CADMUS

# Comprehensive Assessment of Demand-Side Natural Gas Resource Potential (2024–2050)

## CONSERVATION POTENTIAL ASSESSMENT

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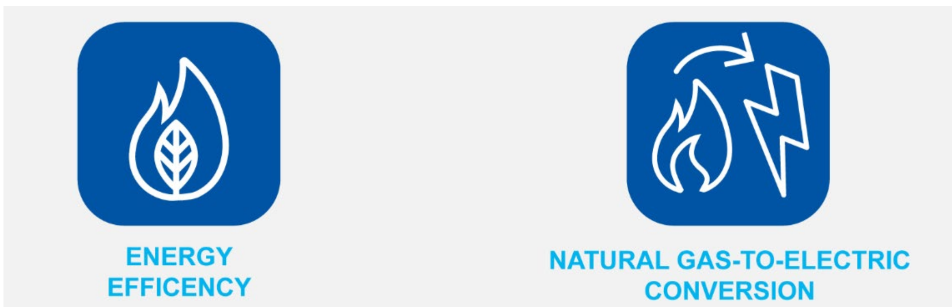
# Acronyms and Abbreviations

| Acronym | Definition |
|---|---|
| ASHP | Air-source heat pump |
| C&I | Commercial and industrial |
| CBSA | *Commercial Building Stock Assessment* |
| Council | Northwest Power and Conservation Council |
| CPA | Conservation potential assessment |
| CPP | Critical peak pricing |
| DHP | Ductless heat pump |
| DLC | Direct load control |
| ECM | Energy conservation measure |
| ERWH | Electric resistance water heater |
| EUL | Effective useful life |
| EVSE | Electric vehicle supply equipment |
| FMY | Future meteorological year |
| HPWH | Heat pump water heater |
| HVAC | Heating, ventilation, and air conditioning |
| IRP | Integrated resource plan |
| MMTherms | Million therms |
| NEEA | Northwest Energy Efficiency Alliance |
| NEI | Non-energy impact |
| O&M | Operations and maintenance |
| PSE | Puget Sound Energy |
| RBSA | *Residential Building Stock Assessment* |
| RCS | *Residential Characteristics Study* |
| RCW | Revised Code of Washington |
| RTF | Regional Technical Forum |
| T&D | Transmission and distribution |
| TMY | Typical meteorological year |
| UEC | Unit energy consumption |
| UES | Unit energy savings |
| WSEC | Washington State Energy Code |

# Executive Summary

This report presents the results of an independent assessment of the technical and achievable technical potential for natural gas demand-side resources in the service territory of Puget Sound Energy (PSE) over the 27-year planning horizon from 2024 to 2050. This conservation potential assessment (CPA), commissioned by PSE as part of its integrated resource planning (IRP) process, is intended to identify demand-side resource potential in terms of energy efficiency. This report also presents the results of an analysis on natural gas–to-electric conversion potential by investigating the effects of replacing natural gas equipment with electric equipment on electric and natural gas system load, evaluating associated measure impacts and costs, estimating electric and natural gas energy efficiency potential, and estimating the impacts of natural gas–to-electric conversion on demand response potential.




The results of this assessment will provide direct inputs into PSE's 2023 IRP and will help PSE to identify cost-effective demand-side resources and design future programming. This study builds upon previous assessments of demand-side resources in PSE's territory and accomplishes several objectives:

**FULFILLS WASHINGTON UTILITIES AND TRANSPORTATION COMMISSION REQUIREMENTS** set for natural gas assessments pursuant to the Revised Code of Washington (RCW 80.28.380), Gas Companies—Conservation Targets,[1] including conditions PSE agreed upon in the fall of 2021. The RCW requires that PSE identify and acquire all conservation measures that are available and cost-effective.

**DEVELOPS UP-TO-DATE ESTIMATES OF ENERGY CONSERVATION** datasets for the residential, commercial, and industrial sectors, as well as small transport customers, using measures consistent with PSE's program measures, the Regional Technical Forum (RTF), the Northwest Power and Conservation Council's (Council) draft *2021 Northwest Conservation and Electric Power Plan* (*2021 Power Plan*), and other data sources.

**PROVIDES INPUTS INTO PSE'S IRP**, which is completed every two years and determines the mixture of supply-side and demand-side resources required over the next 27 years to meet customer demand.

This study incorporates the latest baseline and energy demand-side resource data from various PSE-specific sources (such as PSE program measure business cases); the work of other entities in the region, such as the Council, the Northwest RTF, and the Northwest Energy Efficiency Alliance (NEEA); and other secondary sources (such as various technical reference manuals). The methods we used to evaluate the

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1 Revised Code of Washington. Accessed 2022. "RCW 80.28.380 Gas Companies—Conservation Targets." https://app.leg.wa.gov/RCW/default.aspx?cite=80.28.380&pdf=true

technical and achievable technical energy efficiency potential draw upon best utility industry practices and remain consistent with the methodology used by the Council in its draft *2021 Power Plan* as this assessment was being updated (in January 2022).

