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# Comprehensive Decarbonization Study Report

August 18, 2023


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# Table of Contents

## Tables

# Figures

# Acronyms and Abbreviations

| Acronym | Definition |
|---|---|
| AC | Air conditioner |
| AHRI | Air Conditioning, Heating, and Refrigeration Institute |
| AMI | Area median income |
| AMY | Actual meteorological year |
| ASHP | Air-source heat pump |
| ASHRAE | American Society of Heating, Refrigerating and Air-Conditioning Engineers |
| BYOT | Bring-Your-Own Thermostat |
| C&I | Commercial and industrial |
| CCHP | Cold-climate heat pump |
| CEE | Consortium for Energy Efficiency |
| COP | Coefficient of performance |
| CPA | Conservation Potential Assessment |
| CPP | Critical peak pricing |
| DHP | Ductless heat pump |
| DLC | Direct load control |
| ERWH | Electric resistance water heater |
| EUL | Effective useful life |
| EVSE | Electric vehicle supply equipment |
| HEEHRA | High Efficiency Electric Homes Rebates Act |
| HHP | Hybrid heat pump |
| HOMES Rebate | Home Energy Performance-Based, Whole House Rebates |
| HSPF | Heating Seasonal Performance Factor |
| IRA | Inflation Reduction Act |
| IRP | Integrated Resource Plan |
| NEEA | Northwest Energy Efficiency Alliance |
| NEEP | Northeast Energy Efficiency Partnerships |
| NREL | National Renewable Energy Laboratory |
| PRISM | PRInceton Scorekeeping Method |
| PSE | Puget Sound Energy |
| PUMA | Public use microdata area |
| sCOP | Seasonal coefficient of performance |
| TRC | Total resource cost |
| U.S. DOE | U.S. Department of Energy |

# Executive Summary

This report presents the results of the updated comprehensive decarbonization study as part of Section O of Settlement Stipulation and Agreement (Dockets UE-220066/UG-220067 and UG-210918)[1] between Puget Sound Energy (PSE) and Settling Parties.[2] Several tasks were included in the study scope presented here:

- An updated comprehensive decarbonization study after the 2023 Conservation Potential Assessment (CPA) natural gas-to-electric conversion assessment
- Comprehensive review of air-source heat pump (ASHP) and cold-climate heat pump (CCHP) technologies, and review recent CCHP performance trends and equipment costs
- Review of the Inflation Reduction Act (IRA) for its impacts on electrification
- Evaluation of the impacts of CCHPs and hybrid systems for new and existing customers within the residential sector

Cadmus first conducted research to determine the recent performance trends of CCHPs as well as equipment costs. In addition, we researched and summarized incentives for heat pump and other electrification equipment provided under the IRA and the mechanisms of making these incentives available to the public. This research informed our decarbonization scenario analysis, for which we assessed four different scenarios to account for the impacts of natural gas-to-electric conversions within the residential sector. The scenarios differ based on the heat pump technology being converted—ASHP, CCHP, or hybrid heat pump (HHP)—and on the building vintage—existing or new.

1 Washington Utilities and Transportation Commission. January 2022. "Puget Sound Energy GRC, Docket UE-220066 & UG-220067." https://www.utc.wa.gov/220066

2 As of August 26, 2022, the Settling Parties include the regulatory staff of the Washington Utilities and Transportation Commission, Alliance of Western Energy Consumers, Federal Executive Agencies, Walmart, Inc., The Energy Project, Kroger, Co., NW Energy Coalition, Sierra Club, Front and Centered, Microsoft, and Nucor Steel Seattle Inc.

**SCENARIO 1. FULL ELECTRIFICATION WITH ASHPs (SCENARIO 1 – ASHP FULL)** for new and existing residential customers, similar to the Full Electrification – Policy scenario presented in the 2023 Integrated Resource Plan (IRP) CPA

**SCENARIO 2. FULL ELECTRIFICATION WITH CCHPs (SCENARIO 2 – CCHP FULL)** for new and existing residential customers

**SCENARIO 3. HHP WITH ASHPs (SCENARIO 3 – HHP)** for new and existing residential customers, similar to the Hybrid Heat Pump – Policy scenario presented in the 2023 IRP CPA

**SCENARIO 4. HHP WITH ASHPs FOR EXISTING CUSTOMERS / CCHPs FOR NEW CUSTOMERS (SCENARIO 4 – HHP&CCHP)**

For the residential sector, in addition to space heating, Cadmus assessed the water heating, cooking, and clothes dryer end uses for natural gas-to-electric conversion impacts. We used the same input assumptions as were used for the 2023 IRP CPA for the commercial and industrial (C&I) sectors for all four scenarios. In the commercial sector, we evaluated the space heating (ASHP), cooking, and water heating end uses. For the industrial sector, Cadmus followed the same methodology as was used in the 2023 IRP CPA by converting a portion (~30%) of natural gas loads to electric.

In addition to evaluating electric and natural gas baseline sales impact, Cadmus also assessed the impacts of natural gas-to-electric conversions on energy efficiency and demand response potential, presenting the results of these assessments in this report.

## *Summary of Results*

Table 1 shows the impact of the four scenarios on PSE's baseline sales in 2050 as a percentage decrease for natural gas and a percentage increase for electric, for both residential and all sectors combined. Scenario 1 – ASHP FULL and Scenario 2 – CCHP FULL have the largest decrease in natural gas sales, while Scenario 1 – ASHP FULL has the largest increase in electric sales. For this first scenario, IRA funding may not qualify for all ASHPs.

The increase in electric sales for Scenario 2 – CCHP FULL is similar to the increase for Scenario 3 – HHP and Scenario 4 – HHP&CCHP and IRA funding likely qualifies for most CCHPs. Scenario 3 – HHP has the least reduction in natural gas sales of all scenarios, as IRA funding may not qualify for all ASHPs with backup. Scenario 4 – HHP&CCHP results in a very similar reduction in natural gas sales compared with Scenario 3 – HHP. IRA funding may not qualify for all ASHPs with backup, but it likely qualifies for most CCHPs.

**Table 1. Percentage Change in Natural Gas and Electric Baseline Sales in 2050 Compared with Base Case Sales Forecast**

| Scenarios | Residential Sales Only | | All Sector Sales | |
|---|---|---|---|---|
| | Percentage Decrease in Natural Gas Sales | Percentage Increase Electric Sales | Percentage Decrease in Natural Gas Sales | Percentage Increase Electric Sales |
| Scenario 1 – ASHP FULL | 89% | 40% | 81% | 29% |
| Scenario 2 – CCHP FULL | 89% | 35% | 81% | 26% |
| Scenario 3 – HHP | 82% | 37% | 76% | 28% |
| Scenario 4 – HHP&CCHP | 82% | 36% | 76% | 27% |

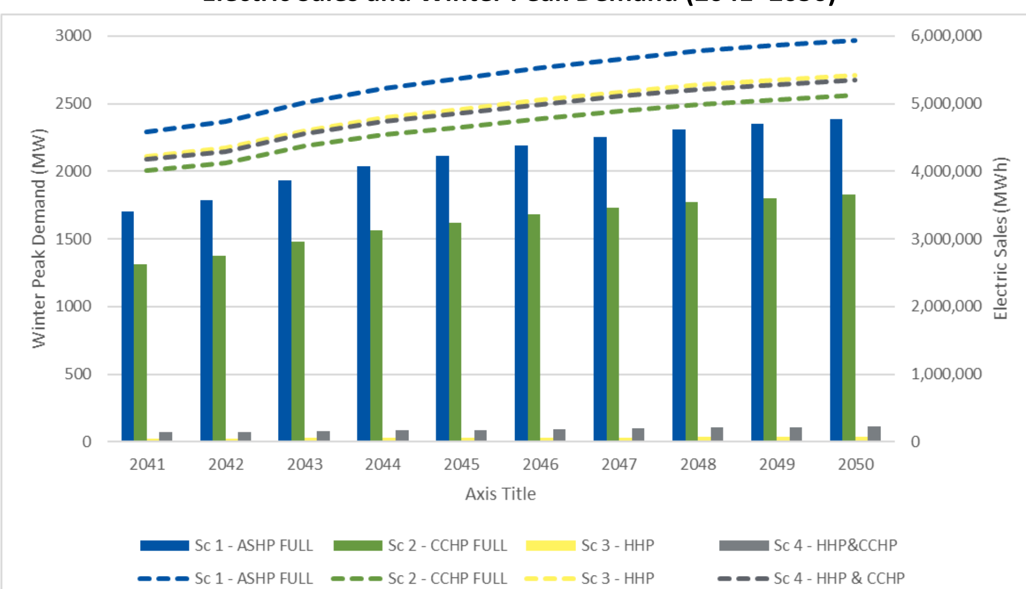
Table 2 presents the impact of the four scenarios on electric winter peak demand in 2050 as compared with Scenario 1 – ASHP FULL, which has the highest peak demand impact. Among all scenarios, Scenario 3 – HHP has the least impact on winter peak demand.

**Table 2. Impact of Four Scenarios on Electric Winter Peak Demand When Compared with Scenario 1**

| Scenarios | Change in Electric Peak Demand as Percentage of Peak Demand for Scenario 1 | |
|---|---|---|
| | Residential Only | All Sectors |
| Scenario 1 – ASHP FULL | 100% | 100% |
| Scenario 2 – CCHP FULL | 79% | 81% |
| Scenario 3 – HHP | 14% | 20% |
| Scenario 4 – HHP&CCHP | 17% | 22% |

As a more granular look, Figure 1 shows the change in impact of natural gas-to-electric conversions on residential heat pump–related sales and winter peak demand in the last 10 years of the study. Similar to the overall impacts for all equipment, Scenario 1 – ASHP FULL has the largest increase in heat pump–related electric sales while Scenario 2 – CCHP FULL has the smallest increase. Scenario 1 – ASHP FULL has also the largest impact on winter peak demand, whereas Scenario 3 – HHP has the smallest impact.

**Figure 1. Impact on Residential Heat Pump–Related Electric Sales and Winter Peak Demand (2041–2050)**




Note: Bars represent winter peak demand and lines represent electric sales.

## *Organization of This Report*

This report presents the results of the decarbonization study in five chapters and four appendices:

- *Chapter 1. Cold-Climate Heat Pump and Inflation Reduction Act Research* presents Cadmus' research findings for determining recent performance trends of CCHPs and equipment costs as well as the incentives provided under the IRA.
- *Chapter 2. Decarbonization Scenario Analysis* presents detailed definitions of the four decarbonization scenarios and the methodology used in this study.
- *Chapter 3. Assessment of the Natural Gas and Electric Load Impacts* discusses the impacts of the four scenarios on natural gas and electric sales.
- *Chapter 4. Assessment of Natural Gas and Electric Energy Efficiency Impacts* reviews the impacts of the four scenarios on natural gas and electric energy efficiency potential.
- *Chapter 5. Assessment of the Effect of Natural Gas-to-Electric Conversion on Demand Response Potential* discusses the impacts of the four scenarios on demand response potential.
- *Appendix A: Heat Pump Load Shapes* provides an Excel workbook with the load shapes for ducted and ductless CCHPs, ASHPs, and HHPs for different residential building segments, vintages, and equity combinations.
- *Appendix B: Winter Peak Demand Estimates from Electrification* presents estimates of the winter peak demand impacts from electrification with heat pumps for different residential building segments, vintages, and equity combinations.
- *Appendix C: Methodology for Creating Load Shapes* presents the methodology for creating the heat pump load shapes for each residential building segment, vintage, and equity combination.
- *Appendix D: Costs of CCHPs and Other Heat Pump Technologies* provides an Excel workbook containing the costs baseline and heat pump technologies and costs for panel upgrades, wiring, and duct/pad improvements.

# Chapter 1. Cold-Climate Heat Pump and Inflation Reduction Act Research

This chapter summarizes the findings of CCHP and IRA research that Cadmus conducted as part of PSE's decarbonization study. The *Cold-Climate Heat Pump Research Findings* section presents the details of recent CCHP performance trends and the approach Cadmus used to create CCHP and non-CCHP load shapes for PSE's service territory, and it elaborates on the costs of different heat pump technologies. *Appendix A: Heat Pump Load Shapes* provides the load shapes for ducted and ductless CCHPs and non-CCHPs, and HHPs for each residential segment (single family, multifamily, and manufactured), vintage (new and existing), and equity (standard and vulnerable population) combination.

The *Inflation Reduction Act Research* section introduces the heat pump and other electrification incentives provided under the IRA and the mechanisms of making these incentives available to households and other partners. The section also discusses the impact of IRA incentives on levelized total resource cost (TRC) calculations.

## *Cold-Climate Heat Pump Research Findings*

This section summarizes the findings of Cadmus' CCHP research. The *Recent Performance Trends* subsection introduces CCHP technologies and discusses their benefits and challenges. Then the *Measuring Performance* subsection explains how CCHP performance is measured. The *Winter Peak Loads from Electrification: CCHP Impacts* subsection discusses CCHP impacts on winter peak load. The *Methodology for Creating Heat Pump Load Shapes* subsection presents the methodology Cadmus used to create CCHP and non-CCHP load shapes specific to PSE's service territory. Finally, the *Costs of CCHPs and Other Heat Pump Technologies* subsection provides an overview of heat pump technology costs.

### Recent Performance Trends

Interest in CCHPs has increased significantly in recent years. In particular, utility and state incentives and market development programs across the Northeast have primarily focused on promoting CCHPs since their entry into the market over decade ago. This subsection introduces and defines CCHPs; discusses their benefits, challenges, and applications; highlights actual in-field performance studies in cold-climate conditions; and discusses potential electrification impacts relative to conventional ASHPs.

**Definition of Cold-Climate Heat Pumps.** ASHPs are a well-established HVAC technology in residential applications. According to the U.S. Energy Information Agency, nearly 19 million housing units in the United States (16%) use ASHPs for primary heating and cooling, most of which are in southern regions with milder winters.[3] ASHPs have traditionally had a reputation for poor performance and high costs in colder weather: This is because ASHPs rely on heat transfer through a refrigerant compression cycle to deliver heating to a space, so capacity and efficiency decline as outdoor air temperatures decline, requiring greater use of supplemental heating (typically inefficient electric resistance). These limitations have historically constrained the widespread adoption of ASHPs in regions with colder climates, including the Pacific Northwest.

Over a decade ago a new generation of heat pumps began entering the North American market, offering improved performance in colder climates due to three key factors:[4]

- **Refrigerants.** R-410A became one of the standard replacements for R-22 in compliance with the Montreal Protocol and it offers improved heat absorption from outdoor air due to a lower boiling point.
- **Variable-speed compressors.** In cold-climate systems, inverter-driven compressors replace single- or dual-stage compressors, allowing for improved comfort during mild conditions when the compressor is operating at partial load, as well as increased speeds at maximum output to increase heating output.
- **Enhanced vapor injection.** Also known as "flash injection," a cold-climate system diverts and reduces the pressure and temperature of a portion of the high-temperature, high-pressure refrigerant leaving the indoor unit. This diverted refrigerant absorbs some heat from the higher-temperature refrigerant before being reinjected into the compressor. This process enhances the transfer of heat in colder weather into the cold refrigerant (by further cooling the refrigerant) and allows the compressor to operate at higher speeds.[5]

Due to growing interest from policymakers, industry, and program administrators to define CCHPs, 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, which designates models of Air Conditioning, Heating, and Refrigeration Institute (AHRI)–certified ASHPs as cold climate. In particular, the NEEP specification adds a requirement backed by engineering or lab testing data for efficiency at 5°F (because 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

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3 U.S. Energy Information Agency. May 2022. *2020 RECS Survey Data*. "Table HC6.8 Space Heating in Homes in the South and West Regions, 2020." https://www.eia.gov/consumption/residential/data/2020/HC206.8.pdf

4 Harrod, Jon. December 2, 2022. "Heat Pumps for Cold Climates." *Green Building Advisor*. https://www.greenbuildingadvisor.com/article/heat-pumps-for-cold-climates

5 Mitsubishi Electric. November 2022. "Inverter Heat Pump Technology Explained." https://www.mitsubishicomfort.com/articles/keep-warm-this-winter-inverter-technology-for-any-climate

CCHPs while including an additional capacity requirement. Further, in 2022, ENERGY STAR adopted a cold-climate designation for residential ASHPs that has many similarities to the NEEP and NEEA designations. The key requirements for these specifications are summarized in Table 3.

**Table 3. NEEA, NEEP, and ENERGY STAR Specifications for CCHP Designation**

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

[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

**Benefits of CCHPs.** Compared with conventional ASHPs, 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. Furthermore, variable capacity output provides improved comfort and efficiency through reduced cycling at mild temperatures and partial loads for both heating and cooling.

**Challenges for CCHPs.** While CCHPs offer some benefits for homes in colder climates, they do have some limitations. While the low temperature performance of CCHPs 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).

Ductless CCHPs can face challenges in serving as the sole source of heating without any auxiliary system. While many ductless CCHP models can comfortably meet the heating load of homes in PSE's territory (by providing 100% of rated capacity at 5°F), they may face challenges with adequately distributing conditioned air throughout a home (as ductless CCHPs do not use an existing central distribution system). As it is neither cost-effective nor technically sound (due to oversizing) to place ductless indoor units in all rooms in a home, rooms without indoor units or that have limited airflow to zones with indoor units may be unevenly heated/cooled. It is common to use electric resistance baseboards in small rooms like bathrooms where placing an indoor unit is infeasible to address comfort concerns, though this adds to installation and operating costs. These added systems (and other backup systems, such as in partial displacement applications) are typically not installed with an integrated controls package in PSE's market and will require separate thermostats or controls for each system.

As noted above, variable capacity output can reduce cycling and improve efficiency and comfort compared with single- and dual-stage heat pumps, though 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 (such as those between 45°F and 50°F or more). Furthermore, CCHPs have a considerable cost premium (see the *Costs of CCHPs and Other Heat Pump Technologies* section below), and despite the widespread availability of cold-climate models (NEEP's Cold Climate Air Source Heat Pump qualifying products list includes over 40,000 entries), awareness at both the customer and contractor levels remains low.[6]

**CCHPs and the Use of Backup Heating**

While certified for cold-climate efficiency, only some CCHPs may be suitable for providing whole-building heating without the use of backup heating such as integrated electric resistance or a dual-fuel natural gas furnace. While some CCHP models can provide 100% of rated heating capacity at 47°F, when at 5°F many models, particularly centrally ducted models, can only provide 60% to 70% of rated capacity at 5°F and approximately 80% to 90% of rated capacity at 24°F (the heating design temperature for Seattle and Tacoma). Depending on the design of the system, backup heating may be necessary to meet heating requirements. The figure below illustrates the average capacity by outdoor temperature of a central CCHP with a rated heating capacity of 30,000 Btu/h at 47°F (shown by the gray line).[7] The orange line represents the illustrative heating demand for a home with a design heating load of 24,000 Btu/h at 24°F. The shaded area indicates the heating demand that will need to be met by supplemental heat as the heat pump capacity declines relative to outdoor temperature.

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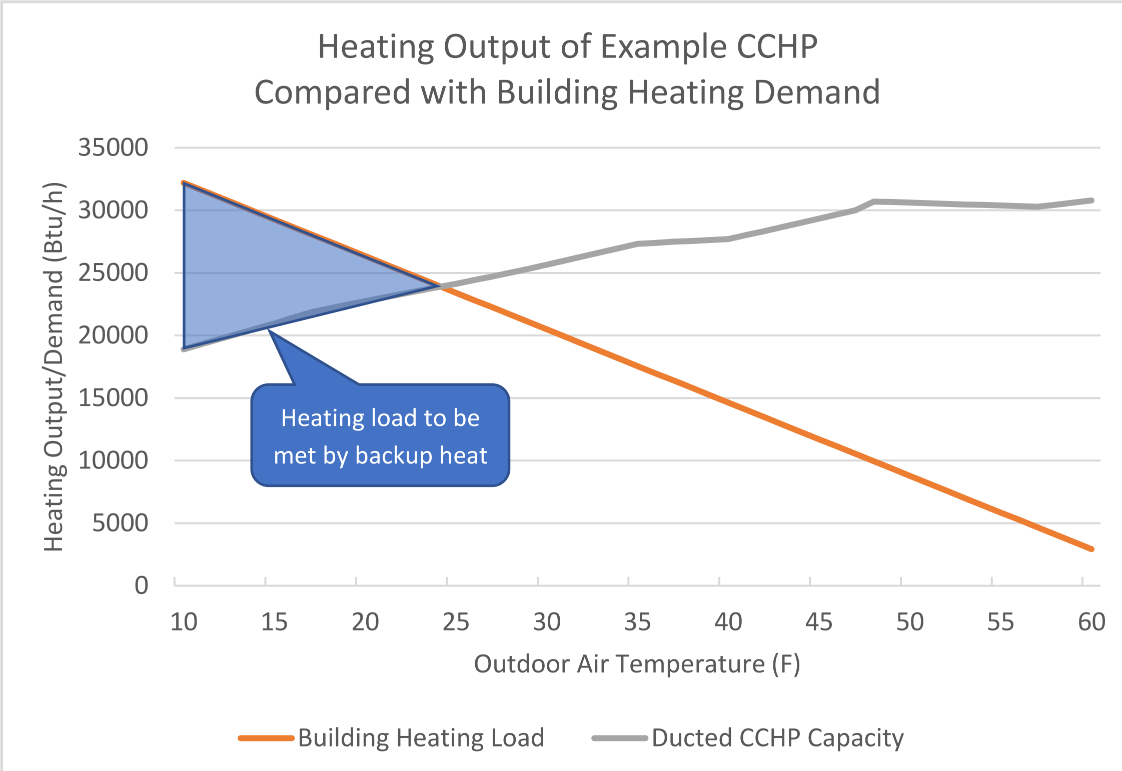
6 Johnson Consulting Group. August 24, 2021. *Ductless Heat Pumps 2020 Long-Term Monitoring and Tracking Report*. Prepared for Northwest Energy Efficiency Alliance. https://neea.org/img/documents/Ductless-Heat-Pumps-2020-Long-Term-Monitoring-and-Tracking-Report.pdf

7 Cadmus analyzed manufacturer-provided performance data from 10 CCHP models from five market-leading manufacturers to estimate central heat pump capacity by temperature.




While heating design temperatures in PSE's territory primarily range from 20°F to 25°F, homes farther inland in Kittitas County will have lower design temperatures (5°F to 10°F). If an appropriate CCHP is selected, supplemental electric resistance usage would be relatively low in most of PSE's territory, with higher impacts in colder regions. Sizing of equipment can limit the use of supplemental heating: in this example, the heat pump selected for the building heating load is sized in a manner such that backup heat is generally unneeded until the temperature drops below 25°F. A heat pump that has a capacity of 6,000 Btu/h less than this example might need to use backup heat starting below 30°F.

**Installations of CCHPs.** The widespread installation of CCHPs has been limited in much of PSE's territory; many of the contractors Cadmus interviewed as part of 2023 IRP CPA were not very familiar with CCHPs. A 2018 market study Cadmus conducted on behalf of NEEA indicated that less than 40% of ductless heat pumps (DHPs) installed in Heating Zone 1 (which has less than 6,000 heating degree days) were cold climate, while installers in colder regions of NEEA's territory (such as Idaho and Montana) reported that 90% of DHP installations were cold climate.[8]

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[8] Cadmus. November 14, 2019. *Northwest Ductless Heat Pump Initiative: Market Progress Evaluation #8.* Prepared for Northwest Energy Efficiency Alliance. https://neea.org/Northwest-Ductless-Heat-Pump-Initiative.pdf

## Measuring Performance

The actual performance of heat pumps has typically been lower than rated efficiencies as measured by HSPF, the standard metric of performance. As discussed above, third-party organizations and ENERGY STAR have attempted to use both HSPF and other requirements to better capture the details of heat pumps that are expected to maintain efficient performance in colder climates, including a tested COP at 5°F. This subsection discusses common ratings and measurements of performance for heat pumps and their limitations.

- **HSPF** is a standard metric of efficiency used by AHRI 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). This seasonal estimate is determined based on steady-state tests at 47°F and 17°F, as well as on a frost accumulation test conducted at 35°F at a relative humidity of approximately 80%, based on the climate expected in Climate Zone 4.[9] In 2022, the U.S. DOE created **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 due to the increased static pressure required for test conditions.[10]
- **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 (such as COP ≥1.75 at 5°F) or as a seasonal measure of efficiency (total heating energy out divided by energy in). Field studies of heat pump performance typically report seasonal heating performance as seasonal COP (or sCOP).

Field studies of CCHP performance in the Northeast have typically demonstrated average **sCOPs of 2.2 to 2.6** (equivalent to HSPF 7.5 to HSPF 8.9) in climate zones 4 through 6,[11] representing a reduction of 12% to 26% below the rated HSPF. The applications for the CCHPs metered in these studies have varied, with most field studies typically assessing supplemental heating installations or installations where the CCHP served as a primary heating system with the existing system used for backup (which are more common than whole-building heat pumps without supplemental heating in the Northeast). Cadmus'

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9 Oak Ridge National Laboratory. August 2015. *Review of Test Procedure for Determining HSPF's of Residential Variable-Speed Heat Pumps.* ORNL/TM-2015/387. https://info.ornl.gov/sites/publications/files/Pub56987.pdf

10 Bullock, Sara. September 2, 2022. "The Impacts of SEER2 and HSPF2." *Ekotrope.* https://www.ekotrope.com/blog/the-impacts-of-seer2-and-hspf2

11 Cadmus. April 22, 2022. "Residential ccASHP Building Electrification Study." PowerPoint presentation. https://e4thefuture.org/wp-content/uploads/2022/06/Residential-ccASHP-Building-Electrification_060322.pdf
The Levy Partnership, Centsible House, and Frontier Energy. January 2022. *Downstate Air Source Heat Pump Demonstration.* https://www.levypartnership.com/Downstate-ASHP_Demonstration.pdf
Cadmus. December 30, 2016. *Ductless Mini-Split Heat Pump Impact Evaluation.* https://ma-eeac.org/wp-content/uploads/Ductless-Mini-Split-Heat-Pump-Impact-Evaluation.pdf
Cadmus. November 3, 2017. *Evaluation of Cold Climate Heat Pumps in Vermont.* https://vermont.gov/Energy_Efficiency/Reports/Evaluation-of-Cold-Climate-Heat-Pumps.pdf

recent field study in Massachusetts and New York included 23 homes where the heat pump was used as the sole source of heating. While this study was not statistically significant, it estimated a sCOP of 2.38 for whole-home installations, which was approximately 29% lower than the sCOP predicted by the rated HSPF of the equipment installed. As the climate in most of PSE's territory is milder than the climate in the Northeast, higher sCOPs may be expected, especially in PSE's service area.

