through the Pilot work with Seattle City Light.
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 to parties on August 31, 2023. Updates were provided to parties at the December 8, 2023 meeting.
I. Include regional forecasted load and market price sensitivities that reflect regional electrification	See E3 presentation to parties on 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 generation and T&D system impact results were shared with parties on September 28, 2023. Rate impact results were shared with parties on November 8, 2023, and December 8, 2023.
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.	PSE will incorporate and expand on this study in the 2025 Natural Gas IRP.

APPENDIX C. SETTLING PARTY ENGAGEMENT AND MEETINGS

DATE	MEETING NAME	PURPOSE/TOPICS
1/20/2023	Kickoff Meeting	PSE held an initial meeting with parties to discuss the settlement's study commitments, including the schedule and scope of the Study.
6/29/2023	Study Methodology and Preliminary Results[18]	Following meetings with the parties to discuss the Targeted Electrification Pilot, PSE held a meeting to discuss the Study's methodology, preliminary results and data regarding heat pump operating parameters, electric and gas load shapes, and estimated IRA demand impacts.
8/10/2023	Final Study Inputs Readout by Cadmus[19]	PSE held a meeting with parties and PSE's Study consultant, Cadmus, where final results pertaining to key inputs (e.g., CCHP research, IRA research, decarbonization scenarios, electric and gas baseline sales impact) were reviewed and presented.
8/24/2023	Final Study Inputs Readout by E3[20]	PSE held a meeting with parties and PSE's Study consultant, E3, where final results pertaining to key inputs (e.g., regional infrastructure impacts, non-emitting electricity and fuel supply and costs) were reviewed and presented.
9/28/2023	Draft Portfolio Modeling Output Results[21]	PSE held a meeting with parties to present PSE's draft study model outputs, including draft electric and gas utility costs, electric and gas portfolio outputs, and other results.
11/8/2023	Draft Financial Results[22]	PSE held a meeting with parties to present draft financial analysis results from the Study.
12/8/2023	Updated Study Final Results[23]	PSE held a final meeting with parties to present the final results of the Study.

[18] To view the recording of the November 8, 2023 meeting with parties please follow the link here: https://www.youtube.com/watch?v=fiwrOs104Fs

[19] To view the recording of the August 10, 2023 meeting with parties please follow the link here: https://www.youtube.com/watch?v=8U59OLMo_Sk

[20] To view the recording of the August 24, 2023 meeting with parties please follow the link here: https://www.youtube.com/watch?v=Lbbr3y74nTk

[21] To view the recording of the September 28, 2023 meeting with parties please follow the link here: https://www.youtube.com/watch?v=KqaTJZJTLDU

[22] To view the recording of the November 8, 2023 meeting with parties please follow the link here: https://www.youtube.com/watch?v=wM8-6VDGglQ

[23] To view the recording of the December 8, 2023 meeting with parties please follow the link here: https://www.youtube.com/watch?v=V-E77wEW6lQ

APPENDIX D. DETAILED DECARBONIZATION STUDY ASSUMPTIONS

NAME/TOPIC	DESCRIPTION	SOURCE
Scenario Development	Provides a detailed explanation of the assumptions and definitions for all four electrification scenarios.	Link (Pg. 20) Link 2 (PDF Pgs. 36-39)
Impact of Scenarios on Electric and Natural Gas Demand	Describes assumptions Cadmus used throughout its analysis on the impacts of the electrification scenarios on electric and natural gas demand.	Link (PDF Pgs. 40-45)
Electric Portfolio Modeling	Explains the starting point for the reference case portfolio model and key changes for each scenario.	Link (Pg. 54)
Gas Portfolio Modeling	Explains the starting point for the reference case portfolio and the assumptions for any changes or additional inputs.	Link (Pg. 62)
Societal Benefits of Reduced Emissions	Describes the steps used to calculate societal benefit and how it is used in the analysis.	Link (Pg. 73)
Gas System Impact Assumptions	Explains qualitative assumptions, considered metrics, and changes since the 2021 E3 Decarbonization Study.	Link (Pgs. 77-79)
Residential And C&I Equipment Adoption	Details the adoption curves used for residential and commercial equipment along with the data source.	Link (Pg. 42)
Equipment Costs	Outlines the average cost per equipment unit based on contractor interviews conducted as a part of the 2023 IRP CPA. Also describes the annual amortization for the different heating systems considered in 2030 and other relevant assumptions.	Link (Pgs. 31 And 90)
Incentives Available for Low-Income Customers	Details the relevant incentives available for low-income customers.	Link (Pg. 96)
Financial Analysis and Impact on Customers	Describes the considerations, input values, and methodologies used to determine the financial impact on PSE customers under each scenario.	Link (Pg. 91)