New in this CPA compared to prior CPAs, the natural gas study incorporates three additional considerations:

| CLIMATE CHANGE | NON-ENERGY IMPACTS (NEIs) | NAMED COMMUNITIES |
|---|---|---|

Cadmus adjusted weather-sensitive measures for the impacts of climate change, accounted for a wider range of NEIs, and estimated demand-side resource potential for named communities based on PSE's vulnerable population data. In addition, we assessed the impacts of recent state and local codes. All these topics are discussed in more detail in the main chapters of this report.

The PSE CPA results for electric demand-side resource potential in terms of energy efficiency, demand response, and distributed generation (including solar photovoltaics and combined heat and power) can be found in a separate companion report titled *Comprehensive Assessment of Demand-Side Electric Resource Potential (2024–2050)*.

## *Scope of the Analysis and Approach*

This section outlines the scope of the energy efficiency and natural gas–to-electric conversion potential analyses while briefly explaining the approach used for each analysis.

### Energy Efficiency

Cadmus estimated the technical and achievable technical potential for more than 175 unique gas energy efficiency measures. The energy efficiency analysis included estimates of the technical and achievable technical potential for natural gas energy efficiency measures. We relied on PSE program data, RTF analysis, the Council's draft *2021 Power Plan* analyses, and regional stock assessments to determine the savings, costs, and applicability for each measure. We also incorporated feedback from PSE staff and regional stakeholders on the list of measures and measure assumptions.

Cadmus prepared 27-year forecasts of potential natural gas energy savings for each energy efficiency measure using an end use–based model. We considered multiple sectors, segments, and vintages, distinguishing between lost opportunity and retrofit measures and accounting for building energy codes as well as future state and federal equipment standards. Achievable technical potential estimates use assumptions that are consistent with the Council's draft *2021 Power Plan*: 85% to 100% of technical potential is achieved over the 27-year study horizon and adoption curves are derived from the Council's draft *2021 Power Plan* ramp rates and 10-year ramp rates for discretionary measures (consistent with PSE's prior CPAs). A detailed discussion of the energy efficiency potential is included in *Chapter 1. Energy Efficiency Potential*.

## Energy Efficiency Potential for Small Transport Customer Sector

Small transport is a class of customers who had less than an average of 25,000 tons of annual carbon dioxide emission per Mscf of their natural gas consumption in the time frame of 2015 through 2019. Per the Climate Commitment Act, PSE included their small transport customer sector into this CPA as a compliance requirement.

## Natural Gas–to-Electric Conversion Potential

In addition to the energy efficiency technical and achievable technical potential, Cadmus also estimated natural gas–to-electric conversion potential by investigating the effects of replacing natural gas equipment with electric equipment on electric and natural gas system load, evaluating associated measure impacts and costs, and estimating electric and natural gas energy efficiency potential in the residential and commercial sectors. We calculated potential for the industrial sector by converting a portion (~30%) of natural gas loads based on prior analysis by Cadmus.

As part of the natural gas–to-electric conversion potential assessment, Cadmus conducted a heat pump market research study and fielded an online customer survey (862 surveys completed) for measuring the residential sector's willingness to pay for natural gas conversions to heat pumps. We also interviewed contractors and builders (14 interviews completed) in PSE's service territory to determine heat pump (hybrid, ductless, ducted, and other) conversion costs, including any additional costs to convert to electric from non-electric equipment, such as electrical panel or wiring upgrades, duct reconfiguration, and added labor costs. The data collected through the survey and interviews supported the analysis for determining the adaption rates and conversion costs.

For the residential sector, Cadmus conducted the natural gas–to-electric conversion potential analysis under three different scenarios:

**HYBRID HEAT PUMP – MARKET**

Cadmus analyzed the effects of a conversion from natural gas heating equipment (such as a natural gas furnace and ductless natural gas heating) to a heat pump (such as a ductless and ducted air-source heat pump [ASHP]) while keeping the natural gas heating equipment as the backup. We obtained the market adoption rates for this scenario from the customer survey.

**HYBRID HEAT PUMP – POLICY**

Cadmus analyzed the effects of a conversion from natural gas heating equipment to a heat pump while keeping the natural gas heating equipment as the backup but, unlike the previous scenario, we adjusted the market adoption rate to a maximum where 100% of applicable residential applications have a hybrid heat pump or ductless system with natural gas back-up. This scenario is meant to represent a policy change where all residential customers are required to convert to a hybrid heat pump at the end of the natural gas equipment's useful life.

**FULL ELECTRIFICATION – POLICY**

Cadmus analyzed the effects of a conversion from natural gas heating equipment to a heat pump without keeping the natural gas heating equipment and assumed full adoption (where the market adaption rate equals 100%) to represent a policy change banning natural gas usage and forcing all customers to convert to heat pumps at the end of the natural gas equipment's useful life.