## Winter Peak Loads from Electrification: CCHP Impacts

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). As previously discussed, actual winter outdoor air temperatures in much of PSE territory may not actually reach 5°F even during periods of extreme cold (beyond standard winter peak conditions). During typical PSE winter peak conditions, demand reductions from CCHPs compared with non-CCHPs may be modest (and minimal compared with higher-efficiency non-CCHPs), assuming use only of the heat pump and not of 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 DHPs 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. As discussed above, 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, such as 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 a backup natural gas furnace (as the systems cannot run simultaneously). From a heat delivery perspective, conventional heat pumps with resistance backup will typically be sized 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. Some contractors may also size heat pump equipment for the peak cooling load rather than the larger peak heating load, which may lead to a high balance point temperature. The contractors Cadmus interviewed for the previous phase of work said they primarily use pre-set numbers or manufacturer-provided calculators to determine balance points.

Ductless CCHPs are not installed with integrated electric resistance backup (though, as discussed above, some customers will choose to install electric resistance zonal heating in spaces that are not directly served with ductless indoor units) and they operate with steadily decreasing efficiency (and increasing demand) as outdoor air temperature declines. Ductless CCHPs are expected to provide demand reduction compared with 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. In our previous analyses of dual-fuel systems, Cadmus has used a switchover temperature of 35°F, which is consistent with the Washington State Energy Code[12] and limits the system's operation in defrost mode, which occurs with greater frequency below 35°F. Other modeling has used a switchover of 30°F,[13] while some PSE staff have reported hearing that contractors use 40°F.

Backup heating may be used more if the occupant is using setbacks: as discussed above, many systems will use auxiliary heat if the difference between the indoor air temperature and the thermostat setpoint exceeds the programmed limit or if the setpoint is not reached after a certain period of time. For ducted CCHPs with electric backup, this may lead to significant demand spikes, particularly during the morning peak period (as most setbacks are overnight); for heat pumps with natural gas backup, this may lead to switching to the natural gas furnace more frequently, resulting in further demand reduction (and increased natural gas consumption). For DHPs without a backup system, the system will run at maximum output (and maximum demand) to meet the setpoint as quickly as possible. For these reasons, and because of overall seasonal efficiency and customer comfort, utility programs typically recommend that customers do not use regular overnight setbacks after installing a heat pump measure, instead suggesting a "set-and-forget" approach.[14]

For PSE's defined winter peak period (the average demand from 7 a.m. to 9:59 a.m. and from 5 p.m. to 6:59 p.m. on weekdays in December) in the actual meteorological year (AMY) 2022 data, approximately

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12 Washington State Building Code Council. July 1, 2020. *Washington State Energy Code – Residential: 2018 Edition*. "Chapter 51-11C WAC." R403.1.2 Heat Pump Supplementary Heat. https://sbcc.wa.gov/sites/default/files/2021-01/2018%20WSEC_R%20Final%20package2.pdf

13 Energy and Environmental Economics. May 2022. *Financial Impact of Fuel Conversion on Consumer Owned Utilities and Customers in Washington*. https://www.commerce.wa.gov/Financial-Impact-of-Fuel-Conversion-on-Consumer-Owned-Utilities-and-Customers-in-Washington.pdf

14 Equipment manufacturers and utility program administrators in cold-climate territories frequently promote a "set-and-forget" strategy for thermostat setbacks, discouraging the use of regular overnight setbacks that are typically encouraged for conventional equipment.
Mass Save. n.d. "Air Source Heat Pump User Tips." MSRRHPIR-0122. https://www.masssave.com/-/media/Files/PDFs/Save/Residential/HeatPump/Air-Source-Heat-Pump-User-Tips.pdf
Efficiency Maine. November 1, 2022. "Heat Pump User Tips." https://www.efficiencymaine.com/docs/Heat-Pump-User-Tips.pdf

35% of hours were at or below 35°F (when backup electric resistance usage starts to increase) and 10% of hours were at or below 27°F (peak design temperature conditions for PSE). Using the existing single-family home as an example and the analysis conducted to develop load shapes (see the *Methodology for Creating Heat Pump Load Shapes* section below), Table 4 and Table 5 show estimates of the average winter peak demand for ducted and ductless CCHPs compared with non-CCHPs, respectively.

**Table 4. Average Winter Peak Demand in Kilowatts from Ducted CCHP Compared with 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 |

**Table 5. Average Winter Peak Demand in Kilowatts from Ductless CCHP Compared with 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 |

This analysis indicates that CCHPs can provide peak demand savings relative to non-CCHPs:

- As shown in Table 4, peak demand savings are driven by two components: (1) improved efficiency of the heat pump component, and (2) reduced electric resistance usage due to a lower balance point for CCHPs. Heat pump demand is higher during the coldest period for the CCHP because a greater proportion of the heating delivered comes from the heat pump (at a higher efficiency than electric resistance), which also reduces the amount of electric resistance needed. As a result, peak demand savings from CCHP compared with non-CCHP increases during colder periods.
- Ductless CCHP has the lowest peak demand due to not having electric resistance. Non-CCHP ductless systems have approximately 42% higher peak demand during the coldest period, while non-CCHP ducted systems have approximately 17% higher peak demand during the coldest period.
- While the peak demand reduction for ducted CCHP systems may appear modest, cold-climate designation (see the *Recent Performance Trends* section) focuses only on efficiency and capacity at 5°F and seasonal efficiency (HSPF2). As most of PSE’s territory is in Climate Zone 4 and does not approach 5°F in a typical year, many of the efficiency benefits of CCHP are not realized when over 80% of hours during PSE’s peak period are above 32°F. Moreover, on an HSPF2 basis, a ducted non-CCHP is expected to use 8% more electricity annually than a ducted CCHP meeting U.S. Environmental Protection Agency HSPF2 requirements.

Tables for all other segment, vintage, and equity combinations are provided in *Appendix B: Winter Peak Demand Estimates from Electrification*.

## Methodology for Creating Heat Pump Load Shapes

Cadmus created the heat pump load shapes for each residential segment (single family, multifamily, and manufactured) by using data from the National Renewable Energy Laboratory's (NREL) ResStock analysis tool,[15] corresponding temperature data, and field data we collected in Massachusetts and New York,[16] along with PSE-specific customer data. Additionally, we conducted weather-normalized regression analyses for the heating and cooling load shapes generated from ResStock's 2018 AMY weather file to convert to PSE's 2022 weather data (as requested by PSE staff). The methodology is detailed in *Appendix C: Methodology for Creating Load Shapes* and summarized below.

Cadmus converted the gas furnace and central air conditioner (AC) profiles from ResStock housing (calibrated to PSE equipment end-use energy consumption and efficiency mixes) to CCHP and non-CCHP profiles for both ducted and ductless equipment, assuming the heat pumps would need to deliver the same amount of hourly heating and cooling as the modeled natural gas furnace and central AC. We then completed further calculations to estimate the capacity, use of backup electric resistance, and efficiency at given outdoor air temperatures to develop complete load shapes. These calculations are described below.

**Capacity.** Since heat pumps lose heating capacity as outdoor air temperature declines, the heat pumps modeled will not be able to supply the same amount of heating as the modeled furnace at all temperature points in a typical year without oversizing or using backup heat. The exception is the ductless CCHP, as there are many widely available ductless CCHP models that maintain 100% of rated capacity at 5°F. We reviewed the manufacturer-published engineering data for 10 CCHPs and 10 non-CCHPs from five market-leading heat pump manufacturers to estimate the capacity of an average CCHP and non-CCHP by outdoor temperature, developing capacity curves estimating the reduction in heating capacity by outdoor air temperature relative to 100% of rated capacity at 47°F, as shown in Figure 2.

Note that Figure 2 only illustrates the percentage of rated heating capacity (at 47°F) that is expected to be provided by the heat pump portion of CCHP and non-CCHP systems as outdoor air temperature declines. It does not illustrate the efficiency of heat delivery at outdoor air temperature, nor does it illustrate the degree of electric resistance backup that would be needed to meet heating demand at given outdoor air temperatures.

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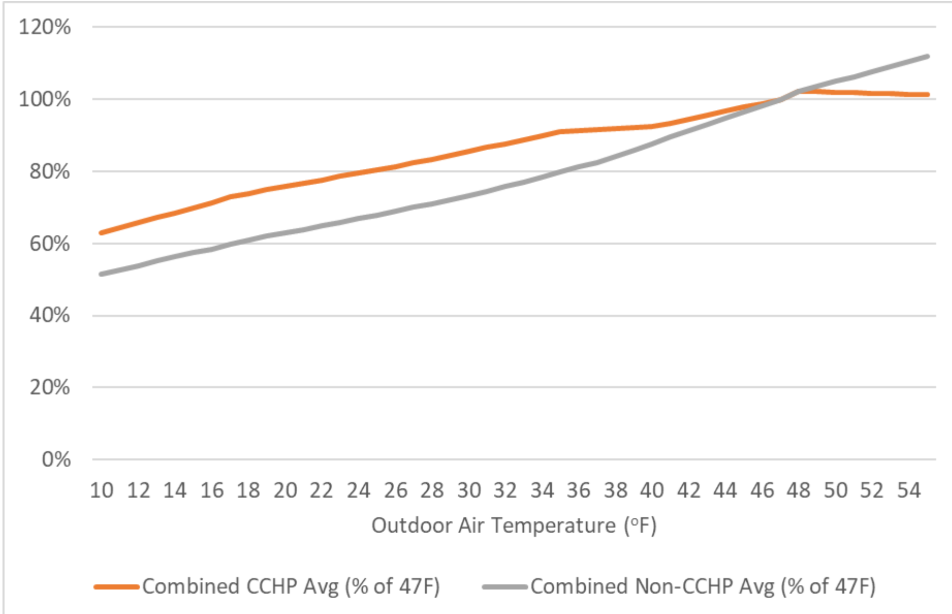
15 National Renewable Energy Laboratory. Accessed February 19, 2023. "ResStock Analysis Tool." https://www.nrel.gov/buildings/resstock.html (data available at https://data.openei.org/s3_viewer?bucket=oedi-data-lake&prefix=nrel-pds-building-stock).

16 Cadmus. April 22, 2022. "Residential ccASHP Building Electrification Study." PowerPoint presentation. https://e4thefuture.org/wp-content/uploads/2022/06/Residential-ccASHP-Building-Electrification_060322.pdf

**Figure 2. Example Capacity Curve for Ducted CCHP vs. Non-CCHP (as a percentage of capacity at 47°F)**




To estimate the building heating load at design conditions, Cadmus sized equipment to ensure a balance point of approximately 30°F to 35°F (as electric resistance usage is not necessary until temperatures are below 35°F) in accordance with typical contractor practices, combined with an analysis of degree-hours and annual natural gas usage. We assumed equipment sizing in half-ton increments (due to limited available equipment size), with a minimum equipment capacity of 2 tons (24,000 Btu/h). Additionally, we oversized ductless systems for certain building segments due to technical limitations from the sizes of heat pumps with the number of indoor units needed to sufficiently distribute conditioned air throughout the building.

**Use of backup electric resistance.** Where heat pump capacity is inadequate to meet the heating needs of the building, backup electric resistance is used for the ducted CCHP and non-CCHP to supplement the heat pump.[17] For ductless systems, we assumed that the ductless CCHP will not use backup electric resistance and that the ductless non-CCHP will use supplemental electric resistance (through space heaters or added baseboards in small rooms) to meet the load.

**Efficiency by outdoor temperature.** To develop an electric load shape after the heat pump retrofit, we developed efficiency curves by outdoor air temperature bin for CCHPs and non-CCHPs. We first used COP versus outdoor air temperature data we had collected for our field study conducted in Massachusetts and New York,[18] where we metered 43 homes using CCHPs over the course of the 2020-

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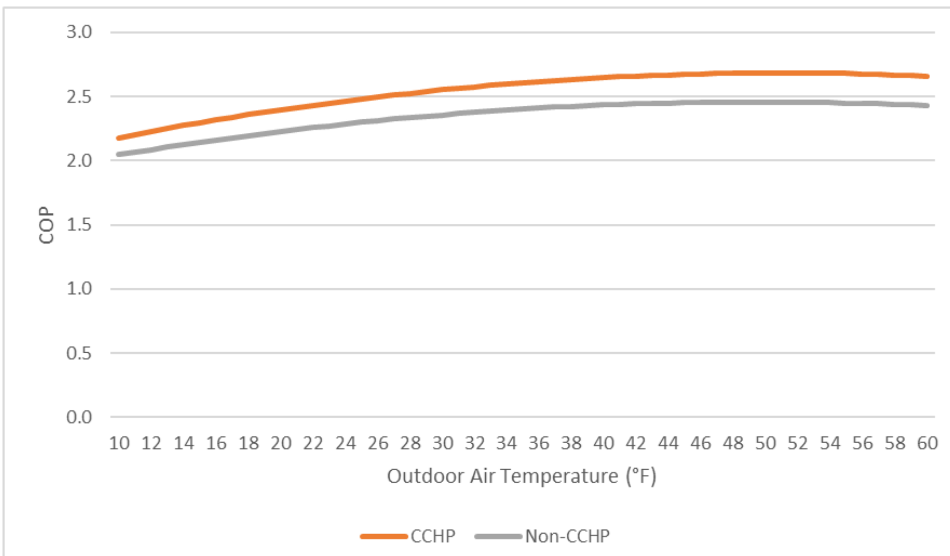
17 Supplemental electric resistance is also used by ducted heat pump systems during defrost cycles (to avoid the disruption of customer comfort when the heat pump is running in defrost) and to quickly meet the increase in the thermostat setpoint. Estimates of these impacts are not included.

18 Cadmus. April 22, 2022. "Residential ccASHP Building Electrification Study." PowerPoint presentation. https://e4thefuture.org/wp-content/uploads/2022/06/Residential-ccASHP-Building-Electrification_060322.pdf

2021 heating season to develop a curve to predict the heat pump's efficiency at any given temperature. To develop a non-CCHP curve, we used manufacturer engineering data from the 10 CCHPs and 10 non-CCHPs to compare expected CCHP and non-CCHP COPs at different temperature points. As field studies have demonstrated that manufacturer efficiency data overstates real-world performance (see the *Measuring Performance* section above), we developed a similar COP curve for non-CCHP by applying the difference between CCHP and non-CCHP COPs by the temperature predicted in the manufacturing data to the CCHP COP curve derived from the Cadmus CCHP field study.

These two curves are shown in Figure 3.[19] Ductless and ducted systems are assumed to have the same COP by outdoor temperature. Note that this figure only shows the expected COP of the heat pump component and does not include the impact of electric resistance (which has a COP of 1) on the overall COP. As applied to develop the load shapes with electric resistance included, CCHPs had sCOPs of 2.60 to 2.64 and non-CCHPs had sCOPs of 2.37 to 2.43.

**Figure 3. COP Curves by Outdoor Air Temperature (Heat Pump Only)**




To estimate heat pump electricity consumption for heating and to develop the heat pump load shapes, we divided the heat expected to be delivered at each hour by the heat pump by the estimated COP and any electric resistance usage (at a COP of 1). We created 48 load shapes using this approach, with ducted/ductless and cold-climate/non-cold-climate load shapes for each of the 12 segment/vintage/equity combinations. These load shapes are presented in *Appendix A: Heat Pump Load Shapes*. Figure 4 shows the ducted CCHP load shape for the single family (standard) segment and for existing construction as an example. Figure 5 shows the ducted non-CCHP load shape for the same segment.

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19 Based on this analysis, non-CCHP systems are expected to be 4-9% less efficient than CCHPs. Given the reliance on manufacturer testing data, this approach may underestimate the efficiency benefits for CCHPs compared with non-CCHPs from variable capacity vs. single stage compressors, particularly at milder temperatures.

**Figure 4. Ducted CCHP Load Shape for Single-Family (standard) Segment and for Existing Construction**

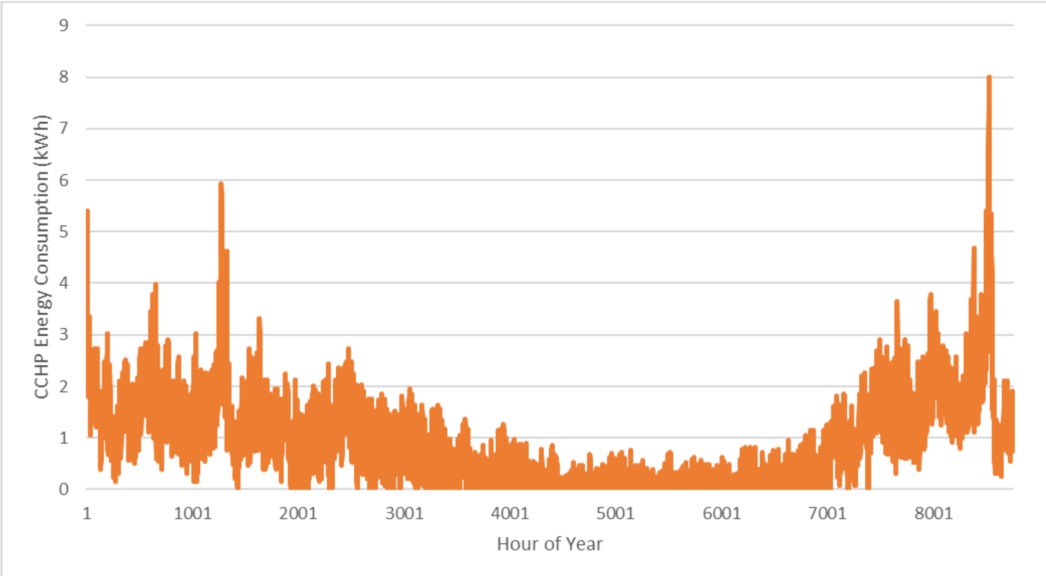
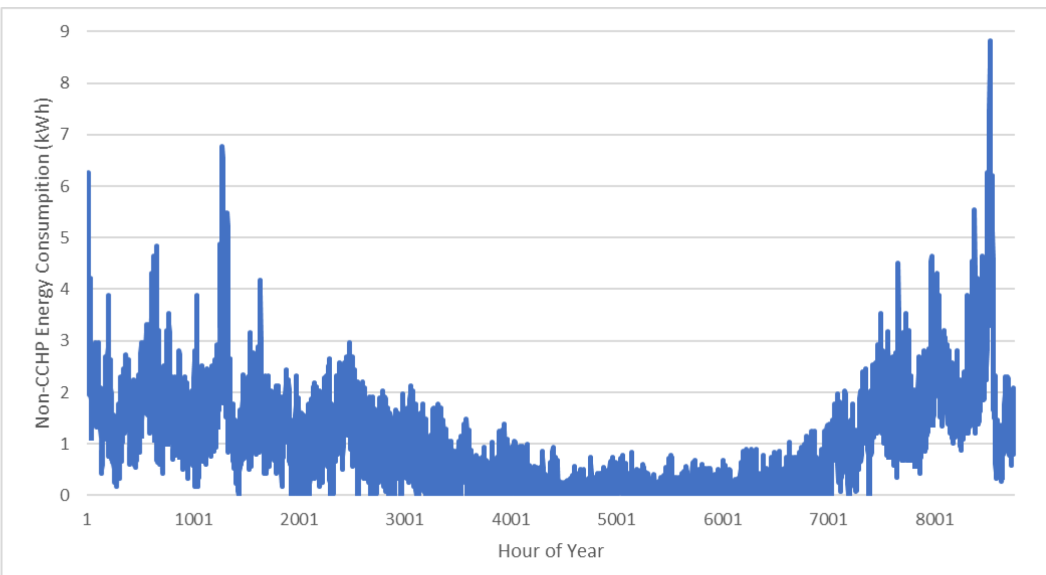



**Figure 5. Ducted non-CCHP Load Shape for Single-Family (standard) Segment and for Existing Construction**




## Costs of CCHPs and Other Heat Pump Technologies

As part of 2023 IRP CPA, in March and April 2022, Cadmus interviewed 12 HVAC contractors participating in PSE's energy efficiency incentive programs to estimate the costs of baseline ductless and centrally ducted heat pumps, as well as adders for higher-efficiency and cold-climate installations.[20] Equipment cost estimates for the typical heat pump installations are summarized in Table 6. The

[20] Cadmus. December 28, 2022. *Comprehensive Assessment of Demand-Side Natural Gas Resource Potential (2024–2050) Conservation Potential Assessment.* Prepared for Puget Sound Energy.

detailed version of this table including panel upgrades, wiring, and duct/pad costs are provided in *Appendix D: Costs of CCHPs and Other Heat Pump Technologies*.

**Table 6. Cost Estimates for Typical Heat Pump Installations**

| Equipment | Equipment Cost | Cost Unit |
|---|---|---|
| **Centrally Ducted ASHP** | | |
| Centrally Ducted ASHP – Base | $14,800 | per unit |
| Centrally Ducted ASHP – Dual Stage | $17,175 | per unit |
| Centrally Ducted ASHP – ENERGY STAR | $17,800 | per unit |
| Centrally Ducted ASHP – Cold Climate | $19,425 | per unit |
| Centrally Ducted ASHP – Dual Fuel | $11,277 | per unit |
| Centrally Ducted ASHP + Furnace – Dual Fuel | $16,250 | per unit |
| **Ductless Mini-Split Heat Pump** | | |
| Ductless Mini-Split Heat Pump – Base | $4,481 | per ton |
| Ductless Mini-Split Heat Pump – ENERGY STAR | $4,962 | per ton |
| Ductless Mini-Split Heat Pump – Cold Climate | $7,041 | per ton |

Source: Cadmus. December 28, 2022. *Comprehensive Assessment of Demand-Side Natural Gas Resource Potential (2024–2050) Conservation Potential Assessment.* Prepared for Puget Sound Energy.

Based on a further review of the contractor interview findings and analysis of other heat pump markets,[21] it is more appropriate to use a lower cost premium for ductless CCHPs over baseline DHPs for several reasons:

- **The equipment cost premium is more limited than what is reported by the contractors.** In comparing DHP models from similar manufacturers with both cold-climate and non-cold-climate options, online cost premiums ranged from $200 to 1,000 per unit, depending on capacity.[22] Equipment cost is the primary driver of higher costs between a cold-climate and non-cold-climate installation of the same capacity, with limited differences in labor and other soft costs.
- **Low market penetration may enable contractors to charge higher premiums.** Since ductless CCHPs are not frequently installed in PSE's territory, contractors may be able to offer them as a premium product at a higher cost, well beyond the equipment cost premium.
- **Contractors with more experience installing CCHPs reported lower cost premiums.** Contractors' cost estimates for the cold-climate premium for DHPs—and their familiarity with and frequency of installing ductless CCHPs—varied significantly: some of the interviewed contractors were not very familiar with CCHPs and tended to propose substantially higher overall cost premiums for installing ductless CCHPs than those who reported frequently installing ductless CCHPs.

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21 Cadmus. December 28, 2022. *Comprehensive Assessment of Demand-Side Natural Gas Resource Potential (2024–2050) Conservation Potential Assessment.* Prepared for Puget Sound Energy.

22 This information was based on searches of Mitsubishi, Fujitsu, and Daikin equipment from three HVAC retailers of cold-climate and non-cold-climate ductless heat pumps that have similar nameplate capacities and model lines.

- **Markets with greater installations of CCHPs have lower cost premiums.** In markets in the Northeast where CCHPs are frequently installed, cost premiums are lower than what was reported by the contractors. A 2018 study in Massachusetts estimated a cost premium of approximately $400 for a 1-ton ductless CCHP over a baseline efficiency DHP, and an approximate $100 premium over a higher-efficiency DHP (adjusted for inflation).[23]

Given the expectation of a greater emphasis on CCHPs in the revised assessment, we expect contractors to become more familiar with CCHPs and to install them more frequently (to meet future incentive requirements). Under these market conditions, the very high cost premiums observed through contractor interviews will decline, eventually aligning with the costs observed in markets where CCHP installation is more common. As a result, it is more reasonable to use a $601 per ton cost premium for ductless CCHPs over the baseline efficiency DHP (representing a $120 per ton cost premium over ENERGY STAR DHPs).[24]

Table 7 presents the equipment costs used in this study. As mentioned before, these costs along with panel upgrades, wiring, and duct/pad costs are presented in detail within *Appendix D: Costs of CCHPs and Other Heat Pump Technologies*.

23 Navigant Consulting, Inc. October 5, 2018. *Ductless Mini-Split Heat Pump Cost Study (RES 28).* Prepared for the Electric Program Administrators of Massachusetts. https://ma-eeac.org/RES28_Assembled_Report_2018.pdf

24 Contractor interviews found ductless cold climate heat pumps to be $7,041 per ton. Cadmus research found lower costs in more active markets, as a result Cadmus adjusted ductless cold climate heat pumps to $5,082 per ton to better align with other markets for this study. Contractor estimates for ducted CCHP premiums better align with expectations observed in other markets, as a result Cadmus did not any further adjustment. The ducted cold climate heat pump cost premium is primarily due to the replacement of a single- or dual-stage compressor with a variable-speed inverter compressor, which increases the cost of the system by a few thousand dollars.

**Table 7. Cost Estimates for Typical Baseline Technologies, Heat Pumps, and Conversion Equipment Costs Used in This Study**

| Equipment | Average Cost per Unit |
|---|---|
| **Baseline Technologies** | |
| Natural Gas Furnace | $5,380 |
| Natural Gas Boiler | $9,500 |
| Natural Gas Wall Unit | $3,513 |
| Central Air Conditioner | $8,450 |
| **Centrally Ducted ASHP** | |
| 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 Pump** | |
| Ductless Heat Pump – Base | $13,174 |
| Ductless Heat Pump – ENERGY STAR | $14,588 |
| Ductless Heat Pump – Cold Climate | $14,941 |
| **Conversion Costs** | |
| Panel Upgrade (average range) | $1,668 |
| Duct configuration (when existing system does not have AC ducts) | $1,400 |
| Wiring | $250 |

Note: Average central AC and dual-fuel heat pump capacities were reported at 2.79 tons. Average ductless and ducted heat pump capacities were reported at 2.94 tons.