APPENDIX E. DECARBONIZATION STUDY COMPLIANCE FILING DOCUMENT TRACKER AND DESCRIPTIONS

FILE NAME	DESCRIPTION	LINK
220066-67-210918-PSE-Decarb-Study-Cltr-(12-21-2023).pdf	Details the documents enclosed for filing along with the requirements of the Study and stakeholder engagement meeting details.	Link
220066-Attachment A-PSE's Decarbonization Study.pdf	Detailed study report, including additional detail on analysis and findings for all Study components.	Link
220066-Attachment B-Cadmus Group Final Report.pdf	Report completed by Cadmus on analysis it conducted to support the Study. This includes research on CCHPs, assessment of IRA impacts, and an evaluation of equipment adoption and costs and the load impacts of the four electrification scenarios.	Link
220066-Attachment C-E3 Literature Review.pdf	Report completed by E3 with background research on decarbonization strategies studied and implemented in the U.S. and abroad with an emphasis on pacific northwest findings and studies.	Link
220066-Attachment D-E3 Regional Infrastructure.pdf	Report completed by E3 that assesses the impact of heating decarbonization pathways on regional electric and gas infrastructure, including the ability of electric transmission systems to deliver firm capacity during winter peak heating events West of the Cascades and the impact on regional gas infrastructure requirements for design day demand planning.	Link
220066-Attachment E-Gas Portfolio Output Summary.xlsx	Gas portfolio modeling outputs for the Study scenarios, including impacts on annual gas consumption and design day demand and resource builds that consider renewed vs. Unrenewed pipelines as well as green hydrogen, supply-side, gas-to-electric, and demand-side resources. Other outputs include gas portfolio costs, gas emissions, and conservation potential by Study scenario.	Link
220066-Attachment F-Gas System Results.xlsx	Gas system modeling outputs for the Study scenarios, including gas capital costs and gas capacity-constrained area assessment.	Link
220066-Attachment G-Electric Portfolio Output Summary.xlsx	Electric portfolio modeling outputs for the Study scenarios, including net present value (NPV) analysis, social cost of greenhouse gases for the scenarios, and resource builds that consider distributed energy resources (DERs), solar, storage, wind, CETA-compliance peaking capacity, and demand-side resources. Other outputs include CETA compliance, emissions with a fixed rate (CETA methodology), and emissions with a variable rate (WECC) by Study scenario.	Link
220066-Attachment H-Electric System Outputs.xlsx	Electric system modeling outputs for the study scenarios, including transmission and distribution infrastructure requirements and costs by Study scenario.	Link
220066-Attachment I-Rate Impact Graph Residential.xlsx	Outputs on the annual cost to a residential customer if they convert to a heat pump compared with the costs of purchasing a new gas heater in 2030 and 2045 across the four Study scenarios.	Link
220066-Attachment J-Rate Impact Graphsched31.xlsx	Outputs on the total annual gas bill for an average industrial customer on rate schedule 31 across the four Study scenarios.	Link
220066-Attachment K-Rate Impact Graphsched31t.xlsx	Outputs on the total annual gas bill for an average industrial customer on rate schedule 31T across the four Study scenarios.	Link
220066-Attachment L-Rate Impact Graphsched41.xlsx	Outputs on the total annual gas bill for an average industrial customer on rate schedule 41 across the four Study scenarios.	Link
220066-Attachment M_ Rate Impact Graphsched41t.xlsx	Outputs on the total annual gas bill for an average industrial customer on rate schedule 41T across the four Study scenarios.	Link

220066-Attachment N-Rate Impact Graphsched87.xlsx	Outputs on the total annual gas bill for an average industrial customer on rate schedule 87 across the four Study scenarios.	Link
220066-Attachment O-Rate Impact Graphsched87t.xlsx	Outputs on the total annual gas bill for an average industrial customer on rate schedule 87T across the four Study scenarios.	Link
220066-Attachment P-Rate Impact Low Income.xlsx	Outputs on the annual cost to a low-income residential customer if they convert to a heat pump compared with the costs of purchasing a new gas heater in 2030 and 2045 across the four Study scenarios. Low-income customer conversion costs are reduced with tax incentives for which they are eligible.	Link