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

Natural gas–to-electric conversion resulted in an increase in electric load and associated electric energy efficiency potential while reducing the natural gas load and associated natural gas energy efficiency potential.[2] Since the CPA looks at the impacts on PSE systems, these impacts are reflected on corresponding services provided by PSE in its territory:

| *PSE ELECTRIC-ONLY SERVICE AREA* | PSE NATURAL GAS-ONLY SERVICE AREA | PSE COMBINATION SERVICE AREA |
| --- | --- | --- |
| Increase in PSE electric load | Decrease in PSE natural gas load | Increase in PSE electric load<br>Decrease in PSE natural gas load |

As the last step of this natural gas–to-electric conversion potential assessment, Cadmus analyzed the impacts of these changes on demand response potential, with the results presented in the *Effect of Natural Gas-to-Electric Conversion on Demand Response Potential* section of *Chapter 3. Natural Gas-to-Electric Potential Assessment.*

2 The assessment estimated the load and energy efficiency impact from shifting from natural gas to electric equipment. The base CPA also estimated the impact associated with codes and standards. However this CPA did not revaluate the codes and standards impact accounting for the shift in natural gas to electric conversion.

## *Summary of Results*

Natural gas energy efficiency represents nearly 192 million therms (MMTherms) of 27-year achievable technical potential and produces 44,180 therms of average coincident peak capacity savings[3], for residential, commercial and industrial sectors as well as small transport customers, as shown in Table 1. All estimates of potential in this report are presented at the generator, which means they include line losses of 0.93%.

**Table 1. Summary of Energy Savings and Peak Capacity Reduction Potential, Cumulative 2050**

| Resource | Energy (MMTherm) | | Winter Coincident Peak Capacity (Peak Therm) | |
|---|---|---|---|---|
| | Technical Potential | Achievable Technical Potential | Technical Potential | Achievable Technical Potential |
| Energy Efficiency (Residential, Commercial, Industrial) | 201 | 165 | 48,040 | 39,625 |
| Energy Efficiency (Transport) | 31 | 26 | 5,408 | 4,555 |

Figure 1 presents the achievable technical potential forecast of natural gas energy efficiency. More savings are achieved in the first 10 years of the study (2024 through 2033) than in the remaining 17 years because the study assumes that discretionary measure potential savings are acquired in the first 10 years (for a selected set of measures that are retrofit in existing homes and businesses). In the remaining years, additional savings come from lost opportunity measures, such as equipment replacement and new construction.

**Figure 1. Achievable Technical Potential Forecast, Cumulative 2024–2050**

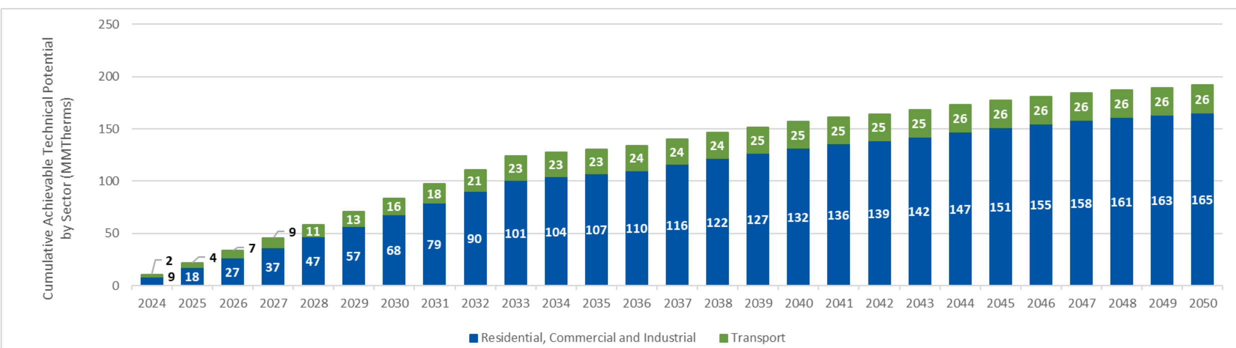


Table 2 presents the total achievable technical potential for natural gas energy efficiency broken out by sector. If the 27-year achievable technical potential is realized, it will produce a load reduction equivalent to 17% of PSE's 2050 baseline natural gas sales. Approximately 58% of this potential is in the residential sector, while 27% is in the commercial sector, 14% is in small transport customer sector, and the remaining 2% is in the industrial sector.

[3] The peak capacity savings represent the average peak impact across all hours occurring in December within hour ending 8AM to hour ending 10AM and hour ending 6PM to hour ending 7PM. This average peak impact does not represent PSE's peak day estimation.