Source: Cadmus. December 28, 2022. *Comprehensive Assessment of Demand-Side Natural Gas Resource Potential (2024–2050) Conservation Potential Assessment.* Prepared for Puget Sound Energy.

For this study, Cadmus modeled replacement costs at the time of equipment failure; therefore, the base equipment cost is compared to the converted electric equipment cost and represents the incremental costs that a customer would have to pay (without incentives or tax credits). As an example shown in Table 7, an existing home with a furnace and central AC would cost roughly $13,800 to replace. A standard ASHP costs roughly $14,800. Assuming that minimal wiring is required, the incremental cost would range from $1,000 to $1,200. To provide context, Cadmus used these incremental cost assumptions for roughly 16% of existing single-family homes (representing homes with existing AC). We used these incremental costs as part of the levelized costs calculations for each measure that informed PSE's IRP optimization modeling. Details of the levelized costs calculation methodology can be found in the *Levelized Costs Calculations* section of this report.

## *Inflation Reduction Act Research*

This section summarizes the findings of IRA research conducted by Cadmus. It starts with a summary of heat pump and other electrification incentives provided under the IRA and the mechanisms of making these incentives available to public and ends with a discussion of the impact of IRA incentives on TRC levelized cost calculations.

## Implementation of Inflation Reduction Act in Washington State

The IRA is one of the major federal initiatives that have been created in recent years with a focus on building decarbonization by dedicating $500 billion to clean energy investments and lowering carbon emissions.[25] The IRA includes rebates and tax incentives geared to helping homeowners make decisions about their energy usage that will result in more efficient appliances and systems within their homes. These monetary and regulatory incentives are expected to drive changes within the energy industry, as well as for other sectors pursuing building decarbonization in the coming years.

Within the IRA, the High Efficiency Electric Homes Rebates Act (HEEHRA) is largely focused on providing rebates to income-eligible consumers for electric equipment and electrification projects. The Home Energy Performance-Based, Whole House Rebates (HOMES Rebate) program provides rebates for homeowners based on whole-house energy retrofits. States will apply to the U.S. DOE for funding to implement HEEHRA and the HOMES Rebate program through their respective state agencies.[26] According to the Washington State Department of Commerce, the U.S. DOE is expected to release rebate funds to states in the summer of 2023, and rebates for both programs will be available in early 2024.[25] Expanded tax credits are available through the IRA as of January 2023, which will mainly benefit homeowners who have sufficient tax liability and the financial flexibility to purchase eligible products and wait until they obtain their tax returns to receive the benefits from these programs. Table 8 presents a high-level summary of the retrofit incentives for single and multifamily homes based on the IRA programs.[27] The measure-level incentives provided by some of these programs are presented in detail in the *Heat Pump and Other Electrification Incentives in Inflation Reduction Act* subsection below.

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[25] Washington State Department of Commerce. Accessed February 19, 2023. "Home Energy Rebates." https://www.commerce.wa.gov/growing-the-economy/energy/federal-funding-for-buildings/

[26] Congressional Research Service, November 28, 2022. "The Inflation Reduction Act: Financial Incentives for Residential Energy Efficiency and Electrification Projects." *In Focus* (12258). https://crsreports.congress.gov/product/pdf/IF/IF12258/2?itid=lk_inline_enhanced-template

[27] American Council for an Energy-Efficient Economy. September 2022. "Home Energy Upgrade Incentives: Programs in the Inflation Reduction Act and Other Recent Federal Laws." https://www.aceee.org/sites/default/files/pdfs/home_energy_upgrade_incentives_9-27-22.pdf

**Table 8. Summary of Retrofit Incentives for Single-Family and Multifamily Buildings in Recent Federal Legislation**

| Program | Funding | Distribution Method | Timeline | Eligible Participants | Eligible Projects | Incentive Amount |
|---|---|---|---|---|---|---|
| HOMES Rebate (U.S. DOE, to be implemented by Washington State Energy Office) [a] | $4.3 billion and ($83.3 million WA portion) | Rebates via SEOs | After U.S. DOE guidance, state application, and program design | Homeowners and landlords, all income levels (or aggregators) including multifamily | Whole-home retrofit projects that reduce modeled energy use at least 20% (15% for measured) | 50% of cost up to $2,000 or $4,000 (depending on savings achieved), doubled for households below 80% of AMI |
| HEEHRA (U.S. DOE, to be implemented by Washington State Energy Office) [a] | $4.5 billion includes $0.225 billion for tribes ($82.8 million WA portion) | Rebates via SEOs and tribes (may be taken by contractor and offered at point of sale) | After U.S. DOE guidance, state application, and program design | Residents, building owners, or contractors, for households below 150% of AMI | Electrical equipment and infrastructure and insulation; for new construction, to replace non-electric or first-time purchase | 50% of project cost for 80% to 150% AMI (100% for households below 80% of AMI) up to $14,000 total with subcaps by measure |
| WAP (U.S. DOE) | $3.5 billion in IIJA | Direct install via WAP agencies | 50% when state plans are approved | Homeowners and landlords, generally household income under 200% of FPL | Whole-home retrofit projects | Typically cost up to about $8,000 per home |
| 25C tax credit [a] | $12.5 billion CBO "score" through 2031 | Via tax returns | 2023–2032 | Homeowners (for their principal residence) | Efficient equipment and components, energy audits | 30% of cost up to $1,200 per year (+$2,000 for heat pumps and wood stoves), with subcaps by measure |
| 179D tax deduction (retrofit portion) | No separate estimate | Via tax returns | 2023–2032 | Owners of multifamily buildings over three stories (nonprofits and governments may transfer the deduction) | Retrofit projects that reduce building energy use at least 25% below minimum ASHRAE requirements | $0.50 to $5 per sq ft of floor area based on energy savings and labor standards |
| Energy efficiency in affordable housing (HUD) | $1 billion | Grants or loans and technical assist | After HUD request for proposals to 2028 | Owners of HUD-assisted affordable housing | Measures to improve energy and water efficiency, air quality, and resilience and energy benchmarking | TBD |
| Greenhouse Gas Reduction Fund (U.S. EPA) | $27 billion (total—portion for housing unknown) | Grants, loans, other financial assistance, and technical assistance | To distributing organizations 2022–2024 | Unspecified, aimed at low-income and disadvantaged communities; distributed via states, tribes, cities, and nonprofit organizations | Zero emission technologies and projects to reduce or avoid GHG emissions and other forms of air pollution | TBD |

Source: American Council for an Energy-Efficient Economy. September 2022. "Home Energy Upgrade Incentives: Programs in the Inflation Reduction Act and Other Recent Federal Laws." https://www.aceee.org/sites/default/files/pdfs/home_energy_upgrade_incentives_9-27-22.pdf

AMI=area median income; ASHRAE=American Society of Heating, Refrigerating and Air-Conditioning Engineers; CBO=Congressional Budget Office; U.S. EPA=Environmental Protection Agency; FPL=federal poverty level; GHG=greenhouse gas; HUD=Department of Housing and Urban Development; IIJA=2021 Infrastructure, Investment, and Jobs Act; SEO=state energy office; TBD=to be decided; WAP=Weatherization Assistance Program

[a] The HOMES Rebate program, HEEHRA, and the 25C tax credit are included in the analysis for this decarbonization study.

In Washington, there are also seven competitive grant opportunities provided within the two federal initiatives that offer funding for a variety of different uses, such as for training individuals to conduct energy audits and for updating building energy codes, and there are research incentives to increase the cost-effectiveness of efficient or clean energy changes.[25]

## Heat Pump and Other Electrification Incentives in Inflation Reduction Act

As mentioned above, across the various programs, the IRA provides funds for home energy improvements such as insulation, sealing, and improved heating and cooling systems. While some programs focus on whole-home retrofits, others focus on specific measures. 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, while the HOMES Rebate program and 179D tax deduction indirectly encourages electrification through incentivizing site energy use or energy cost reduction.[28] Table 9 presents the specific energy-saving measures that are incentivized through IRA rebates and tax incentives from HEEHRA and the Section 25C tax credit. In addition to these programs targeting heat pumps, ground-source heat pumps are eligible for a tax credit of up to 30% under the Section 25D tax credit (stepping down to 26% in 2033, 22% in 2034, and expiring in 2035).[29]

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28 As HEEHRA and the HOMES Rebate program are available to both homeowners and multifamily building owners, building owners may be able to combine the relevant tax incentive (25C tax credit for homeowners of principal residences, 179D for owners of multifamily buildings over three stories tall) with either the HOMES Rebate program or HEEHRA. However, the same measures cannot receive incentives from both the HOMES Rebate program and HEEHRA.

29 "§25D. Residential clean energy credit." *Code of Federal Regulations,* Title 26. https://www.govinfo.gov/content/pkg/USCODE-2021-title26/html/USCODE-2021-title26-subtitleA-chap1-subchapA-partIV-subpartA-sec25D.htm

**Table 9. Rebate and Tax Credit Summary for Specific Measures (HEEHRA and 25C Tax Credit)**

| Measure | HEEHRA | | 25C Tax Credit | |
|---|---|---|---|---|
| | Requirements | Rebate Amount | Requirement | Credit Caps |
| Overall incentive amount and limit | Household <150% AMI | **80%-150% AMI:** 50% of installation cost<br>**<80% AMI:** 100% of costs for households<br>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 for panels 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 |

Sources: "§25C. Nonbusiness energy property." *Code of Federal Regulations*, Title 26. https://www.govinfo.gov/content/pkg/USCODE-2021-title26/html/USCODE-2021-title26-subtitleA-chap1-subchapA-partIV-subpartA-sec25C.htm; 26 C.F.R. § 25C; *An Act to provide for reconciliation pursuant to title II of S. Con. Res. 14*, Public Law 117-169 (2022): 1817–2090. https://www.congress.gov/117/plaws/publ169/PLAW-117publ169.pdf

CEE=Consortium for Energy Efficiency; HHV=high heating value of fuel used; IECC=International Energy Conservation Code; IRS=Internal Revenue Service

[a] HEEHRA allows for qualified ventilation equipment to be included in the $1,600 cap.

Table 10 summarizes rebates, tax deductions, and qualifications for building owners who conduct whole-building retrofits through the HOMES Rebate program and Section 179D, as created or amended through the IRA.

**Table 10. Rebate and Tax Deduction Summary for Whole-Building Retrofits (HOMES Rebate and 179D)**

| Metric | 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 U.S. DOE-approved qualified energy modeling software<br>OR savings relative to building baseline EUI based on a qualified retrofit plan |
| Percentage of project cost | ≥80% AMI: 50%<br><80% AMI [c]: 80% | ≥80% AMI: 50%<br><80% AMI: 80% | N/A |
| Incentive amount/cap at minimum savings level | At ≥20% energy savings:<br>• ≥80% AMI: 50% of project cost up to $2,000 per home or dwelling unit, up to $200,000 per multifamily building<br>• <80% AMI: 80% of project cost up to $4,000 per home or dwelling unit, up to $400,000 per multifamily building<br>At ≥35% energy savings:<br>• ≥80% AMI: 50% up to $4,000 per home or dwelling unit, up to $400,000 per building<br>• <80% AMI: 80% up to $8,000 per 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<br>The $2,000 incentive earned for 20% energy savings can increase or decrease based on actual savings realized (no cap) | Base Rate: $0.50 per sq ft at 25% savings increasing on sliding scale to $1 per sq ft at 50% savings<br>Bonus Rate [d]: $2.50 per sq ft at 25% savings increasing on sliding scale to $5 per sq ft at 50% savings |
| Contractor rebate | $200 for each home in a disadvantaged community | | N/A |

Sources: "§179D. Energy efficient commercial buildings deduction." *Code of Federal Regulations*, Title 26. https://www.govinfo.gov/content/pkg/USCODE-2021-title26/html/USCODE-2021-title26-subtitleA-chap1-subchapB-partVI-sec179D.htm; Inflation Reduction Act, Public Law 117-169 (2022): 1817—2090.

AMI=Area Median Income; ASHRAE=American Society of Heating, Refrigerating and Air-Conditioning Engineers; BPI=Building Performance Institute; EUI=Energy Use Intensity

[a] Applies only to multifamily buildings of at least four stories (ASHRAE 90.1 standard).

[b] For buildings placed in service before 2015, the applicable standard is 90.1-2001. For buildings placed in service from 2015 through 2026, the applicable standard is 90.1-2007. For buildings placed in service after 2027, the applicable standard will be 90.1-2019 (see: Internal Revenue Service (Valdman, Rika). *Update Reference Standard 90.1 for § 179D.* Announcement 2023-1. https://www.irs.gov/pub/irs-drop/a-23-01.pdf.

[c] Includes multifamily buildings with at least 50% households that are below 80% AMI.

[d] The bonus rate is achieved if the labor used meets prevailing wage and apprenticeship requirements.

There remains uncertainty as to how the Washington State Energy Office will design the HEEHRA program, as incentive values and equipment qualification may be changed pending approval from the U.S. DOE. However, Table 11**Error! Reference source not found.** provides an illustrative example of how the combination of the 25C tax credit and the HEEHRA rebate (as written in the text of the law) could impact the net cost of the heat pump equipment examined in this analysis for a customer with a household income in the range of 80% to 150% of AMI.

While incentive values have not been determined for Washington State's implementation of HEEHRA, the combination of these tax credits and IRA rebates may be significant for reducing the upfront cost of ASHPs. Homeowners making less than 150% of AMI and with sufficient tax liability for the Section 25C tax credit may be able to install high-efficiency and/or cold-climate heat pumps at prices at or below the cost of conventional equipment. Homeowners making less than 80% of AMI will be able to maximize the HEEHRA rebate but may lack sufficient tax liability to take full advantage of the tax credit.

**Table 11. Potential Impact of 25C Tax Credit and HEEHRA Rebate on Cost of Heat Pumps (80% to 150% 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 | $11,277 | [b] | [b] | $11,277 |
| Centrally Ducted ASHP + Furnace – Dual Fuel | $16,250 | [b] | [b] | $16,250 |
| **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; *An Act to provide for reconciliation pursuant to title II of S. Con. Res. 14*, Public Law 117-169 (2022): 1817–2090. https://www.congress.gov/117/plaws/publ169/PLAW-117publ169.pdf

[a] While this table shows the HEEHRA rebate estimate for residents making 80% to 150% of AMI, residents making less than 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.

## Impact of Inflation Reduction Act Incentives on TRC Levelized Cost Calculations

The impact of non-utility incentives such as federal tax credits or rebates varies depending on which cost-effectiveness test is being performed. From the utility cost test and participant cost test perspectives, the impact is straightforward. The utility cost test does not consider the measure costs or any participant benefits, so there would be no impact. The participant cost test only considers the costs and benefits from the participant perspective: because the participant receives the federal tax credit or rebate, that credit or rebate is considered as a benefit to the participant.

The TRC test and societal cost test are more nuanced. In general, it depends on whether the funder of the tax credit or rebate is in the same designation as the recipient. Because the funders of the IRA tax credits and rebates are all U.S. taxpayers and the recipients of the credits and rebates are also U.S. taxpayers, the societal cost test cancels out the funders and recipients and there is no impact.

Applying the same comparison to the TRC test, the funders of the IRA tax credits and rebates are all U.S. taxpayers, but the recipients are PSE customers. Consequently, both the *California Standard Practice Manual*[30] and the *National Standard Practice Manual*[31] indicate that the tax incentives or rebates should be treated as a benefit. Some jurisdictions have noted this but also noted that it may be very difficult to determine whether a utility program participant has also received a federal tax credit or rebate. The final treatment will depend on how the state energy office structures their program to implement the IRA. Also, Northwest Power Act of 1980 includes a 10% adder to the avoided costs in Washington, making the TRC a hybrid between a typical TRC and a societal cost test.

30 California Public Utilities Commission. October 2021. *California Standard Practice Manual: Economic Analysis of Demand-Side Programs and Projects.* https://www.cpuc.ca.gov/cpuc-standard-practice-manual.pdf

31 National Energy Screening Project. n.d. *National Standard Practice Manual for Benefit-Cost Analysis of Distributed Energy Resources.* https://www.nationalenergyscreeningproject.org/national-standard-practice-manual/

# Chapter 2. Decarbonization Scenario Analysis

As part of this study, Cadmus assessed the per-unit impacts, in terms of decreases in natural gas usage and increases in electric energy usage, and customer costs of electrification under four different decarbonization scenarios in residential sector. We built these scenarios by converting natural gas heating equipment to heat pumps, and they differ based on the heat pump technology (ASHP, CCHP, or HHP) and the building vintage (existing or new construction), as described below. While the descriptions are for residential customers, all C&I customers have those same adoption rates across all scenarios.

**SCENARIO 1. FULL ELECTRIFICATION WITH ASHPs (SCENARIO 1 – ASHP FULL) for new and existing residential customers, similar to the Full Electrification – Policy scenario presented in the 2023 IRP CPA**

Cadmus analyzed the effects of a conversion from natural gas heating equipment to ASHPs for new and existing residential customers without keeping the natural gas heating equipment and assumed full adoption (where the market adaption rate equals 100%). 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 (SCENARIO 2 – CCHP FULL) for new and existing residential customers**

Cadmus analyzed the effects of a conversion from natural gas heating equipment to CCHP for new and existing residential customers and assumed full adoption (where the market adaption rate equals 100%). Under this scenario 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 (SCENARIO 3 – HHP) for new and existing residential customers, similar to the Hybrid Heat Pump – Policy scenario presented in the 2023 IRP CPA**

Cadmus analyzed the effects of a conversion from natural gas heating equipment to ASHPs while keeping the natural gas heating equipment as the backup for new and existing residential customers. We set the market adoption rate to the maximum where 100% of valid residential applications have a HHP or ductless system with natural gas backup. Under this scenario the end-of-life replacement of natural gas equipment with HHPs will reach 100% annual adoption within the study horizon based on future policy requirements.

**SCENARIO 4. HHP WITH ASHPs FOR EXISTING CUSTOMERS / CCHPs FOR NEW CUSTOMERS (SCENARIO 4 – HHP&CCHP)**

Cadmus analyzed the effects of a conversion from natural gas heating equipment to ASHPs while keeping the natural gas heating equipment as the backup for existing residential customers, but with a conversion from natural gas heating equipment to CCHP for new residential customers. The market adoption rate of HHPs or ductless system with natural gas backup was set at 100% for existing residential applications. All new customers were assumed to have CCHPs.

## *Natural Gas-to-Electric Equipment Overview*

Following the same methodology as used in the 2023 IRP CPA, in addition to space heating, Cadmus assessed per-unit impacts and customer costs of electrification for the water heating, cooking, and clothes dryer end uses for existing and new customers in the residential sector. For the commercial sector, we considered the water heating and cooking end uses in addition to space heating. For the industrial sector, Cadmus followed the same methodology as used in the 2023 IRP CPA by converting a portion (~30%) of natural gas loads to electric. Table 12 summarizes the assumptions used for heat pumps by scenario.

**Table 12. Heat Pump Assumptions by Scenario**

| Heat Pump Assumptions | Scenario 1 – ASHP FULL | Scenario 2 – CCHP FULL | Scenario 3 – HHP | Scenario 4 – HHP&CCHP |
|---|---|---|---|---|
| Ductless Non-CCHP (with electric resistance backup) | ✓ | | | |
| Ductless CCHP (no backup heating) | | ✓ | | ✓ |
| Ducted ASHP (with electric resistance backup) | ✓ | | | |
| Ducted CCHP (with electric resistance backup) | | ✓ | | ✓ |
| HHP (natural gas heating below balance point) | | | ✓ | ✓ |
| Balance point (°F) | 30–35 | 20–25 | 35 | 20–25/35 |
| Updated load shapes | ✓ | ✓ | ✓ | ✓ |

Table 13 through Table 16 detail the natural gas-to-electric equipment being replaced and converted under each scenario.

**Table 13. Scenario 1. Full Electrification with ASHPs – Natural Gas-to-Electric Equipment**

| Electric – Converted To | Natural Gas – Converted From | Vintage |
|---|---|---|
| **Residential** | | |
| Ductless Non-CCHP – Whole Home Central | Furnace – Full Replacement | New and Existing |
| ASHP – Whole Home | Furnace – Full Replacement without Existing AC | New and Existing |
| ASHP – Whole Home | Furnace – Full Replacement with Existing AC | New and Existing |
| Ductless Non-CCHP – Whole Home Zonal | Boiler – Full Replacement | New and Existing |
| Ductless Non-CCHP – Whole Home Zonal | Natural Gas Wall Unit – Full Replacement | New and Existing |
| Cooking Oven (Electric) – Market Average | Cooking Oven (Natural Gas) | New and Existing |
| Cooking Range (Electric) – Market Average | Cooking Range (Natural Gas) | New and Existing |
| Dryer (Electric) – Market Average, Non-HP | Dryer (Natural Gas) | New and Existing |
| Water Heat ≤55 Gal | Water Heat (Natural Gas) | New and Existing |
| Water Heat >55 Gal | Water Heat (Natural Gas) | New and Existing |
| **Commercial** | | |
| ASHP/Variable Refrigerant Flow/DHP | Natural Gas Space Heat – Full Replacement | New and Existing |
| Cooking (Electric) | Cooking (Natural Gas) | New and Existing |
| Water Heat ≤55 Gal | Water Heat (Natural Gas) | New and Existing |
| Water Heat >55 Gal | Water Heat (Natural Gas) | New and Existing |
| **Industrial** | | |
| Target Reduction Conversion of Natural Gas Load 30% Reduction | | Existing |

**Table 14. Scenario 2. Full Electrification with CCHPs – Natural Gas-to-Electric Equipment**

| Electric – Converted To | Natural Gas – Converted From | Vintage |
|---|---|---|
| **Residential** | | |
| Ductless CCHP – Whole Home Central | Furnace – Full Replacement | New and Existing |
| CCHP – Whole Home | Furnace – Full Replacement without Existing AC | New and Existing |
| CCHP – Whole Home | Furnace – Full Replacement with Existing AC | New and Existing |
| Ductless CCHP – Whole Home Zonal | Boiler – Full Replacement | New and Existing |
| Ductless CCHP – Whole Home Zonal | Natural Gas Wall Unit – Full Replacement | New and Existing |
| Cooking Oven (Electric) – Market Average | Cooking Oven (Natural Gas) | New and Existing |
| Cooking Range (Electric) – Market Average | Cooking Range (Natural Gas) | New and Existing |
| Dryer (Electric) – Market Average, Non-HP | Dryer (Natural Gas) | New and Existing |
| Water Heat ≤55 Gal | Water Heat (Natural Gas) | New and Existing |
| Water Heat >55 Gal | Water Heat (Natural Gas) | New and Existing |
| **Commercial** | | |
| ASHP/Variable Refrigerant Flow/DHP | Natural Gas Space Heat – Full Replacement | New and Existing |
| Cooking (Electric) | Cooking (Natural Gas) | New and Existing |
| Water Heat ≤55 Gal | Water Heat (Natural Gas) | New and Existing |
| Water Heat >55 Gal | Water Heat (Natural Gas) | New and Existing |
| **Industrial** | | |
| Target Reduction Conversion of Natural Gas Load 30% Reduction | | Existing |

**Table 15. Scenario 3. HHPs with ASHPs – Natural Gas-to-Electric Equipment**

| Electric – Converted To | Natural Gas – Converted From | Vintage |
|---|---|---|
| **Residential** | | |
| Ductless Non-CCHP with Backup | Furnace – Partial Replacement | Existing |
| Ductless Non-CCHP - Whole Home Central | Furnace – Full Replacement | New |
| Hybrid ASHP with Furnace Backup without Existing AC | Furnace – Partial Replacement without Existing AC | New and Existing |
| Hybrid ASHP with Furnace Backup with Existing AC | Furnace – Partial Replacement with Existing AC | New and Existing |
| Ductless Non-CCHP with Boiler Backup | Boiler – Partial Replacement | Existing |
| Ductless Non-CCHP with Natural Gas Wall Unit Backup | Natural Gas Wall Unit – Partial Replacement | Existing |
| Ductless Non-CCHP - Whole Home Zonal | Boiler – Full Replacement | New |
| Ductless Non-CCHP - Whole Home Zonal | Natural Gas Wall Unit – Full Replacement | New |
| Cooking Oven (Electric) – Market Average | Cooking Oven (Natural Gas) | New and Existing |
| Cooking Range (Electric) – Market Average | Cooking Range (Natural Gas) | New and Existing |
| Dryer (Electric) – Market Average, Non-HP | Dryer (Natural Gas) | New and Existing |
| Water Heat ≤55 Gal | Water Heat (Natural Gas) | New and Existing |
| Water Heat >55 Gal | Water Heat (Natural Gas) | New and Existing |
| **Commercial** | | |
| ASHP/Variable Refrigerant Flow/DHP | Natural Gas Space Heat – Full Replacement | New and Existing |
| Cooking (Electric) | Cooking (Natural Gas) | New and Existing |
| Water Heat ≤55 Gal | Water Heat (Natural Gas) | New and Existing |
| Water Heat >55 Gal | Water Heat (Natural Gas) | New and Existing |
| **Industrial** | | |
| Target Reduction Conversion of Natural Gas Load 30% Reduction | | Existing |

**Table 16. Scenario 4. HHP with ASHPs for Existing Customers / CCHPs for New Customers – Natural Gas-to-Electric Equipment**

| Electric – Converted To | Natural Gas – Converted From | Vintage |
|---|---|---|
| **Residential** | | |
| Ductless Non-CCHP with Furnace Backup | Furnace – Partial Replacement | Existing |
| Hybrid ASHP with Furnace Backup without Existing AC | Furnace – Partial Replacement without Existing AC | Existing |
| Hybrid ASHP with Furnace Backup with Existing AC | Furnace – Partial Replacement with Existing AC | Existing |
| Ductless Non-CCHP with Boiler Backup | Boiler – Partial Replacement | Existing |
| Ductless Non-CCHP with Natural Gas Wall Unit Backup | Natural Gas Wall Unit – Partial Replacement | Existing |
| Ductless CCHP – Whole Home Central | Furnace – Full Replacement | New |
| CCHP – Whole Home | Furnace – Full Replacement without Existing AC | New |
| CCHP – Whole Home | Furnace – Full Replacement with Existing AC | New |
| Ductless CCHP – Whole Home Zonal | Boiler – Full Replacement | New |
| Ductless CCHP – Whole Home Zonal | Natural Gas Wall Unit – Full Replacement | New |
| Cooking Oven (Electric) – Market Average | Cooking Oven (Natural Gas) | New and Existing |
| Cooking Range (Electric) – Market Average | Cooking Range (Natural Gas) | New and Existing |
| Dryer (Electric) – Market Average, Non-HP | Dryer (Natural Gas) | New and Existing |
| Water Heat ≤55 Gal | Water Heat (Natural Gas) | New and Existing |
| Water Heat >55 Gal | Water Heat (Natural Gas) | New and Existing |
| **Commercial** | | |
| ASHP/Variable Refrigerant Flow/DHP | Natural Gas Space Heat – Full Replacement | New and Existing |
| Cooking (Electric) | Cooking (Natural Gas) | New and Existing |
| Water Heat ≤55 Gal | Water Heat (Natural Gas) | New and Existing |
| Water Heat >55 Gal | Water Heat (Natural Gas) | New and Existing |
| **Industrial** | | |
| Target Reduction Conversion of Natural Gas Load 30% Reduction | | Existing |

For Scenario 3- HHP and Scenario 4 - HHP&CCHP, the converted residential space heat equipment is hybrid and partial-load replacement heat pump systems that still rely on natural gas backup heating during cold temperatures.[32] This roughly translates to 88% electric consumption and 12% natural gas consumption based on building simulations[33] using Seattle-area weather data.