**Table 2. Energy Efficiency by Sector, Cumulative 2050**

| Sector | 2050 Baseline Sales (MMTherm) | Achievable Technical Potential | |
|---|---|---|---|
| | | MMTherm | Percentage of Baseline Sales |
| Residential | 617 | 111 | 18% |
| Commercial | 293 | 51 | 18% |
| Industrial | 18 | 3 | 18% |
| Transport | 178 | 26 | 15% |
| **Total** | **1,106** | **192** | **17%** |

### *Comparison to 2021 CPA*

Cadmus incorporated some changes in the 2023 energy efficiency analysis since the completion of PSE's previous CPA in 2021:

- Used an end-use–based approach instead of a units-based approach, as was used in 2021 CPA. This end-use approach is more dynamic for end-use scenario analysis and includes the ability to better account for climate change and natural gas–to-electric load impacts.
- Used PSE's most recent "2022 Demand Forecast" for energy and number of customers.
- Incorporated assumptions for savings, cost, and measure lives derived from PSE's 2022 measure business cases and the RTF's unit energy savings (UES) workbook updates as of January 2022.
- Used the most recent PSE-specific data and regional stock assessments to determine saturations and applicability, including PSE's 2021 Residential Characteristics Study (RCS), NEEA's 2017 *Residential Building Stock Assessment II* (RBSA), and NEEA's 2019 *Commercial Building Stock Assessment* (CBSA),[4] which is PSE-specific for some segments.
- Accounted for recent PSE program accomplishments from high impact program measures (commercial lighting, HVAC equipment, etc.)
- Accounted for the tightening Washington State Energy Code (WSEC) (RCW 19.27A.160),[5] which requires that "… residential and nonresidential construction permitted under the 2031 state energy code achieve a 70% reduction in annual net energy consumption, using the adopted 2006 Washington state energy code as a baseline."

4 Cadmus. May 21, 2020. *Commercial Building Stock Assessment 4 (2019)*. "CBSA 4 Appendix Tables (Weighted)." Prepared for Northwest Energy Efficiency Alliance. https://neea.org/resources/cbsa-4-appendix-tables-weighted

5 Revised Code of Washington. Accessed August 24, 2022. "RCW 19.27A.160 Residential and Nonresidential Construction— Energy Consumption Reduction—Council Report." https://app.leg.wa.gov/RCW/default.aspx?cite=19.27A.160

- Accounted for updates in the Seattle Building Energy Code, which requires all new commercial buildings and large multifamily buildings above three stories to use clean electricity for space and water heating and to maximize building efficiency and on-site renewables like solar.[6]
- Accounted for ordinances passed by city of Shoreline[7] and city of Bellingham[8] for promoting energy efficiency and the decarbonization of commercial and large multifamily buildings and requiring solar readiness for new buildings.
- Accounted for recent changes to federal equipment standards.
- Accounted for the impacts of climate change by using *2021 Power Plan* data and PSE's load forecast and by adjusting weather-sensitive measures by applying the Council's typical meteorological year (TMY) to projected future meteorological year (FMY) adjustment factors to weather-sensitive RTF and PSE business case measures by calibrating the CPA heating end uses with PSE's climate impacts within the annual load forecast.
- Considered a wider range of NEIs (such as comfort, productivity, and health) based on a recent study conducted for PSE.[9]
- Estimated the demand-side resource potential for named communities based on PSE's recent vulnerable population data. This data has a somewhat similar overlay as highly impacted communities, defined by the Washington State Department of Health according to a ranking based on environmental burdens (including fossil fuel pollution and vulnerability to climate change impacts that contribute to health inequities), and best aligned with CPA geographic areas (county-level areas built up from block groups).
- Expanded the bundles on the supply curve and increased the number of bundles from 12 to 18.

Table 3 shows a comparison of the 20-year achievable technical potential, expressed as a percentage of baseline sales, identified in the 2023 and 2021 CPAs. Overall, the 2023 CPA identified 18% lower natural gas achievable technical potential.

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6 The implementation of space and water heating measures took effect in January 2022. The rest of the code went into effect on March 15, 2021 (see Christensen, Eric L., Kirstin K. Gruver, and Rujeko A. Muza. February 4, 2021. "Seattle Bans Natural Gas in New Buildings." *The National Law Review* (Volume XII), Number 241. https://www.natlawreview.com/article/seattle-bans-natural-gas-new-buildings).

7 Ordinance No. 948 "Ordinance of the City of Shoreline, Washington Amending Chapter 15.05, Construction and Building Codes, of the Shoreline Municipal Code, to Provide Amendments to the Washington State Energy Code – Commercial, as Adopted by the State of Washington" took effect on July 1, 2022.

8 "Ordinance of the City of Bellingham Amending Bellingham Municipal Code Chapter 17.10 – Building Codes, to Provide Amendments to the Washington State Energy Code – Commercial, Promoting Energy Efficiency and the Decarbonization of Commercial and Large Multifamily Buildings and Requiring Solar Readiness for New Buildings" took effect on August 7, 2022.

9 DNV Energy. September 30, 2021. *Puget Sound Energy Non-Energy Impacts Final Report*.

**Table 3. Energy Efficiency Comparison of 2023 CPA and 2021 CPA**

| Study | 20-Year Achievable Technical Potential (Percentage of Sales) | | | Total Achievable Technical Potential (MMTherms) |
|---|---|---|---|---|
| | Residential | Commercial | Industrial | |
| 2023 CPA | 15% | 16% | 17% | 142 |
| 2021 CPA | 19% | 7% | 8% | 174 |

Note: This table shows a comparison of 20-year results from the 2023 CPA to 20-year results from the 2021 CPA. The 2023 CPA total achievable technical potential differs from the amount shown in Table 2, which presents the full 27-year potential study results. The 2023 CPA total achievable technical potential is excluding small transport customers, as this sector was not included in the 2021 CPA.

Several factors contributed to the significant changes in natural gas energy efficiency potential between the 2021 CPA and 2023 CPA:

**NEW CONSTRUCTION**

- Reduction in new construction (residential and commercial) achievable technical potential due to state and local code updates.

**RESIDENTIAL**

- Reduction in showerhead potential due to the Washington Administrative Code (WAC 51-56-0400).
- Lower residential natural gas furnace potential through lower unit energy consumption (UEC) due to climate change impacts and an associated decrease in heating loads.

**COMMERCIAL**

- Higher potential identified in higher cost measures such as building management systems and retro-commissioning.
- Updated customer segmentation that impacted the characterization and distribution of potential within each segment.

**INDUSTRIAL**

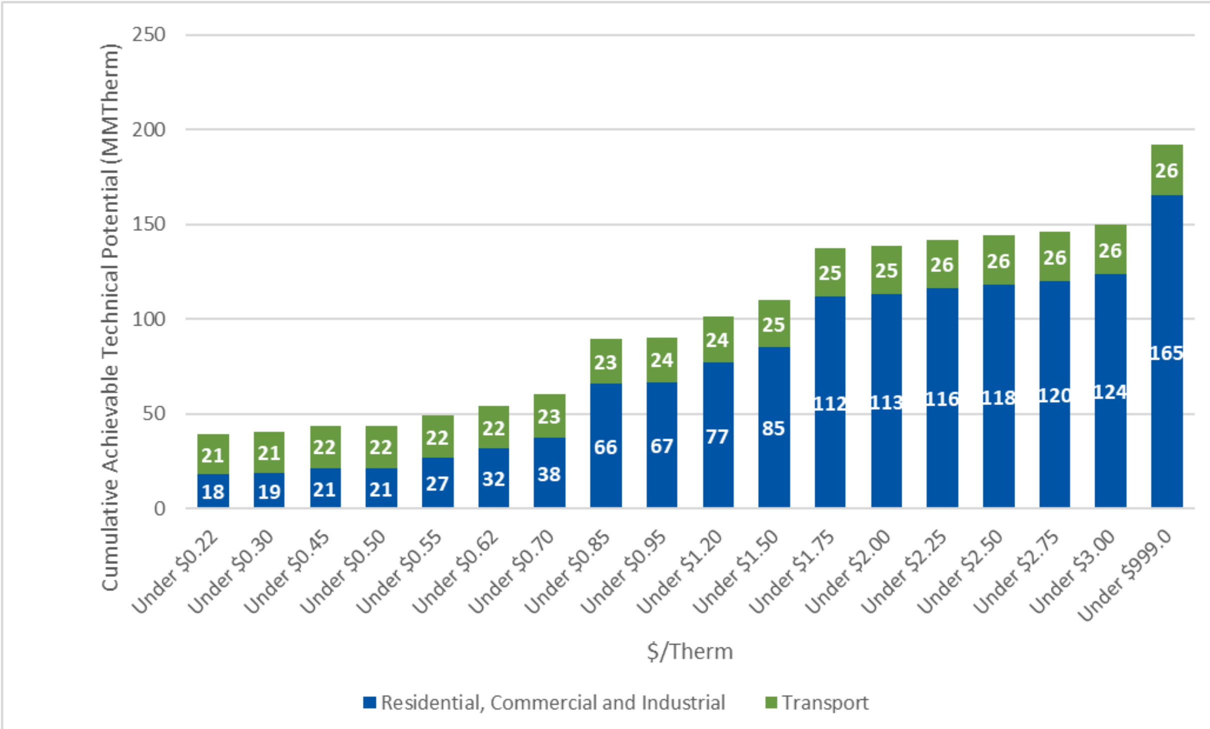
- Updated customer segmentation that impacted the characterization and distribution of potential within each segment.

## *Incorporating Demand-Side Resources into PSE's Integrated Resources Plan*

Cadmus grouped the achievable technical potential shown above by the levelized cost of conserved energy for inclusion in PSE's IRP model. We calculated these costs over a 27-year study period. The *Integrated Resource Plan Input Development* section of *Chapter 4. Energy Efficiency Methodology Details* provides additional detail on the levelized cost methodology. Bundling resources into a number of distinct cost groups allows the model to select the optimal amount of annual demand-side resources based on expected load growth, energy prices, and other factors. Cadmus provides IRP input data by levelized cost bundle (or bins) and we did not incorporate an economic screen on the demand-side resources; instead, we used the CPA IRP inputs to inform PSE's optimization modeling that select the least-cost (most cost-effective) resource.

Cadmus spread the annual savings estimates over 8760-hour load shapes to produce monthly demand-side resource bundles as well as locational estimates by PSE service area zip code. In addition, we assumed that savings are gradually acquired over the year, as opposed to instantly happening on the first day of January. PSE provided intra-year demand-side resource acquisition schedules, which we used to ramp savings across months. Figure 2 shows the annual cumulative potential for energy efficiency by each cost bundle considered in PSE's 2023 IRP.