## *Methodology*

Cadmus calculated the energy, peak demand, and cost impacts of converting natural gas-to-electric equipment within PSE's natural gas service territory. Because PSE's natural gas service territory includes not only PSE electric customers but also electric customers of Seattle City Light, Snohomish County Public Utility District, Tacoma Power, and Lewis County Public Utility District, PSE natural gas-to-electric customer conversion end uses will inevitably affect these other utilities' electric systems. However, for

32 Cadmus assumed a switchover temperature of 35°F based on the 2018 WSEC (R403.1.2). Washington State Building Code Council. July 1, 2020. *Washington State Energy Code – Residential: 2018 Edition*. "Chapter 51-11C WAC." R403.1.2 Heat Pump Supplementary Heat. https://sbcc.wa.gov/sites/default/files/2021-01/2018%20WSEC_R%20Final%20package2.pdf

33 Cadmus used the National Renewable Energy Laboratory's BEopt™ (Building Energy Optimization Tool) software.

the purpose of this study, our electric energy and peak demand potential estimates only apply to PSE's electric service territory and exclude the impacts on other electric utilities.

We applied different analytical approaches for the residential and commercial sectors than for the industrial sector. For the residential and commercial sectors, we counted the number of natural gas equipment units in PSE's service area and applied the energy, demand, and cost impacts to these units. In the industrial sector, we calculated the total industrial natural gas load and then converted a portion (~30%) of this load into electric energy and peak demand following the methodology used in the 2023 IRP CPA.

## Summary of Assumptions

This subsection**Error! Reference source not found.** summarizes all the underlying assumptions used in t he residential, commercial, and industrial analyses.

### *Residential and Commercial Sectors*

Cadmus calculated the number of natural gas equipment units and the number of electric equipment units that could be converted in PSE's service area for both existing and new construction. We took PSE's customers counts and forecasts and applied equipment saturation ratios and fuel shares in each year of the study horizon (2024 through 2050) plus a base year (2023). We incorporated these data into Cadmus' end-use forecast model by aligning energy efficiency and natural gas-to-electric conversion assumptions and produced alterative base case forecasts for each scenario.

Cadmus used PSE customer counts and forecasts, residential equipment saturation and fuel share data from PSE's 2021 *Residential Characteristics Survey*, commercial equipment saturation data from PSE's 2023 IRP CPA, and NEEA's 2019 *Commercial Building Stock Assessment*[34] to estimate natural gas equipment counts. Cadmus used PSE's 2023 IRP CPA to determine the energy impacts of conversion for all equipment except for CCHPs. For determining the energy impacts of converting to CCHPs, Cadmus used the methodology described in the *Methodology for Creating Heat Pump Load Shapes* section. To assess the peak demand impacts, Cadmus used each equipment's hourly end-use profiles and combined these with PSE's peak load hour definition (under PSE's extreme design temperature) to determine the coincident peak impacts. To align with PSE's IRP modeling of natural gas-to-electric conversion peak impacts, Cadmus used this peak load hour definition rather than following the energy efficiency modeling peak hour definitions (representing average peak period). We determined the maximum load hour within the peak period to represent the peak load hour. Table 17 lists the underlying assumptions for residential analysis while Table 18 lists the data sources we used in the residential and commercial analysis.

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34 Northwest Energy Efficiency Alliance. May 21, 2020. *2019 Commercial Building Stock Assessment.* https://neea.org/resources/cbsa-4-2019-final-report

**Table 17. List of the Underlying Assumptions for Residential Analysis**

| Analysis Component | Assumption(s) |
|---|---|
| Costs of baseline ductless and centrally ducted ASHPs, cost adders for higher-efficiency and cold-climate installations, and additional costs for electric conversion | Assumptions are presented in *Appendix D: Costs of CCHPs and Other Heat Pump Technologies* and explained in the *Cost Data: Contractor Interviews* section. |
| Load forecast used | Forecast is based on PSE's sector-load forecasts produced in 2022. |
| Savings | CCHP savings are based on our analysis as explained in the *Methodology for Creating Heat Pump Load Shapes* section. Savings for other equipment is based on PSE's 2023 IRP CPA. |
| Peak calculations | Heat pump end-use load shapes are based on the NREL ResStock database [a] and engineering calculation as explained in the *Methodology for Creating Heat Pump Load Shapes* section. Non-heating load shapes are based on Northwest Power Planning Council load shapes. [b] |
| Adoption and ramp rates | Assumptions are explained in the *Natural Gas-to-Electric Adoption Rates* section. |
| Application of IRA | Assumptions are explained in the *Incorporating Potential Impacts of IRA* section. |

[a] National Renewable Energy Laboratory. Accessed February 19, 2023. "ResStock Analysis Tool." https://www.nrel.gov/buildings/resstock.html (data available at https://data.openei.org/s3_viewer?bucket=oedi-data-lake&prefix=nrel-pds-building-stock).

[b] Northwest Energy Efficiency Alliance. Last revised April 2019. *2017 Residential Building Stock Assessment.* https://neea.org/img/uploads/Residential-Building-Stock-Assessment-II-Single-Family-Homes-Report-2016-2017.pdf

**Table 18. Data Sources for the Residential and Commercial Analysis**

| Sector | Analysis Component | Data Sources |
|---|---|---|
| Residential, Commercial, and Industrial | Customer Counts | 2022 PSE customer counts, PSE customer forecasts |
| Residential | Equipment Fuel Shares and Saturations | PSE's 2021 *Residential Characteristics Survey*, NEEA's *2017 Residential Building Stock Assessment* [a] |
| | Electric Equipment Consumption | PSE 2023 IRP CPA, CCHP load shape work done as part of this study |
| | Electric Equipment Peak Demand | PSE 2023 IRP CPA, end-use load shapes (both Northwest Power Planning Council load shapes [b] and the load shapes developed in this study) |
| | Electric Equipment Costs | PSE 2023 IRP CPA, Cadmus' primary market research (contractor interviews) |
| Commercial | Equipment Fuel Shares and Saturations | NEEA's *2019 Commercial Building Stock Assessment* [b] |
| | Electric Equipment Consumption | PSE 2023 IRP CPA |
| | Electric Equipment Peak Demand | PSE 2023 IRP CPA, end-use load shapes |
| | Electric Equipment Costs | PSE 2023 IRP CPA |

[a] Northwest Energy Efficiency Alliance. Last revised April 2019. *2017 Residential Building Stock Assessment.* https://neea.org/img/uploads/Residential-Building-Stock-Assessment-II-Single-Family-Homes-Report-2016-2017.pdf

[b] Northwest Power and Conservation Council. September 2021. *The 2021 Northwest Power Plan*. Council Document 2021-5. nwcouncil.org/sites/default/files/2021powerplan_2021-5.pdf

[c] Northwest Energy Efficiency Alliance. May 21, 2020. *2019 Commercial Building Stock Assessment.* https://neea.org/resources/cbsa-4-2019-final-report

### *Industrial Sector*

Cadmus followed the same methodology we had used in the natural gas-to-electric conversion assessment done as part of 2023 IRP CPA to estimate the new electric industrial load. We calculated the total industrial non-electric space heating load by proportioning industrial customer natural gas sales using data from PSE's 2023 IRP CPA. We calculated potential for the industrial sector by converting a portion (~30%) of natural gas loads based on our prior analysis. This is consistent with literature showing that industries with low-temperature and medium-temperature (under 750°F) process heat consumptions represent roughly 33% of the overall usage for electric conversion technologies that are available on the market.[35] Higher-temperature applications are either very costly or are not commercially available on the market.

Cadmus applied the annual reduction to natural gas sales based on our prior analysis. We then converted the non-electric MMBtu into electric kilowatt-hours and applied the new electric load on the applicable end uses for each industry type. It should be noted, however, that the forecast of industrial customers declines from year to year. Therefore, the industrial load analysis applied only to the existing construction conversion scenario.

## Cost Data: Contractor Interviews

As part of PSE's 2023 IRP CPA, Cadmus interviewed contractors in PSE's service territory to determine heat pump (HHP, ductless non-CCHP, ASHP, ductless CCHP, and CCHP) conversion costs, including any additional costs to convert from non-electric to electric equipment, such as electrical panel or wiring upgrades, duct reconfiguration, and added labor costs. The data collected through the interviews supported our analysis for determining the conversion costs in this study.

Contractors reported that electrical improvements are the greatest challenge when installing heat pumps in previously natural gas–heated homes, with minor improvements needed over 50% of the time (such as to wiring and conduit). More significant improvements are needed approximately 10% of the time (such as panel or 200-amp electrical service upgrades).

More details on the findings of the interviews can be found in the *Costs of CCHPs and Other Heat Pump Technologies* section above as well as in the Cadmus' 2022 report.[36]

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35 McKinsey & Company. May 28, 2020. "Plugging In: What Electrification Can Do for Industry." https://www.mckinsey.com/industries/electric-power-and-natural-gas/our-insights/plugging-in-what-electrification-can-do-for-industry

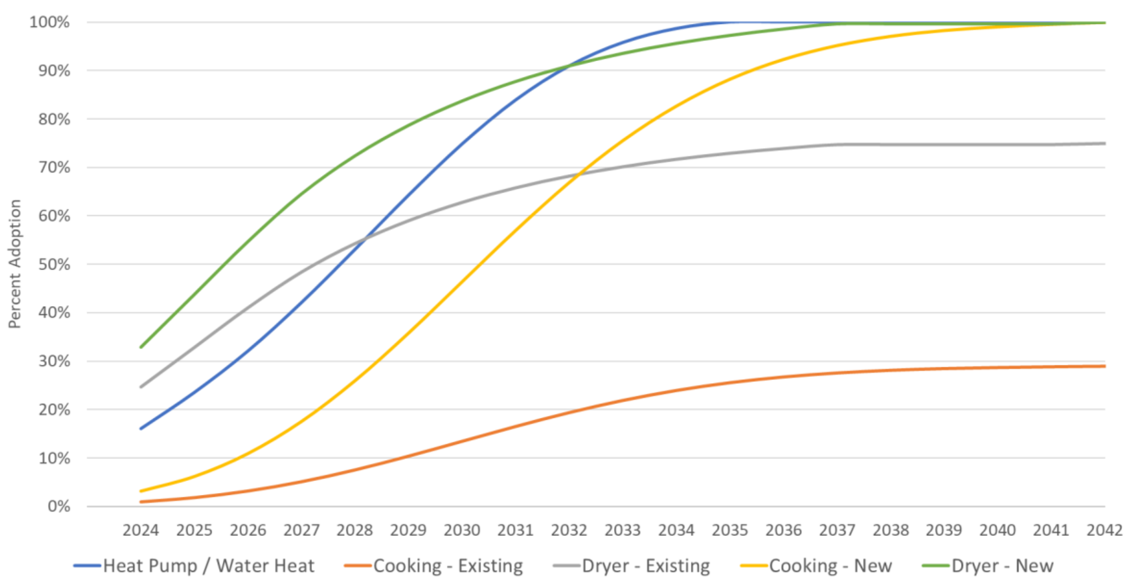
36 Cadmus. December 28, 2022. *Comprehensive Assessment of Demand-Side Natural Gas Resource Potential (2024–2050) Conservation Potential Assessment.* Prepared for Puget Sound Energy.

## Natural Gas-to-Electric Adoption Rates

Cadmus assessed each scenario using the product of technical potential (total units available for conversion) and both the maximum achievability factor and the ramp rate percentage. Maximum achievability factors represent the maximum proportion of technical potential that can be acquired over the study horizon. For all four scenarios, we assumed a maximum achievability factor of 100%.

Ramp rate percentages are annual percentage values representing the proportion of technical annual potential that can be acquired in a given year for equipment (lost opportunity) measures. For each scenario, equipment ramp rates are applied to the proportion of annual technical potential that can be acquired in a given year. Ramp rates are measure specific and we based them on the ramp rates developed for the Northwest Power Planning Council's draft *2021 Power Plan* supply curves,[37] adjusted to account for the 2024 through 2050 study horizon. For space heating and water heating systems, we assumed that there will be phase-in policies over time and that customers will ramp-up to 100% adoption over the study horizon, following the Council's Lost Opportunity 5 Medium ramp rate. For cooking equipment and clothes dryers, we estimated maximum adoptions for existing customers of 29% and 75%, respectively, based on the findings of a market research study we conducted as part of PSE's 2023 IRP CPA. Cooking equipment and clothes dryer ramp rates for new customers are based on Council's ramp rates, Lost Opportunity 3 Slow and Lost Opportunity 12 Medium, respectively, and reaches 100% adoption over the study period. Figure 6 shows the annual ramp rates and maximum achievability factor for heat pumps, water heaters, cooking equipment, and dryers.

**Figure 6. Residential Adoption Curves**

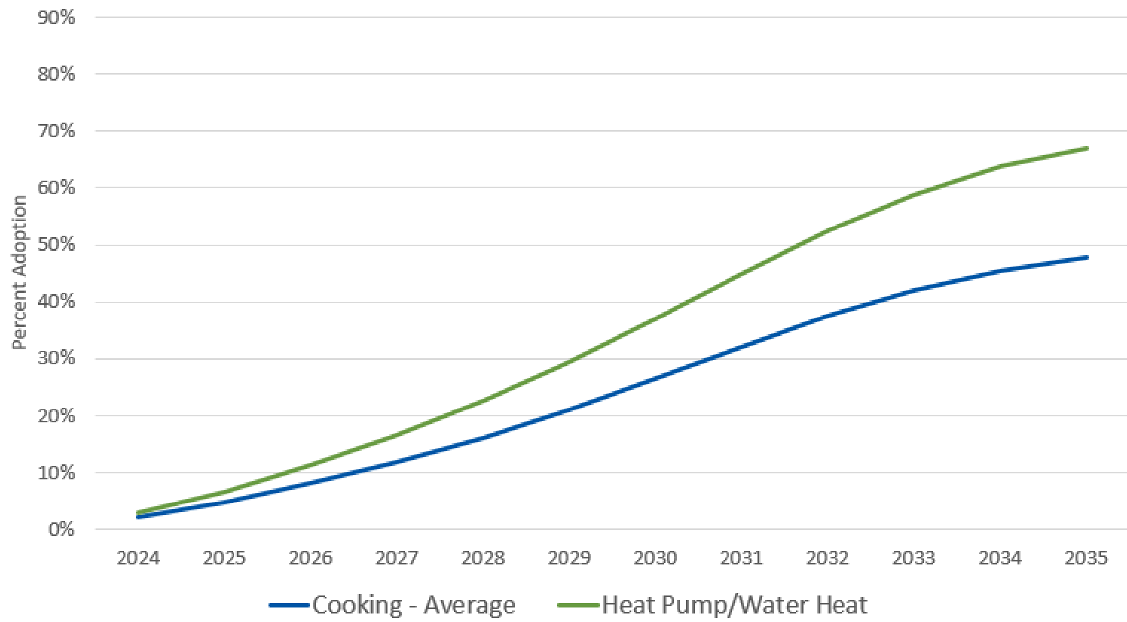



Note: The percentage adoption stays at the same level after 2041 until 2050.

[37] Northwest Power and Conservation Council. September 2021. *The 2021 Northwest Power Plan*. Council Document 2021-5. nwcouncil.org/sites/default/files/2021powerplan_2021-5.pdf

Similar to PSE's 2023 IRP CPA for the commercial sector, we estimated the space heat and water heat maximum adoption as 70% based on an ACEEE study.[38] We assumed cooking equipment to have 50% maximum adoption to account for market barriers in converting some natural gas cooking equipment. Figure 7 shows commercial adoption curves.

**Figure 7. Commercial Adoption Curves**




## Incorporating Potential Impacts of IRA

Unlike PSE's 2023 IRP CPA, this decarbonization study incorporated the potential impacts of IRA on natural gas-to-electric conversion costs. Overall, IRA funding affected some measures by reducing the equipment and panel upgrade costs. This, in turn, lowered the levelized costs for these measures.

In this study, IRA funding was assumed to start in 2024 and end in 2033, lasting 10 years. Cadmus capped the funding for a given year at the available amount for that year. We capped the participation, and in turn the load impact, by the available IRA funding. Cadmus modeled IRA and non-IRA impacts by splitting out the impacts based on a certain share. We used the ratio of number of housing units in Washington[39] to number of housing units in PSE's service area to estimate the total IRA funding available in PSE's service area through the HOMES Rebate program and HEEHRA (see Table 8 for details of the funding available to Washington). This resulted in 43.5% of all funding available in Washington to be

38 American Council for an Energy-Efficient Economy (Nadel, Steven, and C. Perry). October 28, 2020. "Electrifying Space Heating in Existing Commercial Buildings: Opportunities and Challenges." https://www.aceee.org/research-report/b2004

39 There are 3,314,390 housing units in Washington (Source: United States Census Bureau. Accessed May 2023. "QuickFacts: Washington." https://www.census.gov/quickfacts/WA).

allocated to PSE customers. To estimate the funding available through the 25C tax credit, Cadmus used the ratio of number of housing units in the U.S.[40] to number of housing units in PSE's service area. In addition, Cadmus limited 25C tax credit funding based on the eligibility criteria of the federal program, such as limited to only primary residences (e.g., no second homes or rental properties).

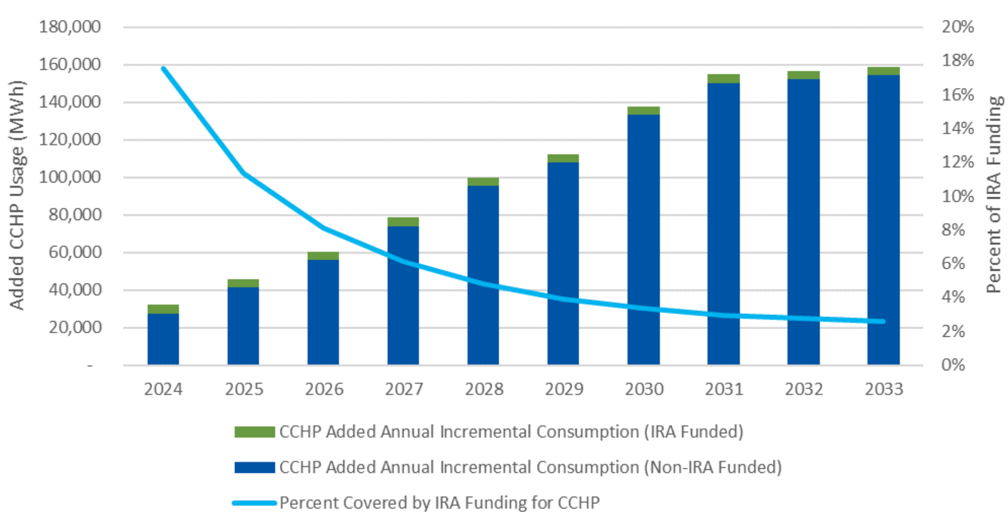
Cadmus assumed that 25% of HOMES Rebate program funding indirectly goes to electrification upgrades by incentivizing measures such as heat pumps, dryers, cooking, and panel upgrades. This performance based program may include other HVAC measures, air sealing, windows, doors, energy audits, and full retrofits. Cadmus also assumed that HEEHRA contributes 75% of funds for electrification measures and that the 25C tax credit only applies to homeowners (primary residence).

Based on Table 9, Cadmus applied several modeling assumptions to this study:

- Capped the full heap pump conversion incentive at $8,000 for vulnerable populations
- Capped the full heat pump conversion incentive at $2,000 for standard-income customers
- Capped panel and wiring costs at $6,500 for vulnerable populations and $600 for standard-income customers
- Added cooking and dryer incentives for vulnerable populations and capped these at $840
- Did not consider cooking and dryer incentives for standard-income customers.

As an example, Figure 8 shows the relation between IRA funding and annual incremental heat pump electric consumption for Scenario 2 – CCHP FULL. As the figure shows, there is a decrease in funding percentage in later years due to an increase in CCHP adoption and decrease in available IRA funding in PSE's service area.

**Figure 8. Share of CCHP Annual Incremental Consumption by IRA and Non-IRA Funding over 10 Years**




40 There are 143,786,655 housing units in the U.S. (Source: United States Census Bureau. Accessed May 2023. "QuickFacts: United States." https://www.census.gov/quickfacts/fact/table/US/PST045222).

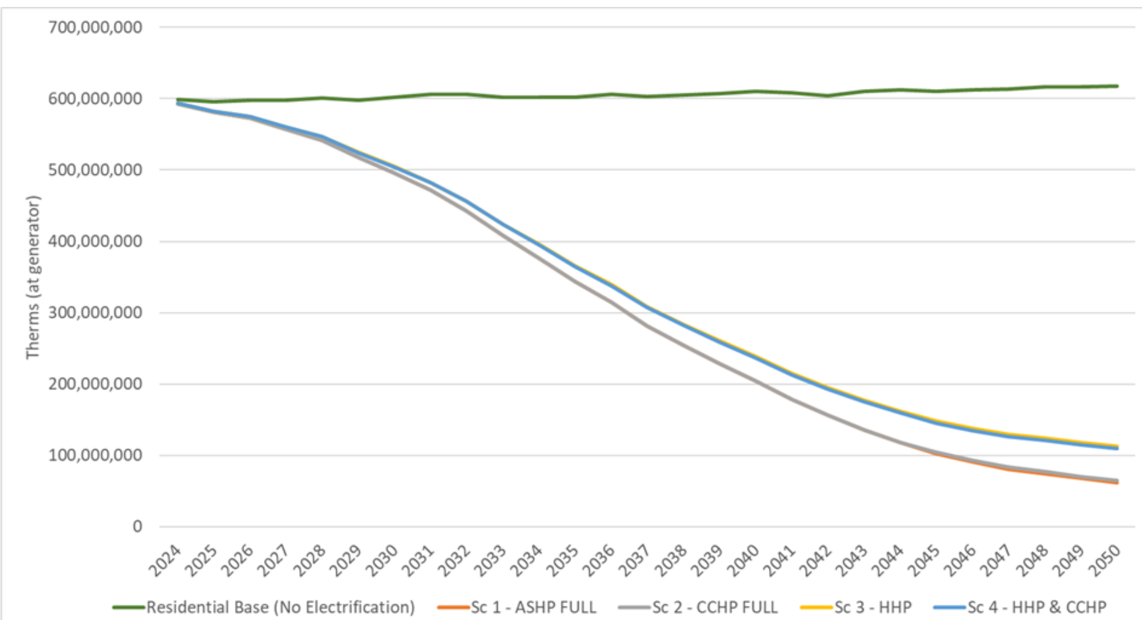
# Chapter 3. Assessment of the Natural Gas and Electric Load Impacts

Cadmus used the change in equipment saturations from the natural gas-to-electric conversion with the applied adoption rates for each of the decarbonization scenarios to assess the natural gas and electric system load impacts within PSE's service territory from 2024 through 2050. We calculated hourly (electric) and monthly (natural gas) system energy load impacts associated with these four scenarios for PSE's IRP modeling. We used hourly end-use load shapes we developed for ducted and ductless CCHPs, non-CCHPs, and HHPs for residential sector (see the *Methodology for Creating Heat Pump Load Shapes* section) and load shapes from the *2021 Power Plan*[41] for the non-heat pump end uses.

## *Natural Gas Reduction Impacts*

Cadmus calculated the associated natural gas reductions at the system level for each of the four scenarios. Figure 9 shows that Scenario 1 – ASHP FULL and Scenario 2 – CCHP FULL decrease the natural gas residential base sales forecast by 81% in 2050 from the PSE base forecast (2023 IRP CPA), whereas Scenario 3 – HHP and Scenario 4 – HHP&CCHP decrease the residential sales forecast by 76% in 2050. The impact of the natural gas-to-electric conversion on C&I natural gas forecasts does not change among scenarios (as shown in Figure 10 and Figure 11). The reduction in natural gas forecast is at 67% for the commercial sector and 29% for the industrial sector in 2050. Figure 12 shows the overall impact of the natural gas-to-electric conversion on the natural gas forecast for all scenarios with all sectors combined.