**Figure 2. Natural Gas Supply Curve – Cumulative 27-Year Achievable Technical Potential**




## *Organization of This Report*

This report presents the findings of demand-side natural gas resource potential assessment in several chapters and four appendices:

- *Chapter 1. Energy Efficiency Potential* includes an overview of the methodology Cadmus and PSE used to estimate technical and achievable technical potential as well as detailed sector, segment, and end-use–specific estimates of conservation potential for the residential, commercial, and industrial sectors. This chapter also presents a discussion of the top-saving measures in each sector and comparison with PSE's 2021 CPA.
- *Chapter 2. Energy Efficiency Potential for Small Transport Customer Sector* presents and discusses the forecasts of technical and achievable technical potential for the small transport customer sector.
- *Chapter 3. Natural Gas-to-Electric Potential* presents and discusses the results of three different scenarios Cadmus ran on energy efficiency potential as explained above. This chapter also presents the impacts of natural gas-to-electric conversion on demand response potential.
- *Chapter 4. Energy Efficiency Methodology Details* describes Cadmus' combined top-down, bottom-up modeling approach for calculating technical and achievable technical potential by giving details on the steps for estimating energy efficiency potential.
- *Appendix A* presents the heat pump market research findings in the form of PowerPoint slides.
- *Appendix B* presents heat pump customer survey questions.
- *Appendix C* presents heat pump contractor interview questions.

- *Appendix D* presents heat pump builder interview questions.

# Chapter 1. Energy Efficiency Potential

PSE requires accurate estimates of technical and achievable technical energy efficiency potential, which are essential for its IRP and program planning efforts. PSE then bundles these potentials in terms of the levelized costs of conserved energy so the IRP model can be used to determine the optimal amount of energy efficiency potential.

To support these efforts, Cadmus performed an in-depth assessment of technical potential and achievable technical potential for natural gas resources in the residential, commercial, industrial, and small transport customer sectors. The *Energy Efficiency Potential - Methodology Overview* section gives an overview of the methodology we used for this purpose, which is then described in greater detail in *Chapter 4. Energy Efficiency Methodology Details*. The methodology below is followed by an explanation of considerations about the design of this potential study. Lastly, the results of energy efficiency potential assessment for residential, commercial, and industrial sectors are presented in detail. The results for small transport customer sector are discussed separately in *Chapter 2. Energy Efficiency Potential for Small Transport Customer Sector*.

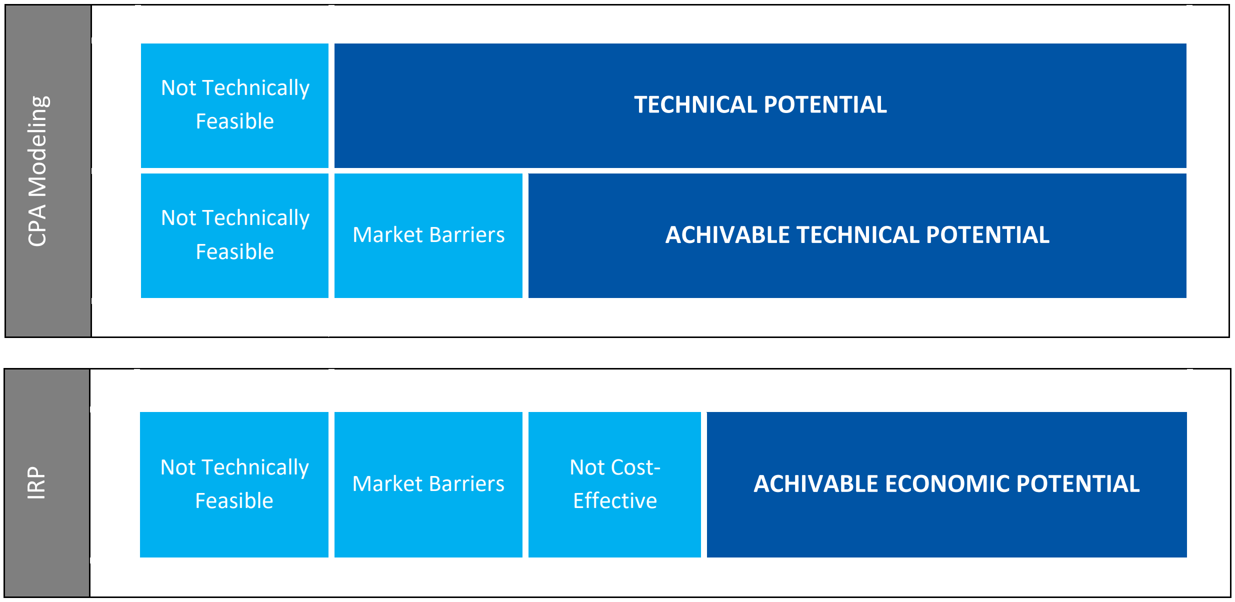
## *Energy Efficiency Potential - Methodology Overview*

Consistent with the Washington Administrative Code requirements, Cadmus assessed two types of energy efficiency potential—technical and achievable technical. PSE determined a third type of potential—achievable economic—through the IRP's optimization modeling. These three types of potential are illustrated in Figure 3.

- ***Technical potential*** assumes that all technically feasible resource opportunities may be captured, regardless of their costs or other market barriers. It represents the total energy efficiency potential in PSE's service territory, after accounting for purely technical constraints.
- ***Achievable technical potential*** is the portion of technical potential assumed to be achievable during the study's forecast, regardless of the acquisition mechanism. For example, savings may be acquired through utility programs, improved codes and standards, and market transformation.
- ***Achievable economic potential*** is the portion of achievable technical potential determined to be cost-effective by the IRP's optimization modeling, in which either bundles or individual energy efficiency measures are selected based on costs and savings. The cumulative potential for these selected bundles constitutes achievable economic potential.

Cadmus provided PSE with forecasts of achievable technical potential, which PSE then entered as variables in the IRP's optimization model to determine achievable economic potential.

**Figure 3. Types of Energy Efficiency Potential**




The timing of resource availability is a key consideration in determining conservation potential. There are two distinct categories of resources:

- ***Discretionary resources*** are retrofit opportunities in existing facilities that, theoretically, are available at any point over the study period. Discretionary resources are also referred to as retrofit measures. Examples include weatherization and shell upgrades, furnace tune-ups, and low-flow showerheads.
- ***Lost opportunity resources***, such as conservation opportunities in new construction and replacements of equipment upon failure (natural replacement), are nondiscretionary. These resources become available according to economic and technical factors beyond a program administrator's control. Examples of natural replacement measures include HVAC equipment, water heaters, and appliances.

Cadmus analyzed four sectors—residential, commercial, industrial, and small transport—and, where applicable, considered multiple market segments, construction vintages (new and existing), and end uses. The details of small transport customer sector are given separately in *Chapter 2. Energy Efficiency Potential for Small Transport Customer Sector*.

| **RESIDENTIAL** | **COMMERCIAL** | **INDUSTRIAL** |
|---|---|---|
| **SIX SEGMENTS**<br>Single family, multifamily, manufactured, single family - vulnerable population, multifamily - vulnerable population, and manufactured - vulnerable population | **EIGHTEEN SEGMENTS**<br>Office, retail, and food sales segments further divided into categories based on building size, aligning with the *2021 Power Plan* | **EIGHTEEN SEGMENTS**<br>Paper, chemical, wood, hi-tech, and additional manufacturing segment types that align with the *2021 Power Plan* |

> **Vulnerable Populations Attributes**
> Identified as socioeconomic factors including unemployment, high housing and transportation costs relative to income, low access to food and health care, and linguistic isolation. Includes sensitivity factors, such as low birth weight and higher rates of hospitalization.
>
> **Highly Impacted Communities**
> Ranks communities with environmental burdens including fossil fuel pollution and vulnerability to climate change impacts that contribute to health inequities. Includes any census tract with tribal lands.

For this study, Cadmus defined PSE's named communities and equity to represent the vulnerable population and highly impacted communities within the PSE's service area (defined on the right). We reviewed the data available and determined that the vulnerable population data best aligned with the CPA geographic areas (such as the county level built up from block groups). As a result, we used the vulnerable population data (over the highly impacted communities data) as basis of our analysis within this study. Cadmus segmented PSE residential accounts for vulnerable populations by county and used PSE 2021 RCS data to inform equipment saturations and fuel shares for the vulnerable population (based on income).

Cadmus used an end-use approach to forecast energy efficiency potential in all four sectors, taking several primary steps:

- Developed the baseline forecast by determining the 27-year future energy consumption by segment and end use. Calibrated the base year (2023) to PSE's sector level load forecast produced in 2022. Baseline forecasts in this report included the estimated impacts of climate change and of codes and standards on commercial and residential energy usage.
- Estimated technical potential based on the incremental difference between the baseline load forecast and an alternative forecast reflecting the technical impacts of specific energy efficiency measures.
- Estimated achievable technical potential by applying ramp rates and achievability percentages to technical potential, described in greater detail in *Chapter 4. Energy Efficiency Methodology Details*.

There are two advantages offered by this approach:

- Savings estimates were driven by a baseline forecast that is consistent with the assumptions used in PSE's adopted 2022 corporate load forecast.
- It helped to maintain consistency among all assumptions underlying the baseline and alternative forecasts for technical and achievable technical potential. The alternative forecasts used different relevant inputs at the end-use level to reflect energy conservation measure (ECM) impacts. Because estimated savings represent the difference between baseline and alternative forecasts, they could be directly attributed to specific changes made to analysis inputs.

Cadmus' methodology can be best described as a combined top-down, bottom-up approach for the residential and commercial sectors. As shown in Figure 4, we began the top-down component with the most current load forecast, adjusting for building codes, equipment efficiency standards, and market trends. Cadmus then disaggregated this load forecast into its constituent customer sectors, customer segments, and end-use components.