**Figure 9. Residential Natural Gas Load Impact by Scenario, All End Uses2024–2050 (Therms)**




41 Northwest Power and Conservation Council. September 2021. *The 2021 Northwest Power Plan*. Council Document 2021-5. nwcouncil.org/sites/default/files/2021powerplan_2021-5.pdf

**Figure 10. Commercial Natural Gas Load Impact by Scenario, All End Uses 2024–2050 (Therms)**

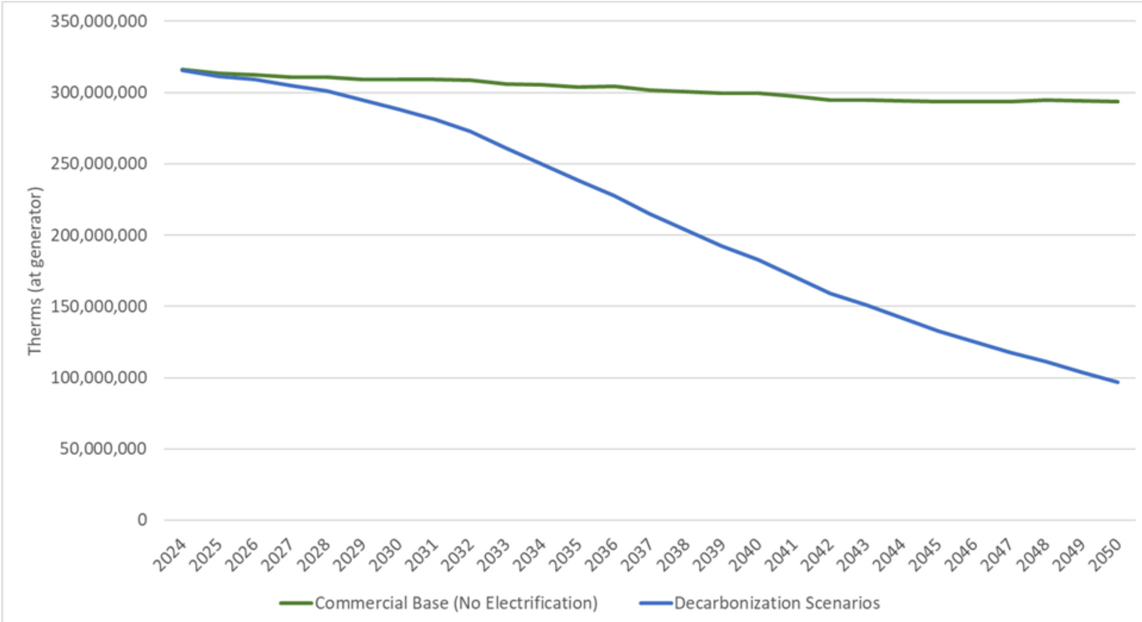



**Figure 11. Industrial Natural Gas Load Impact by Scenario, All End Uses 2024–2050 (Therms)**

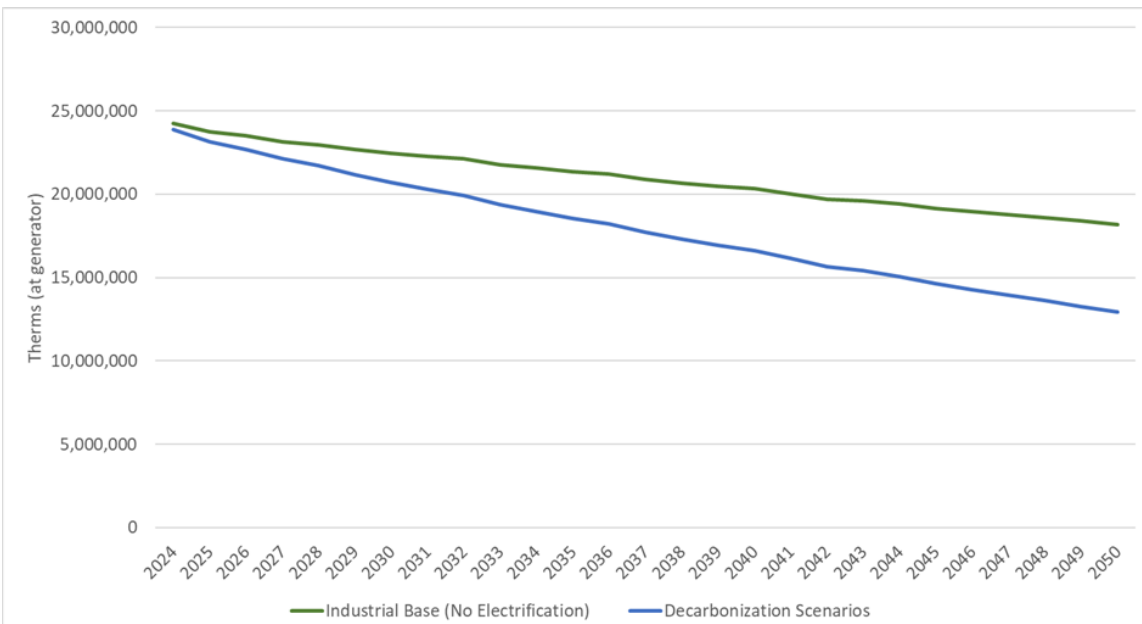
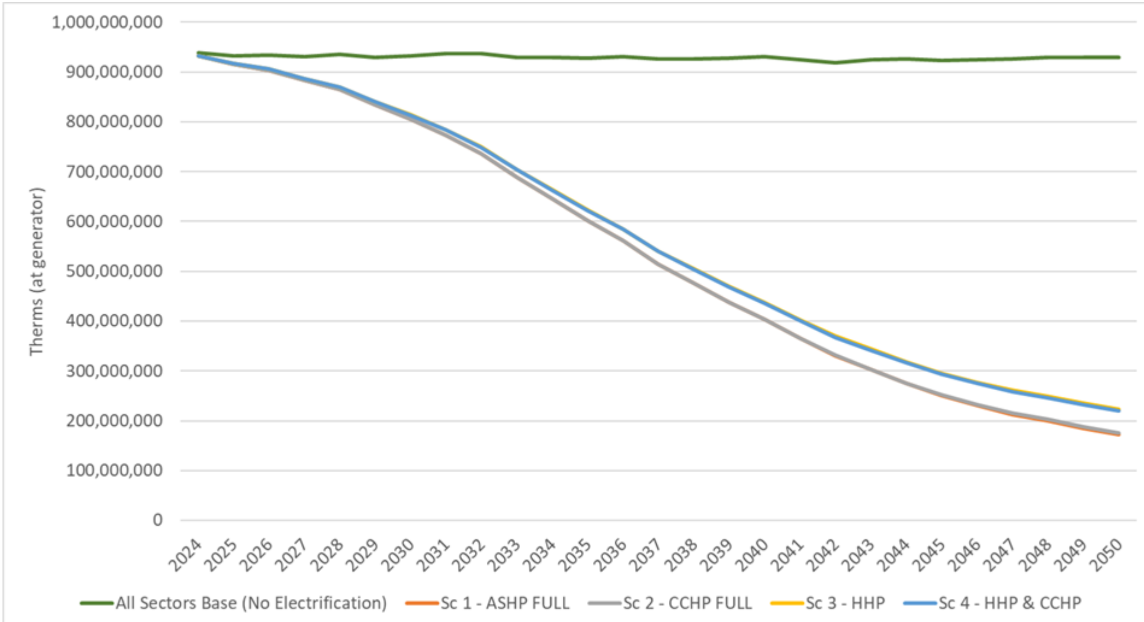


**Figure 12. Natural Gas Load Impact of All Sectors by Scenario, All End Uses 2024–2050 (Therms)**




## *Electric Energy Impacts*

Figure 13 shows the residential electric energy impacts by scenario from 2024 to 2050. Scenario 1 – ASHP FULL has the largest increase in the electric residential sales forecast of 40% in 2050 from the PSE base forecast (2023 IRP CPA). Scenario 3 – HHP has the second largest increase on the electric residential sales forecast of 37% in 2050. Scenario 2 – CCHP FULL and Scenario 4 – HHP&CCHP increases the sales forecast by 35% and 36% in 2050, respectively. Figure 14 and Figure 15 present the impact of natural gas-to-electric conversions on C&I electric forecasts, respectively. The impact on commercial electric forecast is 13% whereas it is 21% on industrial forecast in 2050. Figure 16 shows the overall impact of the natural gas-to-electric conversion on the electric forecast for all scenarios with all sectors combined. When all sectors considered, Scenario 1 – ASHP FULL has the largest increase with 29% in 2050 compared to the PSE base forecast. Scenario 3 – HHP has the second largest increase with 28% in 2050. Scenario 2 – CCHP FULL and Scenario 4 – HHP&CCHP increases the sales forecast by 26% and 27% in 2050, respectively.

**Figure 13. Residential Electric Load Impact by Scenario, All End Uses 2024–2050 (MWh)**

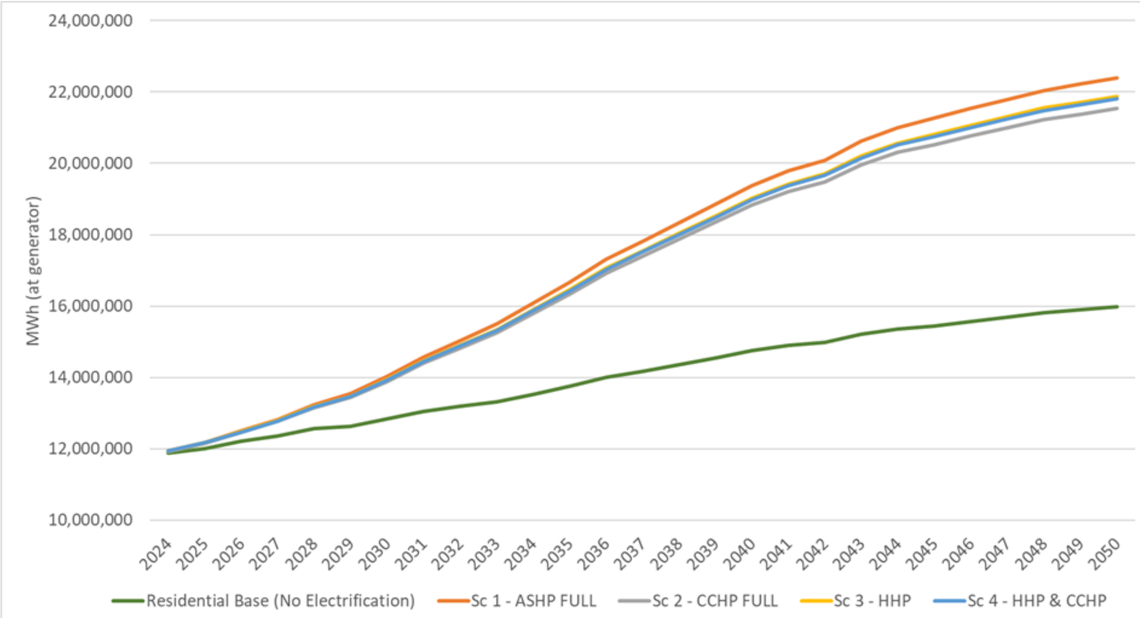



**Figure 14. Commercial Electric Load Impact by Scenario, All End Uses 2024–2050 (MWh)**

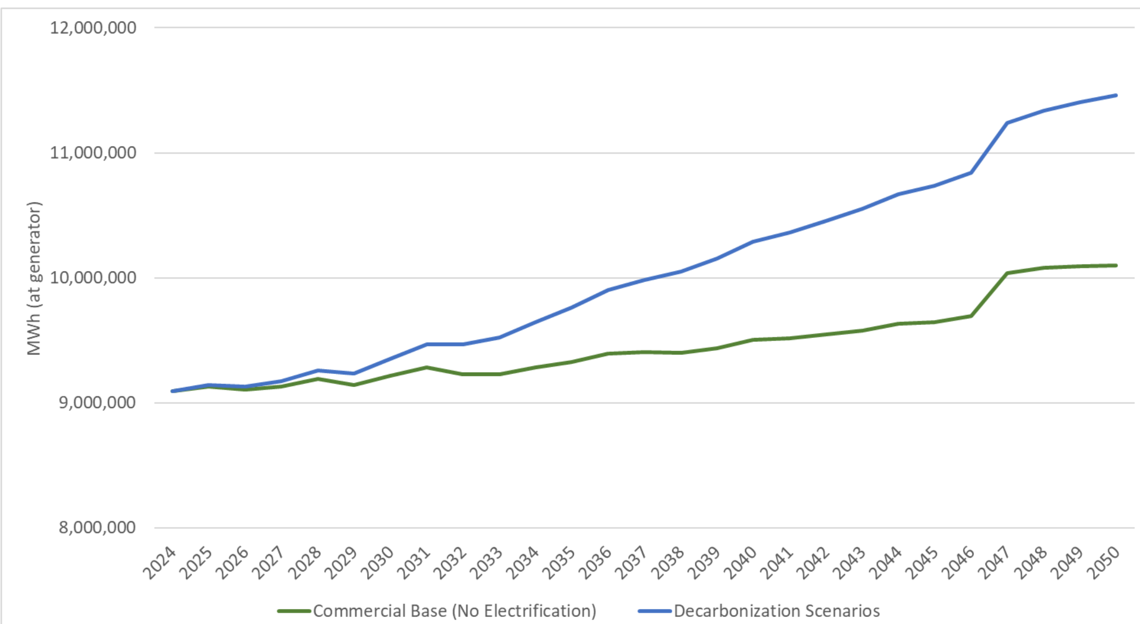


**Figure 15. Industrial Electric Load Impact by Scenario, All End Uses 2024–2050 (MWh)**

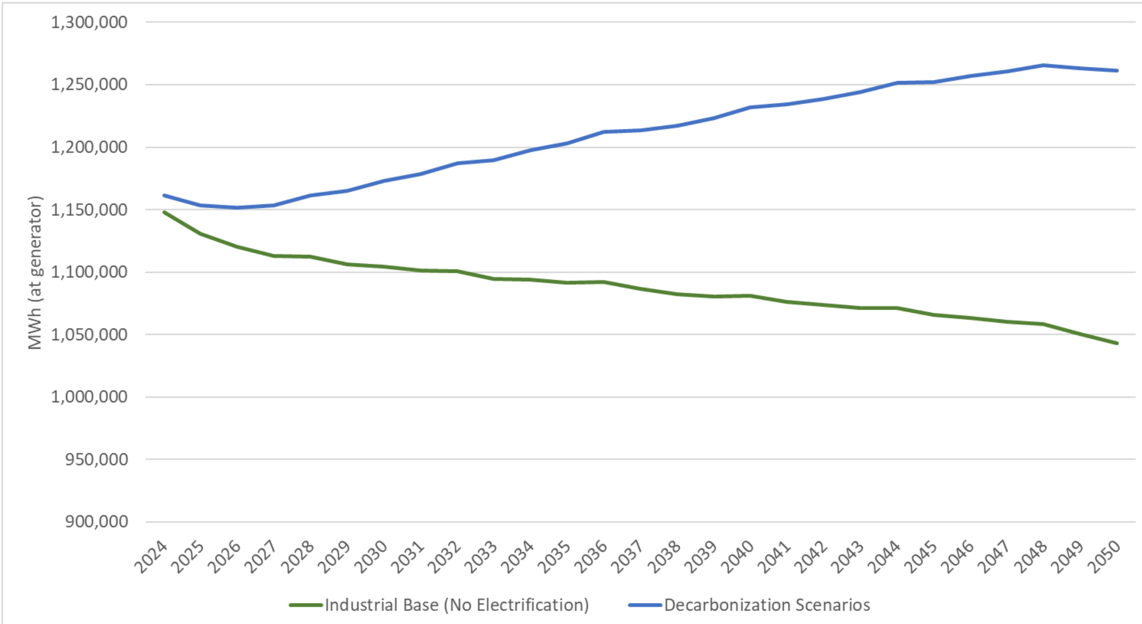
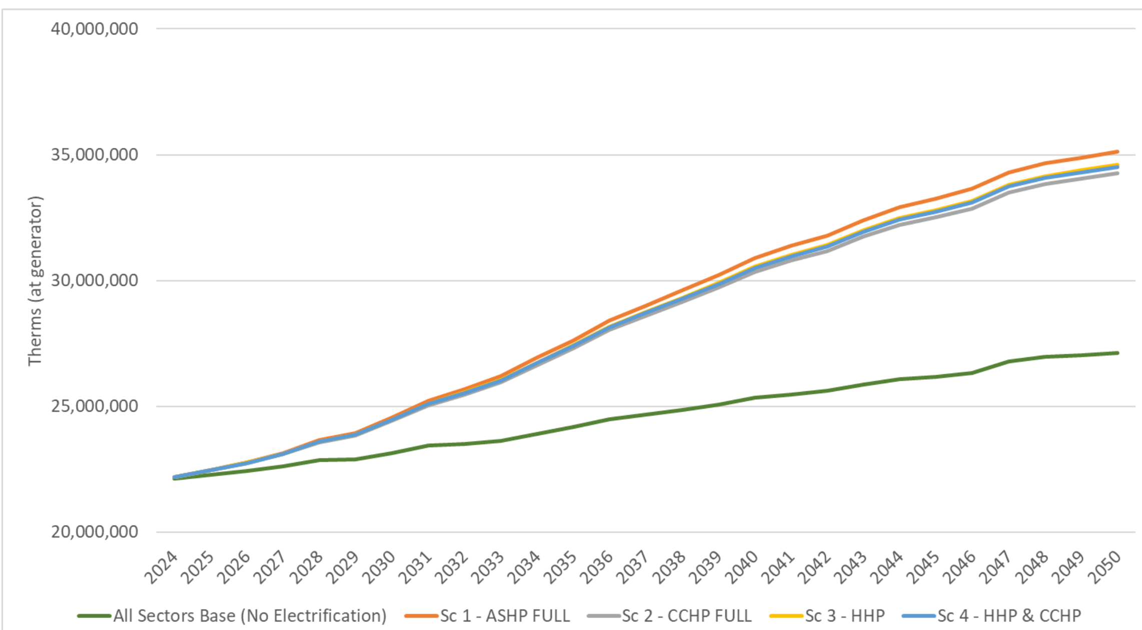



**Figure 16. Electric Load Impact of All Sectors by Scenario, All End Uses 2024–2050 (MWh)**



## *Peak Demand Impacts*

Cadmus calculated the cumulative peak winter demand impacts in PSE's electric service area by scenario from 2024 to 2050, as shown in Figure 17 and Figure 18. The main increase in electric peak winter demand is observed for Scenario 1 - ASHP FULL and Scenario 2 – CCHP FULL due to heat pumps without natural gas backup operating during peak. In Scenario 3 – HHP and Scenario 4 – HHP&CCHP, the main driver of the decrease in peak demand is the backup natural gas heating equipment being operated during peak and resulting in zero peak demand increases. The end uses representing peak demand in the figure are ductless heat pumps for new construction in Scenario 3 – HHP and ductless and ducted CCHPs for new construction for Scenario 4 – HHP&CCHP, with both scenarios including water heaters, ovens/ranges, and dryers. These end uses are less coincident to PSE's winter peak (under extreme weather conditions), except ductless heat pumps and ductless CCHPs.

For the residential sector (shown in Figure 17), the peak demand impact of Scenario 2 – CCHP FULL is equal to 79% of that for Scenario 1 - ASHP FULL. As explained in the *Winter Peak Loads from Electrification: CCHP Impacts* section above, this is due to the improved efficiency of CCHPs and reduced electric resistance backup usage due to a lower balance point for CCHPs. In addition, Scenario 4 – HHP&CCHP has 17% more peak demand than Scenario 3 – HHP because it uses ducted CCHPs for new construction.

**Figure 17. Cumulative Electric Residential Winter Demand Impacts by Scenario (MW)**

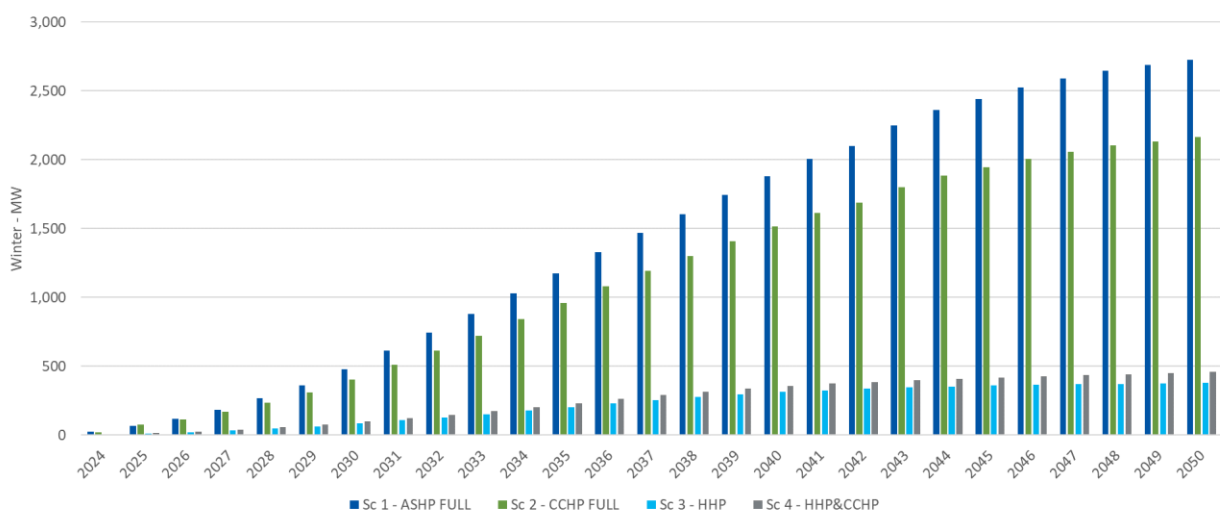
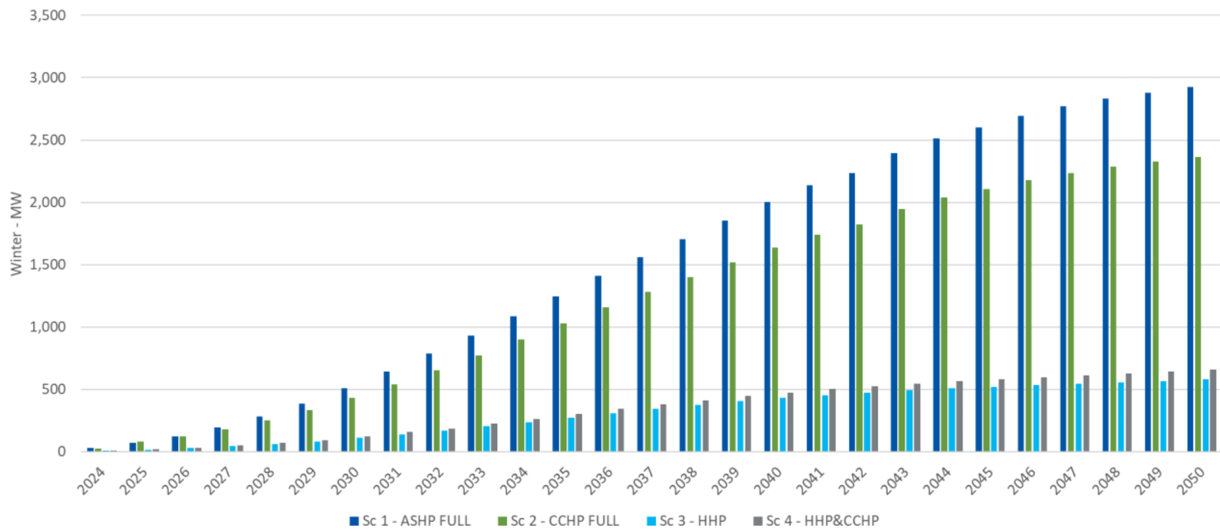



Figure 18 shows the overall winter peak demand impact of the natural gas-to-electric conversion with all sectors combined.

**Figure 18. Cumulative Electric Winter Demand Impacts for All Sectors by Scenario (MW)**




## *Equipment Adoption Forecasts*

With the implementation of natural gas-to-electric conversions, the number of units of electric equipment is expected to increase over time. In the residential sector, the growth in the number of non-heat pump equipment (water heaters, clothes dryers, and cooking equipment) was the same for all scenarios (and is shown in Table 19).

**Table 19. Change in Number of Residential Non-Heat Pump Equipment in 10 and 27 Years for All Scenarios**

| Equipment Type | Approximate Equipment Number | |
|---|---|---|
| | In 10 Years | In 27 Years |
| Water heaters | 314,000 | 778,000 |
| Clothes dryers | 67,000 | 132,000 |
| Cooking equipment | 77,000 | 418,000 |

For residential sector, the type of heat pumps and their growth was different in each scenario, as shown in Table 20. Figure 19 through Figure 22 show this growth throughout the 27-year study period.

**Table 20. Change in Number of Residential Heat Pump Equipment in 10 and 27 Years for Each Scenario**

| Scenario | ASHP | CCHP | HHP | Ductless |
|---|---|---|---|---|
| **Approximate Equipment Number in 10 Years** | | | | |
| Scenario 1 | 167,000 | N/A | N/A | 61,000 |
| Scenario 2 | N/A | 229,000 | N/A | N/A |
| Scenario 3 | N/A | N/A | 167,000 | 61,000 |
| Scenario 4 | N/A | 44,000 | 134,000 | 49,000 |
| **Approximate Equipment Number in 27 Years** | | | | |
| Scenario 1 | 591,000 | N/A | N/A | 206,000 |
| Scenario 2 | N/A | 797,000 | N/A | N/A |
| Scenario 3 | N/A | N/A | 591,000 | 206,000 |
| Scenario 4 | N/A | 172,000 | 464,000 | 161,000 |

**Figure 19. Residential Electric Equipment Adoption Forecast for Scenario 1 (2024–2050)**

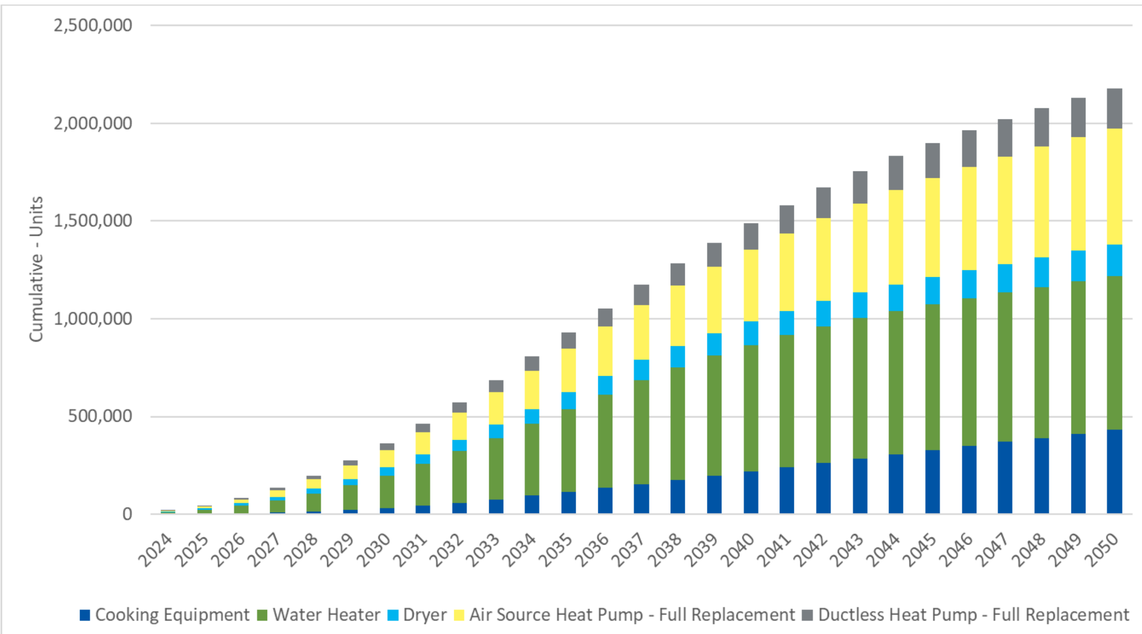


**Figure 20. Residential Electric Equipment Adoption Forecast for Scenario 2 (2024–2050)**

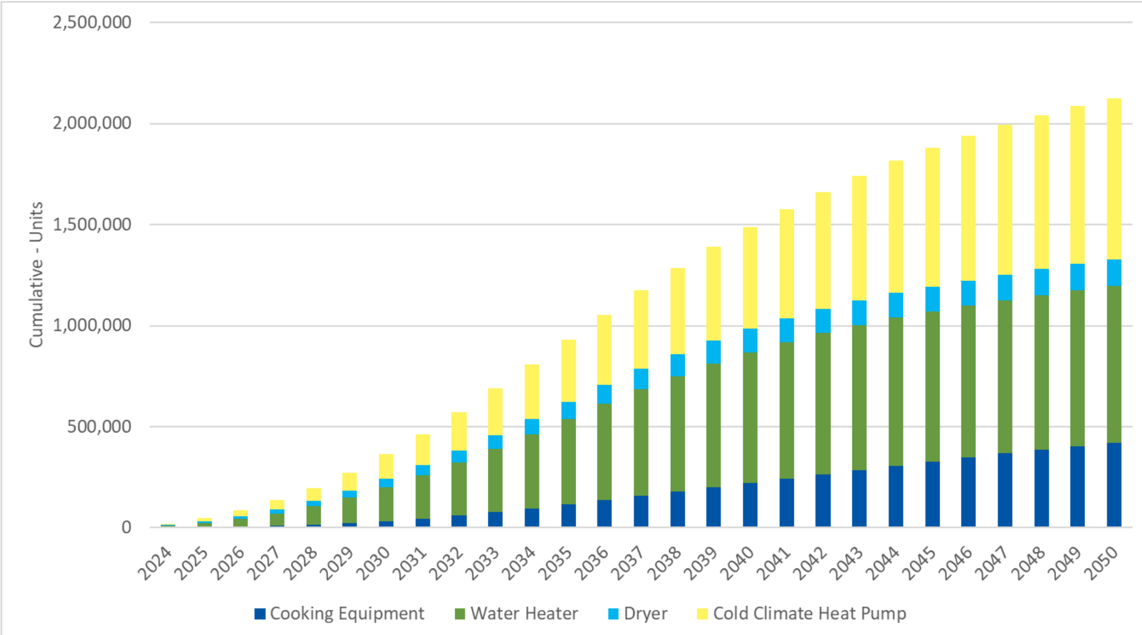



**Figure 21. Residential Electric Equipment Adoption Forecast for Scenario 3 (2024–2050)**

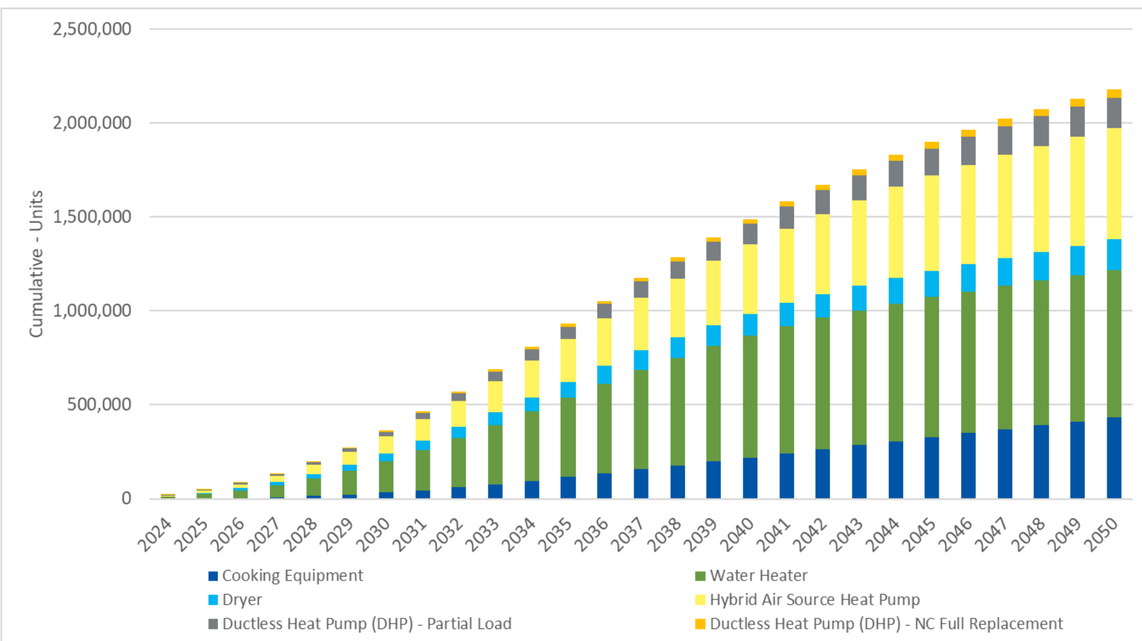


**Figure 22. Residential Electric Equipment Adoption Forecast for Scenario 4 (2024–2050)**

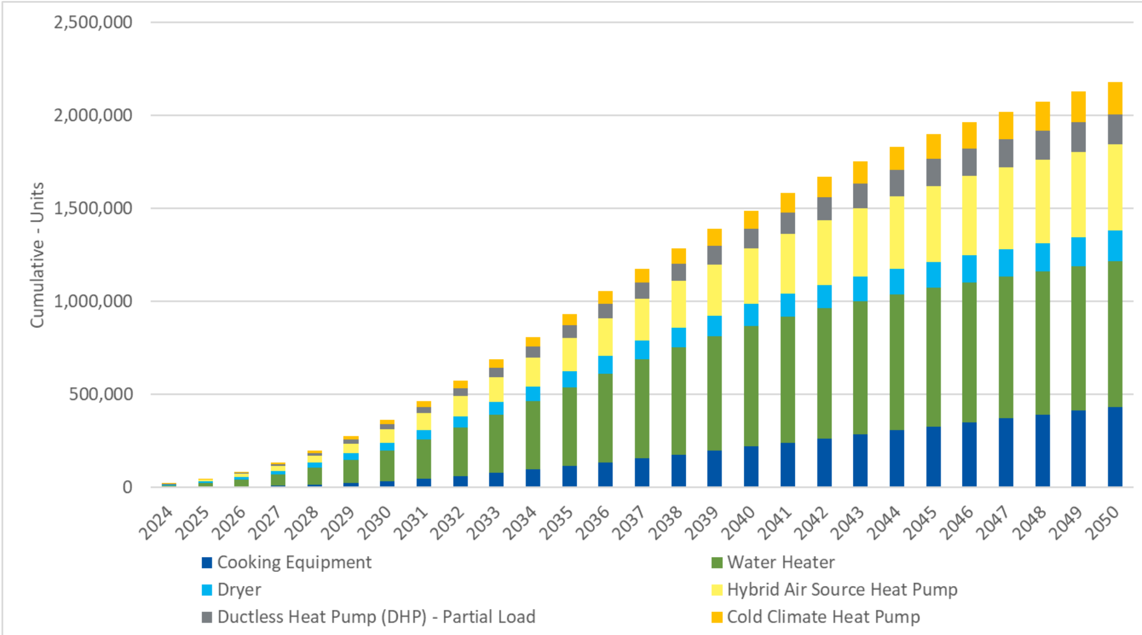
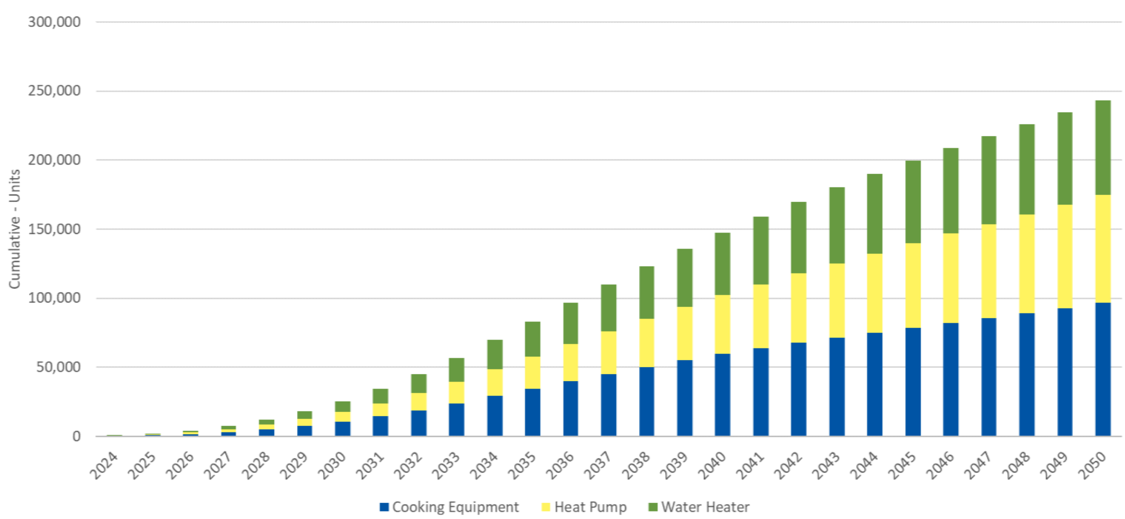



Figure 23 shows the forecasted impacts of electric equipment being adopted over the 27 years in the commercial sector.

**Figure 23. Commercial Equipment Adoption Forecast**



## *Levelized Costs Calculations*

To incorporate the decarbonization scenario results in PSE's IRP scenario, Cadmus developed levelized cost estimates for the natural gas reductions, which PSE modeled comparably to energy efficiency. The potential is grouped by levelized cost over a 27-year period for the natural gas reductions. The 27-year natural gas levelized-cost calculations incorporate numerous factors, shown in Table 21.

**Table 21. Levelized Cost Components**

| Type | Component |
|---|---|
| Costs Included [a] | Present Value Capital Cost of Equipment Conversion |
| | Program Cost (HVAC equipment program admin adder based on energy efficiency potential estimates, all other end uses based on 21% of equipment conversion cost) |
| | Added Electric Transmission and Distribution Costs (for non-hybrid systems) |
| | Panel Upgrade Cost |
| Benefits Netted Out | Present Value of Natural Gas Avoided |
| | Present Value of Conservation Credit (10% of conserved natural gas energy) |
| | Present Value of Non-Energy Impacts |

[a] Costs for the electric energy generation and capacity are separately accounted for within PSE's electric portfolio analysis.

Cadmus incorporated the costs associated with expanding the existing transmission and distribution to meet the new electric peak demands (as PSE's IRP model accounts for these variables). PSE's generation capacity and transmission and distribution system would require increased investments to handle the increased load due to electrification. Cadmus accounted for the transmission and distribution costs for all non-HHP systems (we modeled HHP systems to have zero impact during winter peak).

In addition to the annual natural gas energy savings from converted to electric, the TRC levelized-cost calculation incorporates several additional factors:

- ***Capital cost of equipment conversion.*** Cadmus considered the costs required to sustain savings over a 27-year horizon, including reinstallation costs for measures with an effective useful life (EUL) of less than 27 years. If a measure's EUL extends beyond the end of the 27-year study, Cadmus incorporated an end effect that treats the levelized cost of that measure over its EUL as an annual reinstallation cost for the remainder of the 27-year period.[42] Costs other than equipment included wiring and panel upgrades for a portion of PSE's population.
- ***Administrative adder.*** Cadmus assumed a program administrative cost equal to 21% of incremental measure costs for non-HVAC measures. For HVAC equipment, Cadmus used nominal values (rather than a percentage of incremental cost) from the energy efficiency

42 In this context, EUL refers to levelizing over the measure's useful life. This is equivalent to spreading incremental measure costs over a measure's EUL in equal payments assuming a discount rate equal to PSE's weighted average cost of capital (6.62%). Cadmus applied this method both to measures with an EUL of greater than 27 years and to measures with an EUL that extends beyond the study horizon at the time of reinstallation.

potential estimates for the program administrative adders since incremental costs for natural gas-to-electric conversions tend to be larger than costs for traditional energy efficiency upgrades.

- ***Non-energy impacts.*** This study incorporated non-energy impacts for residential customers who did not have existing cooling but received cooling comfort through the heat pump installation.
- ***The regional 10% conservation credit.*** The addition of this credit per the Northwest Power Act[43] is consistent with the Northwest Power and Conservation Council's methodology and is effectively an adder to account for the unquantified external benefits of conservation when compared with other resources. This credit is only applied to the natural gas savings.

43 Northwest Power and Conservation Council. January 1, 2010. "Northwest Power Act." http://www.nwcouncil.org/library/poweract/default.htm

# Chapter 4. Assessment of Natural Gas and Electric Energy Efficiency Impacts

As part of this decarbonization study, Cadmus accounted for the interaction of energy efficiency savings from various equipment and retrofit measures and assessed both electric and natural gas energy efficiency potential for all four scenarios. Table 22 summarizes the analysis results. All estimates of potential in this report are presented at the generator, which means they include line losses of 8.14% for electric and 1.12% for natural gas.

**Table 22. Decarbonization Scenario Impacts on Electric and Natural Gas Energy Efficiency Potential**

| Sector | Achievable Technical Energy Efficiency Potential, Cumulative 2050 (27-Year) | | | | |
|---|---|---|---|---|---|
| | Base | Scenario 1 – ASHP FULL | Scenario 2 – CCHP FULL | Scenario 3 – HHP | Scenario 4 – HHP&CCHP |
| **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** |

## *Residential Impacts*

The results show that for the residential sector, Scenario 1 – ASHP FULL has the highest electric energy efficiency potential (with a 56% increase over the base potential) and the lowest natural gas energy efficiency potential (with a 77% decrease from the base potential). The residential sector for Scenario 2 – CCHP FULL has the lowest electric energy efficiency potential (with a 37% increase over the base potential) and the same natural gas energy efficiency potential as Scenario 1 – ASHP FULL (with a 77% decrease from the base potential). Scenario 3 – HHP has 38% higher electric and 73% lower natural gas energy efficiency potential compared to the base potential. Scenario 4 – HHP&CCHP has 38% higher electric and 73% lower natural gas energy efficiency potential compared to the base potential. These details are visualized in Figure 24 and Figure 25.

**Figure 24. Residential Electric Energy Efficiency Potential Compared to Base Case for All Four Scenarios**

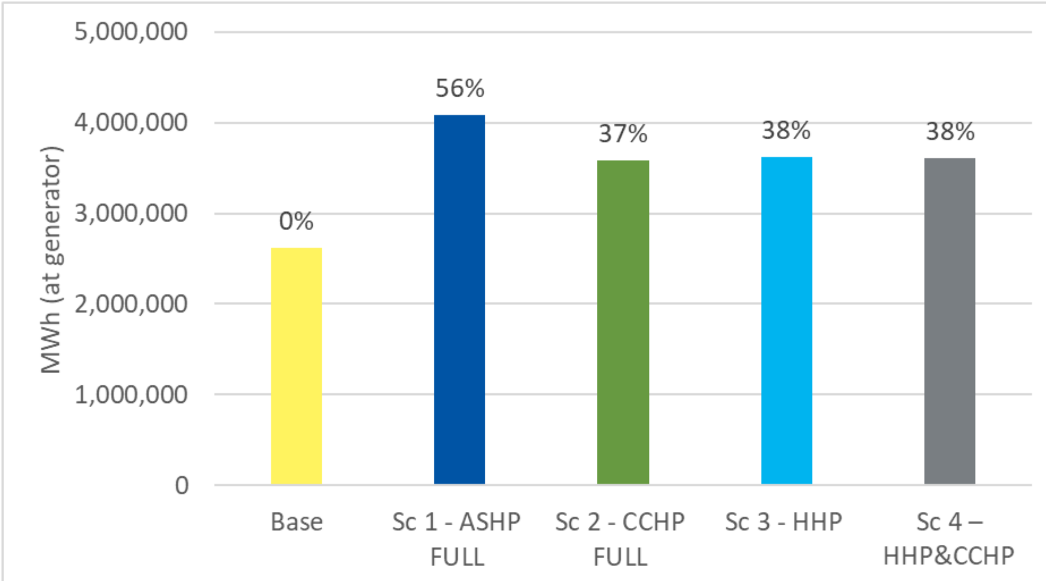
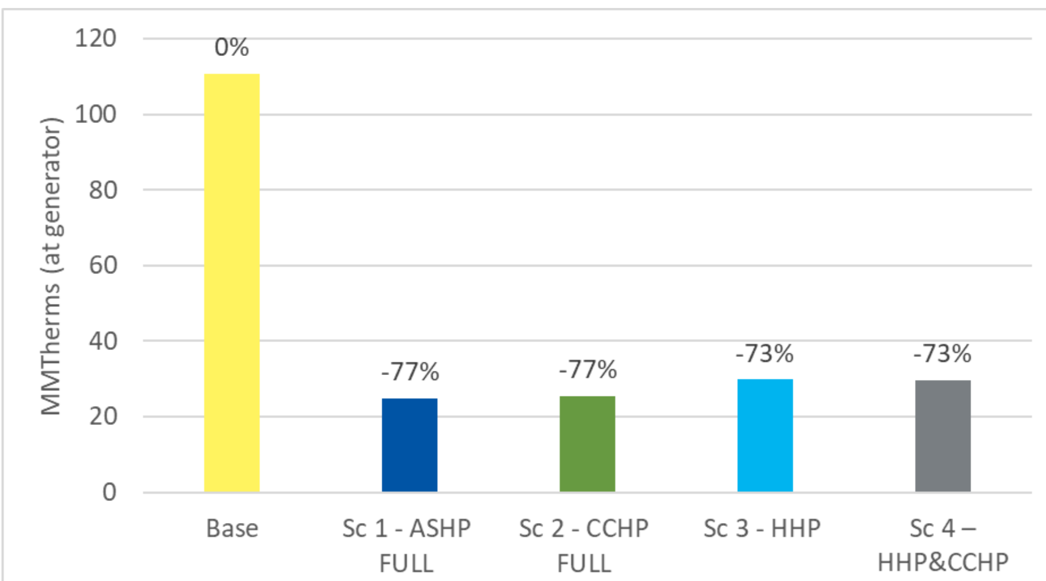



**Figure 25. Residential Natural Gas Energy Efficiency Potential Compared to Base Case for All Four Scenarios**




## *Combined Sector Impacts*

With sectors combined, Scenario 1 – ASHP FULL still has the highest electric energy efficiency potential (with a 36% increase over the base potential) and the lowest natural gas energy efficiency potential (with a 71% decrease from the base potential). Scenario 2 – CCHP FULL has the lowest electric energy efficiency potential (with a 26% increase over the base potential) and the same natural gas energy efficiency potential as Scenario 1 – ASHP FULL (with a 71% decrease from the base potential). Scenario 3 – HHP has 27% higher electric and 69% lower natural gas energy efficiency potential compared to the base potential. Scenario 4 – HHP&CCHP has 26% higher electric and 69% lower natural gas energy efficiency potential than the base potential. Figure 26 and Figure 27 visualize these details.

**Figure 26. Electric Energy Efficiency Potential Compared to Base Case for All Sectors and All Four Scenarios**

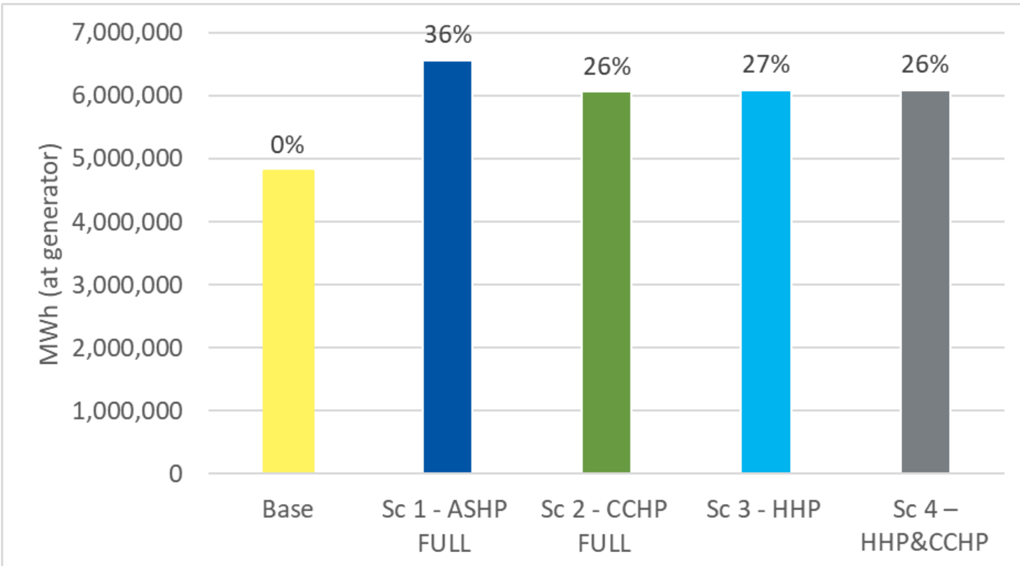
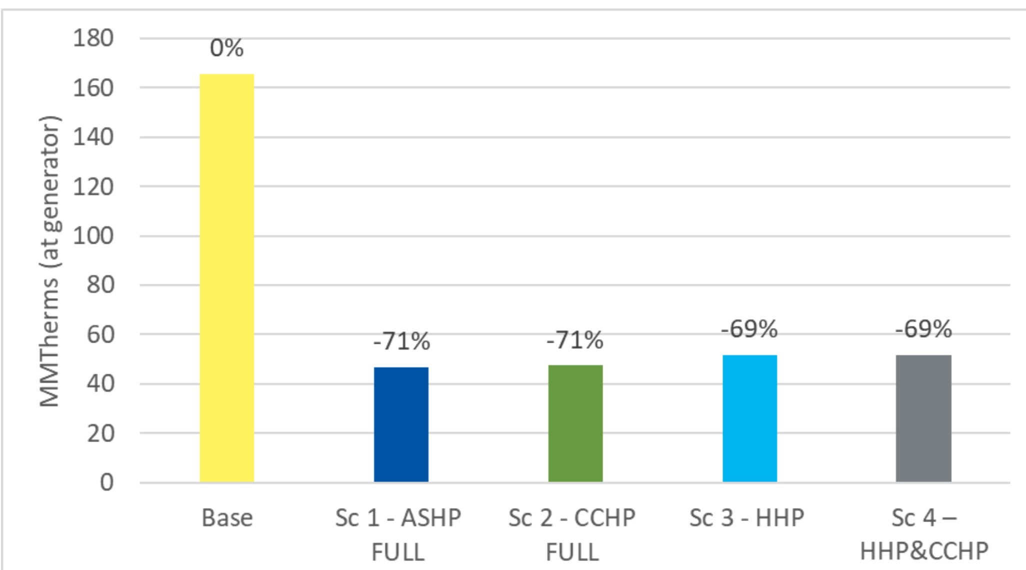



**Figure 27. Natural Gas Energy Efficiency Potential Compared to Base Case for All Sectors and All Four Scenarios**



# Chapter 5. Assessment of the Effect of Natural Gas-to-Electric Conversion on Demand Response Potential

Demand response programmatic options help reduce peak demand during system emergencies or periods of extreme market prices and promote improved system reliability. Demand response programs provide incentives for customers to curtail loads during utility-specified events (such as direct load control [DLC] programs) or offer pricing structures to induce participants to shift load away from peak periods (such as critical peak pricing [CPP] programs).

As part of this study, Cadmus analyzed the magnitude of impacts of the natural gas-to-electric conversion on demand response potential for all four scenarios. For this purpose, Cadmus focused on the same programs that were analyzed in the *Demand-Side Electric Resource Potential Assessment*[44] and aimed at reducing PSE's winter and summer peak demand. These programs include residential and commercial DLC HVAC, residential DLC water heat, residential electric vehicle supply equipment (EVSE), residential and C&I CPP, and C&I load curtailment and provide options for all major customer segments and end uses in PSE's service territory. Each of these programs may have more than one product option. For example, the residential DLC water heat program is available for customers with either a HPWH or electric resistance water heater (ERWH). A water heater can also be grid-enabled or controlled by a switch.

Cadmus mainly based the program assumptions on the inputs used in the draft *2021 Power Plan*,[45] with a few modifications to account for additional benchmarking. Details of these inputs can be found in the *Comprehensive Assessment of Demand-Side Electric Resource Potential (2024–2050)* report. To determine the impact of natural gas-to-electric conversion on demand response potential, Cadmus adjusted some inputs. For the residential sector, we increased the number of ASHPs, DHPs, electric water heaters, dryers, and cooking equipment for each of four scenarios. Similarly, for the commercial sector, we increased the number of ASHPs, water heaters, and cooking equipment, using the same assumptions as used in the 2023 IRP CPA. In addition, we increased the total electric load (MWh) for each sector due to the additional load from natural gas-to-electric conversions.

We also adjusted the winter peak kilowatt impact of CCHPs for the residential DLC HVAC programs (Residential HVAC DLC Switch and Residential Bring-Your-Own Thermostat (BYOT) DLC) for Scenario 2 – CCHP FULL and Scenario 4 – HHP&CCHP. As CCHPs are generally more efficient and use less supplemental electric resistance than non-CCHPs, the kilowatt impact of winter demand response

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44 The PSE 2023 IRP CPA results for electric demand-side resource potential in terms of demand response are in a separate companion report titled *Comprehensive Assessment of Demand-Side Electric Resource Potential (2024–2050)*.

45 Northwest Power and Conservation Council. September 2021. *The 2021 Northwest Power Plan*. Council Document 2021-5. nwcouncil.org/sites/default/files/2021powerplan_2021-5.pdf

events is expected to be relatively lower. To estimate the winter kilowatt impact, we reviewed the load shapes developed for CCHPs and non-CCHPs as part of this study.

- As a majority of residential customers are in single-family homes, we analyzed the non-CCHP load shape to identify the 10 independent four-hour periods during PSE's winter peak with the highest average demand. We then compared average demand across these 10 four-hour periods between CCHPs and non-CCHPs for each building type.
- Across the existing building load shapes, CCHPs had approximately 18% lower average demand than non-CCHPs. As a result, we reduced the demand response winter peak impact estimate for CCHP by 18% from the non-CCHP estimate.

As there is no significant efficiency gain expected for CCHPs over ASHPs during the summer, the kilowatt impact of summer demand response events kept the same for all heat pump types in all scenarios.

| RESIDENTIAL | COMMERCIAL | INDUSTRIAL |
| --- | --- | --- |
| • Highest increase in electric sales in Scenario 1 – ASHP FULL<br>• Lowest increase in electric sales in Scenario 2 – CCHP FULL<br>• Moderate increase in electric sales in Scenario 3 – HHP and Scenario 4 – HHP&CCHP<br>• Increase in equipment counts for all scenarios:<br>**Scenario 1 – ASHP FULL**<br>ASHPs, DHPs-full replacement, water heaters, dryers, stoves/cooktops<br>**Scenario 2 – CCHP FULL**<br>CCHPs, ductless CCHPs-full replacement, water heaters, dryers, stoves/cooktops<br>**Scenario 3 – HHP**<br>HHPs, DHPs-partial load, DHPs-new construction full replacement, water heaters, dryers, stoves/cooktops<br>**Scenario 4 – HHP&CCHP**<br>HHPs, DHPs-partial load, CCHPs, ductless CCHPs-full replacement, water heaters, dryers, stoves/cooktops | • Increase in electric sales at the same level for all scenarios<br>• Increase in equipment counts for ASHPs, water heaters, and cooking equipment at the same level for all scenarios | • Increase in electric sales at the same level for all scenarios |

After making these adjustments, we estimated the achievable potential for the four natural gas-to-electric conversion scenarios, shown in Table 23. Although PSE's electric distribution system incurs peak demand in winter, Cadmus also estimated the demand response potential for the summer season, shown in Table 24. The demand response potential shown in this report represents the achievable potential and includes both cost-effective and non-cost-effective demand response products.

### Table 23. Comparison of Achievable Potential: Base Case and Decarbonization Scenarios, Winter 2050

| Program | Product Option | Achievable Potential (MW) | | | | |
|---|---|---|---|---|---|---|
| | | Base Case | 1 – ASHP FULL | 2 – CCHP FULL | 3 – HHP | 4 – HHP&CCHP |
| Residential DLC Water Heat | Residential ERWH DLC Switch | 0 | 0 | 0 | 0 | 0 |
| | Residential ERWH DLC Grid-Enabled | 32 | 63 | 63 | 63 | 63 |
| | Residential HPWH DLC Switch | 0 | 0 | 0 | 0 | 0 |
| | Residential HPWH DLC Grid-Enabled | 58 | 114 | 114 | 114 | 114 |
| Residential DLC HVAC | Residential HVAC DLC Switch | 98 | 192 | 174 | 102 | 114 |
| | Residential Bring-Your-Own Thermostat (BYOT) DLC | 108 | 365 | 323 | 123 | 154 |
| Residential DLC EVSE | Residential EVSE DLC Switch | 42 | 42 | 42 | 42 | 42 |
| Residential CPP | Residential CPP | 33 | 45 | 41 | 33 | 33 |
| **Residential Sector Total** | | **371** | **821** | **757** | **477** | **520** |
| Non-Residential DLC HVAC | Medium Commercial HVAC DLC Switch | 18 | 45 | 45 | 45 | 45 |
| | Small Commercial HVAC DLC Switch | 3 | 7 | 7 | 7 | 7 |
| | Small Commercial BYOT DLC | 3 | 18 | 18 | 18 | 18 |
| C&I Curtailment | Commercial Curtailment | 16 | 19 | 19 | 19 | 19 |
| Commercial CPP | Commercial CPP | 21 | 24 | 24 | 24 | 24 |
| **Commercial Sector Total** | | **61** | **113** | **113** | **113** | **113** |
| C&I Curtailment | Industrial Curtailment | 5 | 6 | 6 | 6 | 6 |
| Industrial CPP | Industrial CPP | 2 | 2 | 2 | 2 | 2 |
| **Industrial Sector Total** | | **7** | **8** | **8** | **8** | **8** |
| **Total** | | **439** | **942** | **878** | **598** | **641** |

Note: The reported potential is at the generator, calculated by taking an electric line loss of 8.14% into account.

### Table 24. Comparison of Achievable Potential: Base Case and Decarbonization Scenarios, Summer 2050

| Program | Product Option | Achievable Potential (MW) | | | | |
|---|---|---|---|---|---|---|
| | | Base Case | 1 – ASHP FULL | 2 – CCHP FULL | 3 – HHP | 4 – HHP&CCHP |
| Residential DLC Water Heat | Residential ERWH DLC Switch | 0 | 0 | 0 | 0 | 0 |
| | Residential ERWH DLC Grid-Enabled | 22 | 42 | 42 | 42 | 42 |
| | Residential HPWH DLC Switch | 0 | 0 | 0 | 0 | 0 |
| | Residential HPWH DLC Grid-Enabled | 29 | 57 | 57 | 57 | 57 |
| Residential DLC HVAC | Residential HVAC DLC Switch | 50 | 68 | 68 | 68 | 68 |
| | Residential BYOT DLC | 100 | 187 | 187 | 187 | 187 |
| Residential DLC EVSE | Residential EVSE DLC Switch | 42 | 42 | 42 | 42 | 42 |
| Residential CPP | Residential CPP | 75 | 101 | 96 | 98 | 98 |
| **Residential Sector Total** | | **318** | **497** | **492** | **494** | **494** |
| Non-Residential DLC HVAC | Medium Commercial HVAC DLC Switch | 77 | 117 | 117 | 117 | 117 |
| | Small Commercial HVAC DLC Switch | 5 | 8 | 8 | 8 | 8 |
| | Small Commercial BYOT DLC | 4 | 9 | 9 | 9 | 9 |
| C&I Curtailment | Commercial Curtailment | 20 | 23 | 23 | 23 | 23 |
| Commercial CPP | Commercial CPP | 27 | 30 | 30 | 30 | 30 |
| **Commercial Sector Total** | | **133** | **187** | **187** | **187** | **187** |
| C&I Curtailment | Industrial Curtailment | 5 | 6 | 6 | 6 | 6 |
| Industrial CPP | Industrial CPP | 2 | 2 | 2 | 2 | 2 |
| **Industrial Sector Total** | | **7** | **8** | **8** | **8** | **8** |
| **Total** | | **458** | **692** | **687** | **689** | **689** |

Note: The reported potential is at the generator, calculated by taking electric line loss of 8.14% into account.

## *Scenario 1. Full Electrification with ASHPs*

Figure 28 presents the forecast of demand response achievable potential over the study period by product for Scenario 1 – ASHP FULL for winter. Product potential ramps up fast in the early years of the study and slows down once the market begins to reach maturity. The Residential DLC HVAC program, which includes the Residential HVAC DLC Switch and Residential BYOT DLC products, makes up most of the available winter demand response potential (59% of total achievable potential in 2050) due to the increased number of ASHPs. Residential DLC Water Heat has the second largest share of total achievable potential, at 19% in 2050, followed by Non-Residential DLC HVAC, at 7% in 2050.

**Figure 28. Demand Response Achievable Potential Forecast by Program for Scenario 1 – ASHP FULL, Winter**

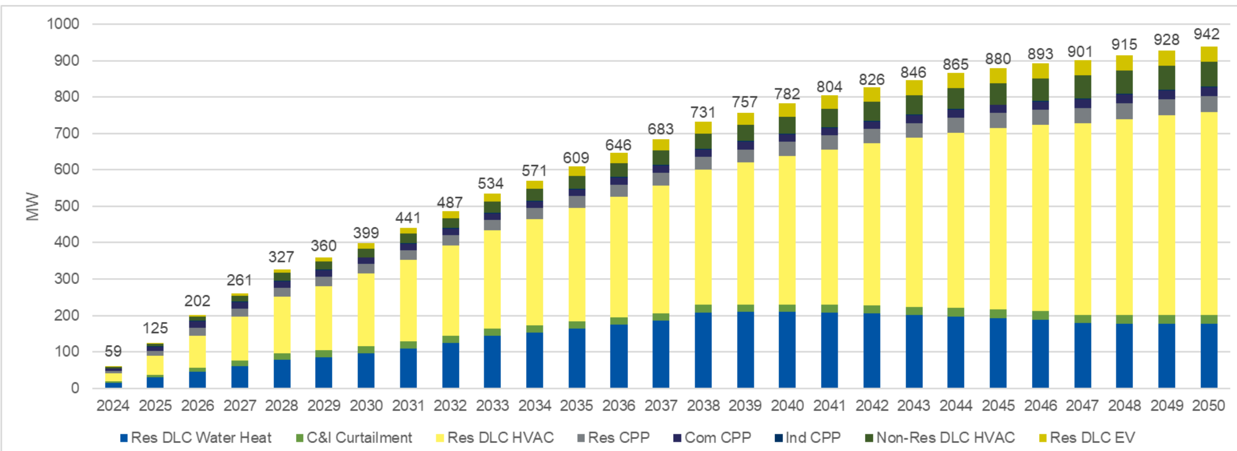
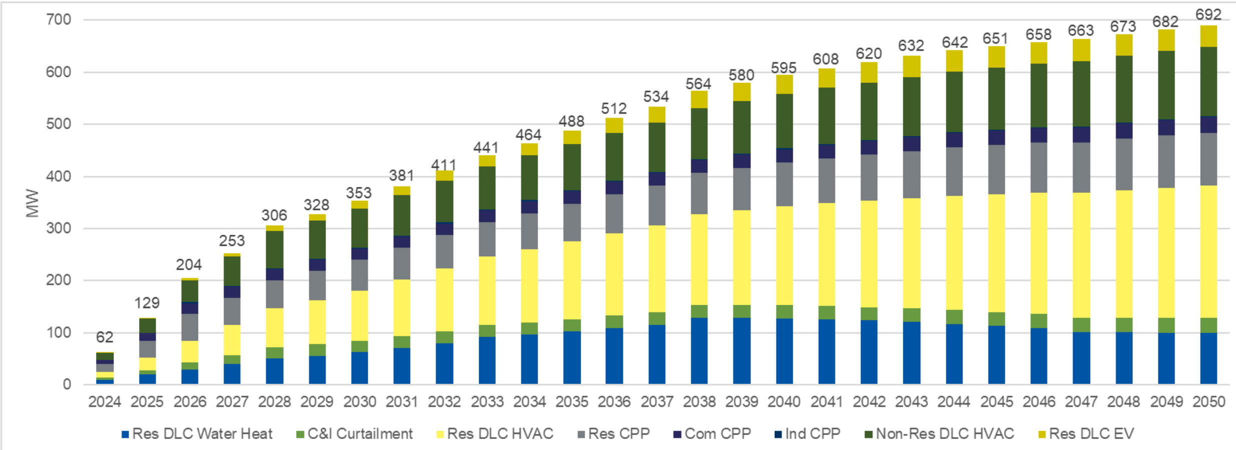



Figure 29 presents the forecast of for demand response achievable potential over the study period by product for Scenario 1 – ASHP FULL for summer. Similar to winter, the Residential DLC HVAC program has the largest share of total available summer demand response potential (37% of total achievable potential in 2050) due to the increased number of ASHPs. Non-Residential DLC HVAC has the second largest share of total achievable potential, at 19% in 2050, followed by Residential CPP, at 15% in 2050.

**Figure 29. Demand Response Achievable Potential Forecast by Program for Scenario 1 – ASHP FULL, Summer**




## *Scenario 2. Full Electrification with CCHPs*

Figure 30 presents the forecast of demand response achievable potential over the study period by product for Scenario 2 – CCHP FULL for winter. Similar to Scenario 1 – ASHP FULL, Residential DLC HVAC has the largest share of total available winter demand response potential, at 57% in 2050, due to the increased number of heat pumps, followed by Residential DLC Water Heat, at 20% in 2050.

**Figure 30. Demand Response Achievable Potential Forecast by Program for Scenario 2 – CCHP FULL, Winter**

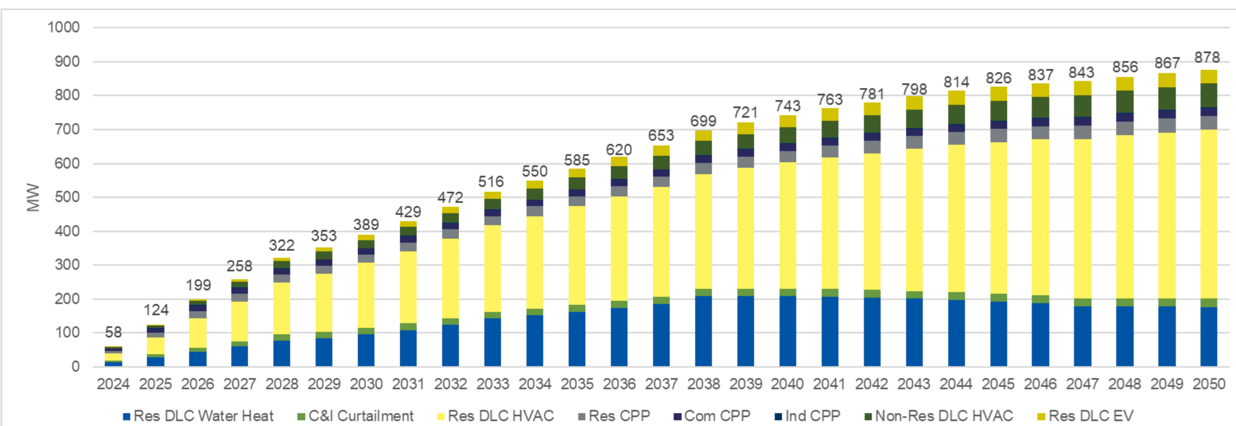
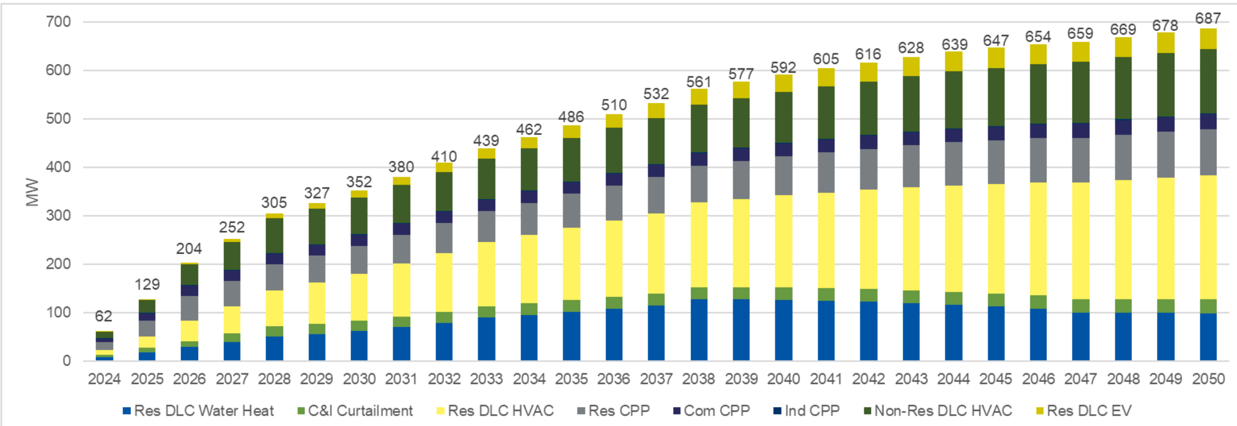



Figure 31 presents the forecast of demand response achievable potential over the study period by product for Scenario 2 – CCHP FULL for summer. Similar to Scenario 1 – ASHP FULL, Residential DLC HVAC has the largest share of total available summer demand response achievable potential (at 37% in 2050). Non-Residential DLC HVAC has the second largest share of total achievable potential, at 19% in 2050, followed by Residential CPP and Residential DLC Water Heat, at 14% each in 2050.

For this scenario, summer demand response potential is the same as that for Scenario 1 – ASHP FULL for all products because of having the same number of equipment as well as the same summer per-unit kilowatt impacts between these two scenarios.

**Figure 31. Demand Response Achievable Potential Forecast by Program for Scenario 2 – CCHP FULL, Summer**




## *Scenario 3. HHP with ASHPs*

Figure 32 presents the forecast of demand response achievable potential over the study period by product for Scenario 3 – HHP for winter. This scenario has the lowest total winter potential among all scenarios mainly because HHPs run on natural gas back-up equipment during winter peak demand hours and have no contribution to winter demand.

**Figure 32. Demand Response Achievable Potential Forecast by Program for Scenario 3 – HHP, Winter**

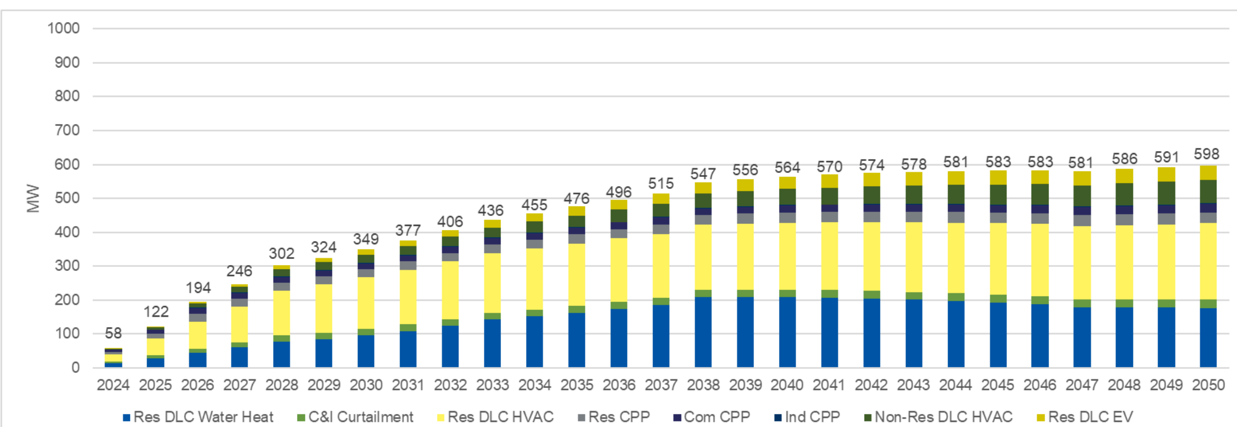
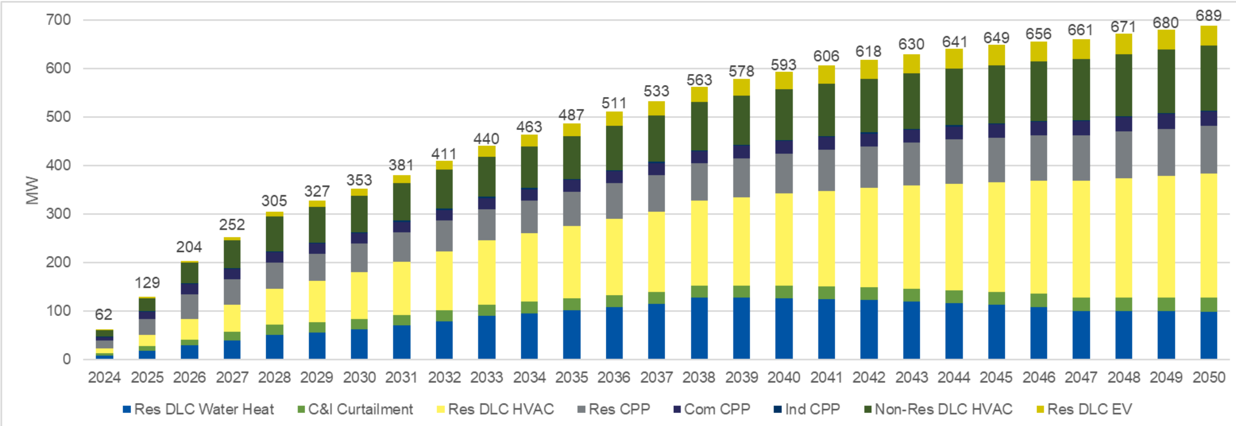



Figure 33 presents the forecast of demand response achievable potential over the study period by product for Scenario 3 – HHP for summer. The distribution of the potential among products and total demand response achievable potential for this scenario is very similar to Scenario 1 – ASHP FULL and Scenario 2 – CCHP FULL for summer.

Figure 33. Demand Response Achievable Potential Forecast by Program for Scenario 3 – HHP, Summer




## *Scenario 4. HHP with ASHPs for Existing Customers / CCHPs for New Customers*

Figure 34 presents the forecast of demand response achievable potential over the study period by product for Scenario 4 – HHP&CCHP for winter. This scenario has higher total winter potential than Scenario 3 – HHP due to having CCHPs in the equipment mix but has lower winter potential than Scenario 1 – ASHP FULL and Scenario 2 – CCHP FULL because HHPs run on natural gas back-up equipment during winter peak demand hours.

Figure 34. Demand Response Achievable Potential Forecast
by Program for Scenario 4 – HHP&CCHP, Winter

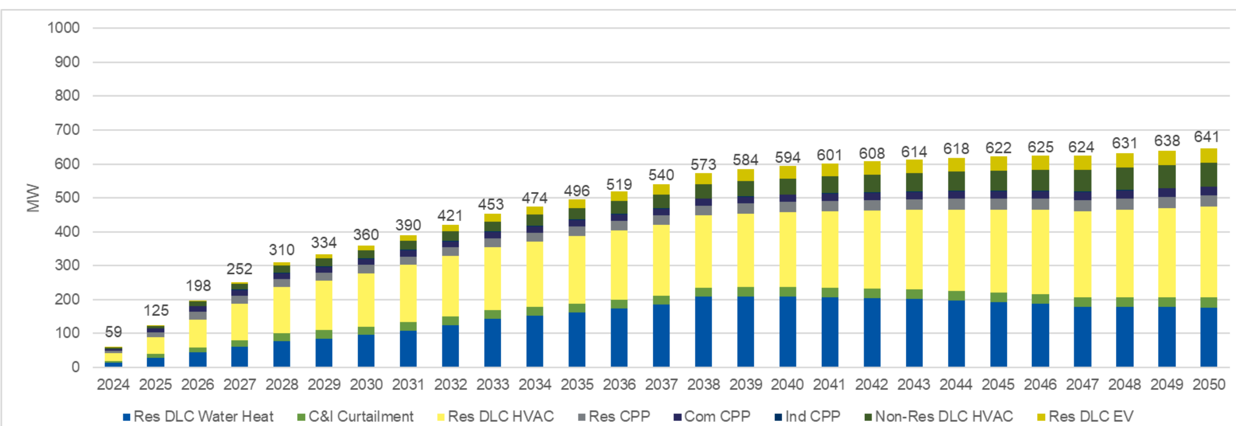
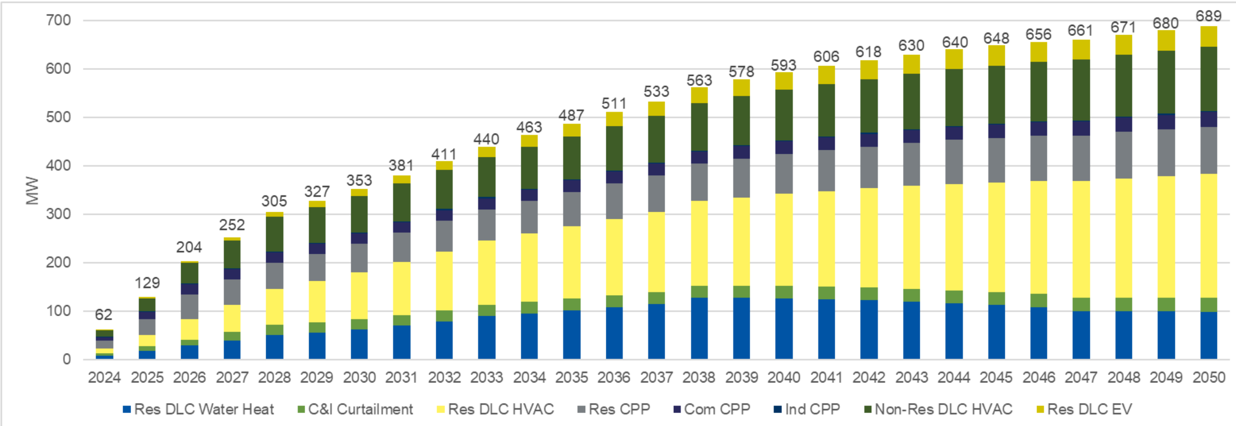



Figure 35 presents the forecast of demand response achievable potential over the study period by product for Scenario 4 – HHP&CCHP for summer. The distribution of the potential among products and total demand response achievable potential for this scenario is very similar to the other three scenarios for summer.

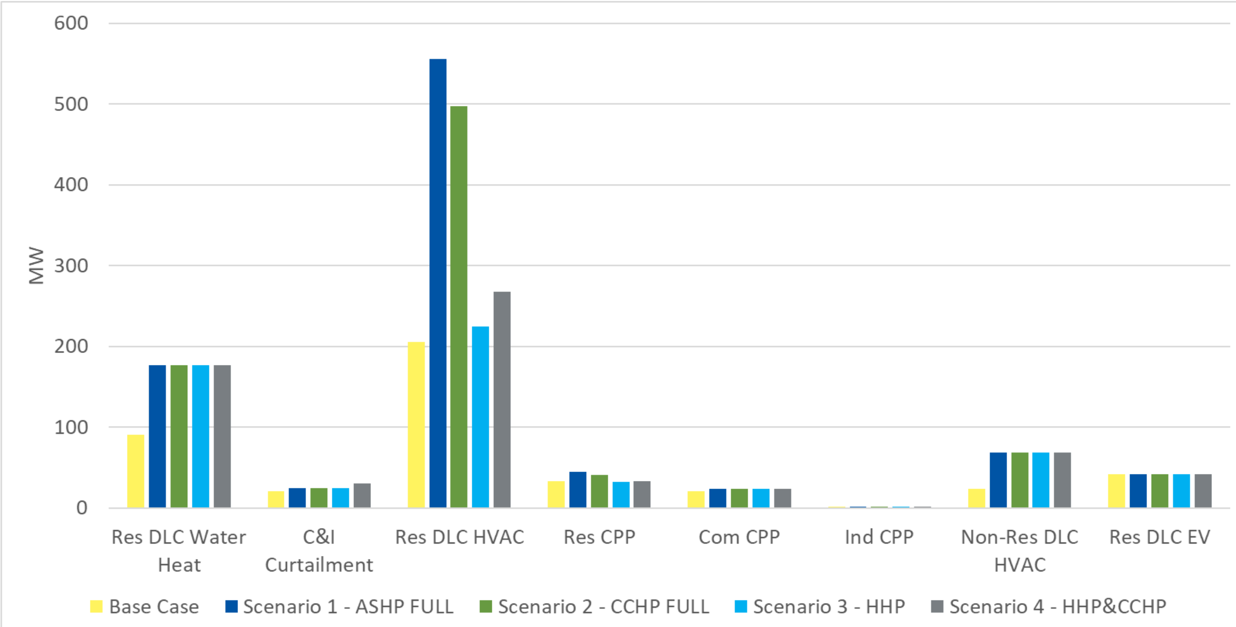
**Figure 35. Demand Response Achievable Potential Forecast by Program for Scenario 4 – HHP&CCHP, Summer**




## *Comparison of Decarbonization Scenarios with Base Case*

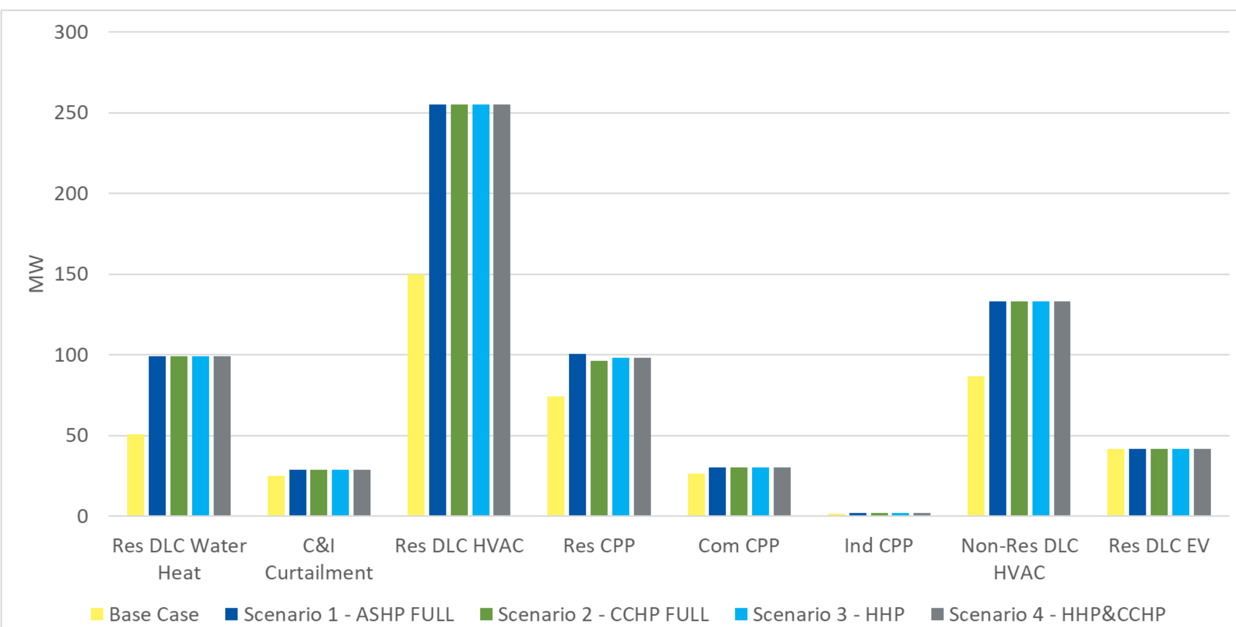
Figure 36 presents the impact of natural gas-to-electric conversion on winter demand response potential by comparing the base case (where there is no natural gas-to-electric conversion) with all four scenarios. As shown in the figure, except Residential DLC EV, all products were impacted by natural gas-to-electric conversion to some extent. In winter, the Non-Residential DLC HVAC product was the most impacted, with a 186% increase in achievable potential compared to the base case for all scenarios. This was followed by Residential DLC HVAC, with a 170% increase in achievable potential for Scenario 1 – ASHP FULL and a 141% increase for Scenario 2 – CCHP FULL. The impact on Residential DLC HVAC for Scenario 3 – HHP and Scenario 4 – HHP&CCHP were lower (at 9% and 30%, respectively) due to having HHPs in these scenarios where backup natural gas equipment was used during peak hours. The third mostly impacted product was Residential DLC Water Heat, with a 95% increase in achievable potential compared to the base case.

**Figure 36. Comparison of Demand Response Achievable Potential for Scenarios and Base Case, Winter 2050**




As mentioned before, even though PSE's electric distribution system incurs peak demand in winter, Cadmus also estimated the impact of natural gas-to-electric conversion on summer demand response potential, as shown in Figure 37. In summer, the Residential DLC Water Heat product was the most impacted, with a 95% increase in achievable potential compared to the base case. Residential DLC HVAC is the second most impacted product, with a 70% increase in achievable potential, followed by Non-Residential DLC HVAC, with a 54% increase compared to the base case.

**Figure 37. Comparison of Demand Response Achievable Potential for Scenarios and Base Case, Summer 2050**



# Appendix A: Heat Pump Load Shapes

As an attachment to this report, we are providing an Excel workbook that includes the load shapes for ducted and ductless CCHPs, non-CCHPs, and HHPs for each residential segment (single family, multifamily, and manufactured), vintage (new and existing construction), and equity (standard and vulnerable population) combination.

# Appendix B: Winter Peak Demand Estimates from Electrification

Table 25 through Table 27 present estimates of the winter peak demand impacts from electrification with CCHP and non-CCHP (ducted and ductless) across each of the 12 building segment, vintage, and equity combinations. The tables show the total impacts, as well as the impacts for heat pumps only and for electric resistance (ER) backup heating.

**Table 25. Single-Family Estimates of Winter Peak Demand Impacts from Electrification**

| Vintage, Equity, and Heat Pump Type Combination | Average Demand Impacts (kW) | | | | | |
|---|---|---|---|---|---|---|
| | CCHP (Total) | CCHP (HP Only) | CCHP (ER) | Non-CCHP (Total) | Non-CCHP (HP Only) | Non-CCHP (ER) |
| **Existing (Ducted)** | | | | | | |
| 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 |
| **Existing (Ductless)** | | | | | | |
| 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 |
| **Existing, Highly Impacted (Ducted)** | | | | | | |
| Peak Period | 1.63 | 1.48 | 0.14 | 1.84 | 1.54 | 0.30 |
| Peak Period (≤35°F) | 2.42 | 2.01 | 0.41 | 2.83 | 1.99 | 0.83 |
| Peak Period (≤27°F) | 3.46 | 2.20 | 1.26 | 4.05 | 2.03 | 2.02 |
| **Existing, Highly Impacted (Ductless)** | | | | | | |
| Peak Period | 1.54 | 1.54 | 0.00 | 1.74 | 1.62 | 0.12 |
| Peak Period (≤35°F) | 2.18 | 2.18 | 0.00 | 2.54 | 2.21 | 0.33 |
| Peak Period (≤27°F) | 2.72 | 2.72 | 0.00 | 3.53 | 2.44 | 1.09 |
| **New Construction (Ducted)** | | | | | | |
| Peak Period | 1.22 | 1.18 | 0.03 | 1.34 | 1.26 | 0.08 |
| Peak Period (≤35°F) | 1.75 | 1.66 | 0.09 | 1.96 | 1.73 | 0.22 |
| Peak Period (≤27°F) | 2.30 | 1.98 | 0.32 | 2.70 | 1.93 | 0.76 |
| **New Construction (Ductless)** | | | | | | |
| Peak Period | 1.20 | 1.20 | 0.00 | 1.31 | 1.29 | 0.03 |
| Peak Period (≤35°F) | 1.70 | 1.70 | 0.00 | 1.88 | 1.80 | 0.08 |
| Peak Period (≤27°F) | 2.11 | 2.11 | 0.00 | 2.43 | 2.15 | 0.27 |
| **New Construction, Highly Impacted (Ducted)** | | | | | | |
| Peak Period | 0.86 | 0.86 | 0.00 | 0.94 | 0.93 | 0.01 |
| Peak Period (≤35°F) | 1.22 | 1.22 | 0.00 | 1.33 | 1.31 | 0.02 |
| Peak Period (≤27°F) | 1.52 | 1.52 | 0.00 | 1.68 | 1.60 | 0.08 |
| **New Construction, Highly Impacted (Ductless)** | | | | | | |
| Peak Period | 0.86 | 0.86 | 0.00 | 0.93 | 0.93 | 0.00 |
| Peak Period (≤35°F) | 1.22 | 1.22 | 0.00 | 1.32 | 1.32 | 0.00 |
| Peak Period (≤27°F) | 1.52 | 1.52 | 0.00 | 1.64 | 1.64 | 0.00 |

**Table 26. Multifamily Estimates of Winter Peak Demand Impacts from Electrification**

| Vintage, Equity, and Heat Pump Type Combination | Average Demand Impacts (kW) | | | | | |
|---|---|---|---|---|---|---|
| | CCHP (Total) | CCHP (HP Only) | CCHP (ER) | Non-CCHP (Total) | Non-CCHP (HP Only) | Non-CCHP (ER) |
| **Existing (Ducted)** | | | | | | |
| Peak Period | 1.69 | 1.45 | 0.24 | 1.91 | 1.51 | 0.40 |
| Peak Period (≤35°F) | 2.66 | 1.98 | 0.68 | 3.07 | 1.96 | 1.11 |
| Peak Period (≤27°F) | 3.89 | 2.14 | 1.75 | 4.41 | 2.03 | 2.38 |
| **Existing (Ductless)** | | | | | | |
| Peak Period | 1.55 | 1.55 | 0.00 | 1.91 | 1.51 | 0.40 |
| Peak Period (≤35°F) | 2.26 | 2.26 | 0.00 | 3.07 | 1.96 | 1.11 |
| Peak Period (≤27°F) | 2.86 | 2.86 | 0.00 | 4.41 | 2.03 | 2.38 |
| **Existing, Highly Impacted (Ducted)** | | | | | | |
| Peak Period | 1.38 | 1.27 | 0.11 | 1.54 | 1.34 | 0.20 |
| Peak Period (≤35°F) | 2.09 | 1.79 | 0.30 | 2.39 | 1.82 | 0.57 |
| Peak Period (≤27°F) | 3.00 | 2.03 | 0.97 | 3.46 | 1.94 | 1.52 |
| **Existing, Highly Impacted (Ductless)** | | | | | | |
| Peak Period | 1.32 | 1.32 | 0.00 | 1.54 | 1.34 | 0.20 |
| Peak Period (≤35°F) | 1.92 | 1.92 | 0.00 | 2.39 | 1.82 | 0.57 |
| Peak Period (≤27°F) | 2.43 | 2.43 | 0.00 | 3.46 | 1.94 | 1.52 |
| **New Construction (Ducted)** | | | | | | |
| Peak Period | 0.87 | 0.86 | 0.01 | 0.95 | 0.93 | 0.02 |
| Peak Period (≤35°F) | 1.27 | 1.25 | 0.02 | 1.40 | 1.34 | 0.06 |
| Peak Period (≤27°F) | 1.64 | 1.57 | 0.06 | 1.84 | 1.63 | 0.21 |
| **New Construction (Ductless)** | | | | | | |
| Peak Period | 0.87 | 0.87 | 0.00 | 0.95 | 0.93 | 0.02 |
| Peak Period (≤35°F) | 1.26 | 1.26 | 0.00 | 1.40 | 1.34 | 0.06 |
| Peak Period (≤27°F) | 1.60 | 1.60 | 0.00 | 1.84 | 1.63 | 0.21 |
| **New Construction, Highly Impacted (Ducted)** | | | | | | |
| Peak Period | 0.74 | 0.74 | 0.00 | 0.80 | 0.79 | 0.01 |
| Peak Period (≤35°F) | 1.07 | 1.07 | 0.00 | 1.17 | 1.15 | 0.02 |
| Peak Period (≤27°F) | 1.36 | 1.36 | 0.00 | 1.50 | 1.43 | 0.06 |
| **New Construction, Highly Impacted (Ductless)** | | | | | | |
| Peak Period | 0.74 | 0.74 | 0.00 | 0.80 | 0.79 | 0.01 |
| Peak Period (≤35°F) | 1.07 | 1.07 | 0.00 | 1.17 | 1.15 | 0.02 |
| Peak Period (≤27°F) | 1.36 | 1.36 | 0.00 | 1.50 | 1.43 | 0.06 |

**Table 27. Manufactured Home Estimates of Winter Peak Demand Impacts from Electrification**

| Vintage, Equity, and Heat Pump Type Combination | Average Demand Impacts (kW) | | | | | |
|---|---|---|---|---|---|---|
| | CCHP (Total) | CCHP (HP Only) | CCHP (ER) | Non-CCHP (Total) | Non-CCHP (HP Only) | Non-CCHP (ER) |
| **Existing (Ducted)** | | | | | | |
| Peak Period | 1.96 | 1.83 | 0.13 | 2.21 | 1.92 | 0.29 |
| Peak Period (≤35°F) | 2.84 | 2.46 | 0.38 | 3.29 | 2.46 | 0.83 |
| Peak Period (≤27°F) | 3.96 | 2.74 | 1.22 | 4.69 | 2.54 | 2.16 |
| **Existing (Ductless)** | | | | | | |
| Peak Period | 1.88 | 1.88 | 0.00 | 2.21 | 1.92 | 0.29 |
| Peak Period (≤35°F) | 2.62 | 2.62 | 0.00 | 3.29 | 2.46 | 0.83 |
| Peak Period (≤27°F) | 3.25 | 3.25 | 0.00 | 4.69 | 2.54 | 2.16 |
| **Existing, Highly Impacted (Ducted)** | | | | | | |
| Peak Period | 1.51 | 1.42 | 0.09 | 1.70 | 1.50 | 0.20 |
| Peak Period (≤35°F) | 2.18 | 1.92 | 0.25 | 2.50 | 1.95 | 0.56 |
| Peak Period (≤27°F) | 3.01 | 2.17 | 0.84 | 3.56 | 2.03 | 1.53 |
| **Existing, Highly Impacted (Ductless)** | | | | | | |
| Peak Period | 1.46 | 1.46 | 0.00 | 1.62 | 1.55 | 0.07 |
| Peak Period (≤35°F) | 2.03 | 2.03 | 0.00 | 2.30 | 2.11 | 0.19 |
| Peak Period (≤27°F) | 2.52 | 2.52 | 0.00 | 3.09 | 2.40 | 0.69 |
| **New Construction (Ducted)** | | | | | | |
| Peak Period | 1.06 | 1.05 | 0.01 | 1.16 | 1.13 | 0.03 |
| Peak Period (≤35°F) | 1.47 | 1.45 | 0.02 | 1.62 | 1.54 | 0.08 |
| Peak Period (≤27°F) | 1.86 | 1.78 | 0.08 | 2.11 | 1.82 | 0.29 |
| **New Construction (Ductless)** | | | | | | |
| Peak Period | 1.05 | 1.05 | 0.00 | 1.16 | 1.13 | 0.03 |
| Peak Period (≤35°F) | 1.46 | 1.46 | 0.00 | 1.62 | 1.54 | 0.08 |
| Peak Period (≤27°F) | 1.81 | 1.81 | 0.00 | 2.11 | 1.82 | 0.29 |
| **New Construction, Highly Impacted (Ducted)** | | | | | | |
| Peak Period | 0.82 | 0.82 | 0.00 | 0.89 | 0.88 | 0.00 |
| Peak Period (≤35°F) | 1.13 | 1.13 | 0.00 | 1.23 | 1.22 | 0.00 |
| Peak Period (≤27°F) | 1.41 | 1.41 | 0.00 | 1.52 | 1.51 | 0.02 |
| **New Construction, Highly Impacted (Ductless)** | | | | | | |
| Peak Period | 0.82 | 0.82 | 0.00 | 0.89 | 0.88 | 0.00 |
| Peak Period (≤35°F) | 1.13 | 1.13 | 0.00 | 1.23 | 1.22 | 0.00 |
| Peak Period (≤27°F) | 1.41 | 1.41 | 0.00 | 1.52 | 1.51 | 0.02 |

# Appendix C: Methodology for Creating Load Shapes

Cadmus created the heat pump load shapes for each residential segment (single family, multifamily, and manufactured) using data from the NREL ResStock analysis tool,[46] corresponding temperature data, and field data we collected in Massachusetts and New York,[47] along with PSE-specific customer data.

NREL leveraged the U.S. DOE's open-source building energy modeling program EnergyPlus™ for the ResStock analysis tool and has run millions of simulations using a statistical model of housing stock characteristics to create the ResStock datasets. The datasets are available at different levels of granularity down to the level of Public Use Microdata Area (PUMA).

Cadmus first determined which PUMAs are in the PSE service territory. For this purpose, we leveraged the data generated for the PSE low-income household needs assessment study completed in December 2021[48]. Since the main focus of this decarbonization study was on the regions where PSE offers both natural gas and electric service (combined service territory), Cadmus selected the PUMAs where 100% of the PUMA is in PSE service territory and where 80% or more of the PUMA area was in the combined service territory. This analysis resulted in nine PUMAs (numbers 5311401, 5311504, 5311506, 5311607, 5311608, 5311609, 5311610, 5311613, and 5311614).

Cadmus used the ResStock natural gas heating end-use and cooling end-use load profiles generated using 2018 AMY weather data for single family, multifamily, and manufactured homes located in these nine PUMAs. We also obtained the corresponding AMY weather data used for ResStock building simulations from the ResStock data lake.[49] Using the number of households in each segment in each PUMA of interest (based on the data generated during the PSE low-income household needs assessment study), Cadmus weighted the temperature data to determine a single weather file applicable to all nine PUMAs for the specific segment. Similarly, using the number of households in each segment in each PUMA of interest, Cadmus weighted the end-use profile data to determine a single heating end-use profile applicable to each residential segment. We also weighted ResStock cooling electricity load profiles to eliminate buildings without cooling and to calibrate hourly consumption based on the varying efficiencies and types of cooling equipment indicated in the metadata.

PSE staff noted that 2018 AMY represented an unusually warm winter, and that the limited winter peak days represented in the 2018 AMY file might not be representative of a more typical year. Using a 2022

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46 National Renewable Energy Laboratory. Accessed February 19, 2023. "ResStock Analysis Tool." https://www.nrel.gov/buildings/resstock.html (data available at https://data.openei.org/s3_viewer?bucket=oedi-data-lake&prefix=nrel-pds-building-stock).

47 Cadmus. April 22, 2022. "Residential ccASHP Building Electrification Study." PowerPoint presentation. https://e4thefuture.org/wp-content/uploads/2022/06/Residential-ccASHP-Building-Electrification_060322.pdf

48 Cadmus, December 2021. "PSE Low-Income Household Needs Assessment. Phase 2 Report"

49 National Renewable Energy Laboratory. 2020. ResStock AMY2018 weather data. https://data.openei.org/nrel-pds-building-stock_end-use-load-profiles

weather file provided by PSE that represented its service territory, Cadmus conducted weather normalization regression analyses through PRInceton Scorekeeping Method (PRISM) modeling for the heating and cooling load shapes generated by ResStock to predict the heating and cooling loads for 2022. The methodology for the PRISM modeling is described below.

### *PRISM Modeling Methodology for Heating*

Cadmus estimated heating hourly PRISM type model specifications for several heating bases for single family, multifamily, and manufactured homes for CCHP heating load shapes. The original load shapes used 2018 AMY data and we developed models to weather normalize the hourly heating load to 2022 AMY data.

The hourly heating PRISM models generally used the following specification[50]:

$$Heat\_kW\_2018_t = \beta_1 HDH\_2018_t + \varepsilon_t$$

where for each hour '*t*':

| | | |
|---|---|---|
| $Heat\_kW\_2018_t$ | = | Hourly CCHP 2018 heating kilowatts |
| $\beta_1$ | = | The model space heating slope, which is the average change in hourly heating kilowatt usage resulting from an increase of one hourly heating degree hour (HDH_2018) |
| $HDH\_2018_t$ | = | The base 50°F to 70°F heating degree hours for Seattle Tacoma International Airport (SeaTac) for 2018 |
| $\varepsilon_{it}$ | = | The error term |

Using the best hourly model, Cadmus computed weather-normalized heating kilowatt predictions for 2022 weather for each of the 8,760 hours as follows:

$$Heat\_kW\_2022_t = \beta_1 HDH\_2022_t$$

where for each hour 't':

| | | |
|---|---|---|
| $Heat\_kW\_2022_t$ | = | Hourly CCHP weather-normalized 2022 heating kilowatts |
| $HDH\_2022_t$ | = | The base 50°F to 70°F hourly heating degree hours for SeaTac for 2022 |
| $\beta_1 HDH\_2022_t$ | | Hourly CCHP weather-normalized 2022 heating kilowatts |

### *PRISM Modeling Methodology for Cooling*

Cadmus estimated cooling hourly PRISM type model specification for several cooling bases for single family, multifamily, and manufactured homes for CCHP cooling load shapes. The original load shapes

50 There are 24 hourly models estimated for the year (since we have 8,760 observations in one year, the variation in the hourly models is the daily variation in the specific hour) so each hourly model has 365 observations included in the regression. We estimated separate models for each heating base reference temperature (from 50°F to 70°F). We selected the weather-normalized model in each hour with the highest r-squared for a heating degree hour base. The final selected (and best) heating models had bases ranging from 53°F to 68°F.

used 2018 AMY data and we developed models to weather normalize the hourly cooling load to 2022 AMY data.

The hourly cooling PRISM models generally used the following specification[51]:

$$Cool\_kW\_2018_t = \beta_1 CDH\_2018_t + \varepsilon_t$$

where for each hour '*t*':

| | | |
|---|---|---|
| *Cool_kW_2018t* | = | Hourly CCHP actual 2018 cooling kilowatts |
| $\beta_1$ | = | The model space cooling slope, which is the average change in hourly cooling kilowatt usage resulting from an increase of one hourly cooling degree hour (CDH_2018) |
| $CDH\_2018_t$ | = | The base 55°F to 70°F hourly cooling degree hours for SeaTac for 2018 |
| $\varepsilon_{it}$ | = | The error term |

Using the best hourly model, Cadmus computed weather-normalized cooling kilowatt predictions for 2022 weather for each of the 8,760 hours as follows:

$$Cool\_kW\_2022_t = \beta_1 CDH\_2022_t$$

where for each hour 't':

| | | |
|---|---|---|
| $Cool\_kW\_2022_t$ | = | Hourly CCHP weather-normalized 2022 cooling kilowatts |
| $CDH\_2022_t$ | = | The base 55°F to 70°F hourly cooling degree hours for SeaTac for 2022 |
| $\beta_1 CDH\_2022_t$ | = | Hourly CCHP weather-normalized 2022 cooling kilowatts |

Cadmus then calibrated these segment-specific end-use load profiles to the furnace and central AC consumptions used in PSE's 2023 IRP CPA by accounting for the vintage (new and existing) and equity (vulnerable population and standard). To calculate the amount of heating and cooling delivered by the natural gas furnaces and central ACs, Cadmus multiplied each hourly data point on the heating and cooling end-use load profile by the weighted average furnace efficiency (85.8% for existing and 95.3% for new construction) and by the weighted SEER of the central ACs (10.6 for existing and 14.1 for new construction), respectively.

We then converted the resulting natural gas furnace and central AC profiles to CCHP and non-CCHP profiles for both ducted and ductless equipment, assuming the heat pumps would need to deliver the same amount of hourly heating and cooling as the modeled natural gas furnace and central AC. Further calculations were completed to estimate the capacity, use of backup electric resistance, and efficiency at given outdoor air temperatures to develop complete load shapes, as discussed in the body of this report.

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51 There are 24 hourly models estimated for the year (since we have 8,760 observations in one year, the variation in the hourly models is the daily variation in the specific hour) so each hourly model has 365 observations included in the regression. We estimated separate models for each cooling base reference temperature (from 55°F to 70°F). We selected the weather-normalized model in each hour with the highest r-squared for a cooling degree hour base. The final selected (and best) cooling models had bases ranging from 55°F to 68°F.

# Appendix D: Costs of CCHPs and Other Heat Pump Technologies

As an attachment to this report, we are providing an Excel workbook that contains costs baseline and heat pump technologies and costs for panel upgrades, wiring, and duct/pad improvements.