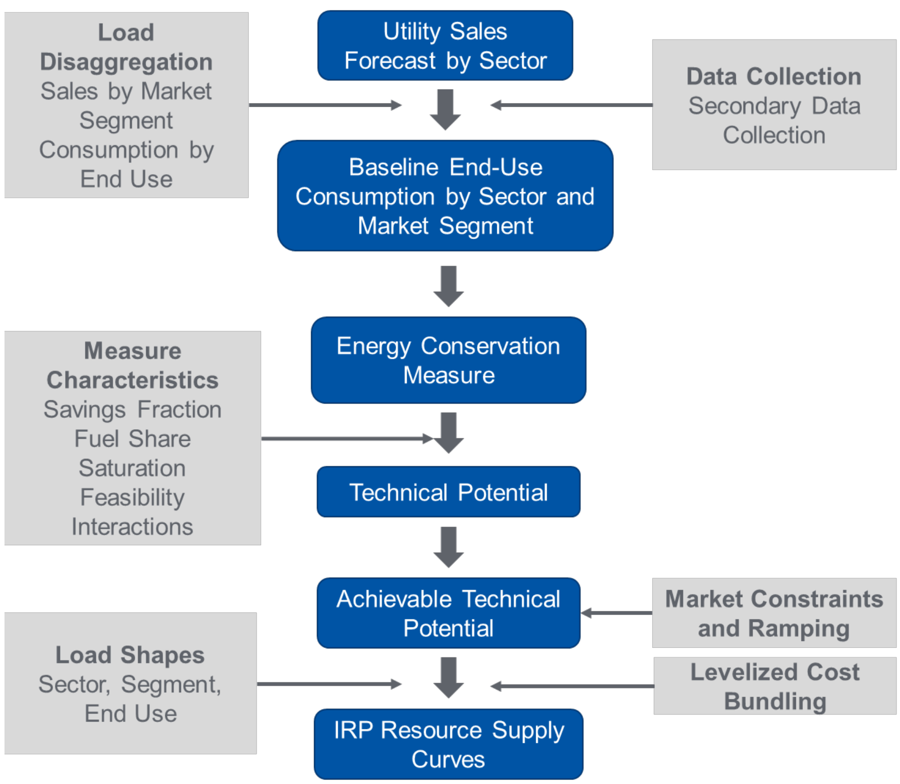
For the bottom-up component, Cadmus estimated natural gas consumptions for each major building end use and applied potential technical impacts of various ECMs to each end use. This bottom-up analysis includes assumptions about end-use equipment saturations, fuel shares, ECM technical feasibility, ECM cost, and engineering estimates of ECM UEC and UES.

For the industrial sector, Cadmus calculated technical potential as a percentage reduction to the baseline industrial forecast. We first estimated baseline end-use loads for each industrial segment, then calculated the potential using estimates of each measures' end-use percentage savings.

When characterizing measure and end-use consumptions, Cadmus used *2021 Power Plan* data (whenever possible) for weather-sensitive measures to account for climate change.[10] Next, we calibrated annual changes in residential and commercial heating end-use consumptions with PSE's climate impacts within annual load forecasts to reflect the effects of climate change on CPA estimates.

A detailed description of the methodology can be found in *Chapter 4. Energy Efficiency Methodology Details*.

**Figure 4. Conservation Potential Assessment Methodology**




10 Cadmus applied climate change adjustment factors based on the Council's data (TMY to projected FMY) to non-Council weather-sensitive RTF and PSE business case measures.

In the final step, Cadmus developed energy efficiency supply curves so that PSE's IRP portfolio optimization model could identify the amount of cost-effectiveness for energy efficiency. The portfolio optimization model required monthly forecasts of natural gas energy efficiency potential. To produce those monthly forecasts, Cadmus applied monthly end-use load profiles (converted from hourly profiles) to annual estimates of achievable technical potential for each measure. These profiles are generally similar to the shapes the Council used in its draft *2021 Power Plan* supply curves and as the RTF used in its UES measure workbooks.

***Considerations and Limitations***

This study is intended to support PSE's program planning by providing insights into which measures can be offered in future programs as well as informing the program targets. Several considerations about the design of this potential study may cause future program plans to differ from study results:

- This potential study uses broad assumptions about the adoption of energy efficiency measures. Program design, however, requires a more detailed examination of historical participation and incentive levels on a measure-by-measure basis. This study can inform planning for measures PSE has not historically offered or can help PSE to focus program design on areas with remaining potential identified in this study.
- This potential study cannot predict market changes over time. Even though it accounts for changes in codes and standards as they are enacted today, the study cannot predict future changes in policies, pending codes and standards, and which new technologies may become commercially available. PSE programs are not static and have the flexibility to address changes in the marketplace, whereas the potential study estimates the energy efficiency potential using information collected at a single point in time.
- This potential study does not attempt to forecast or otherwise predict future changes in energy efficiency measure costs. The study includes PSE program measure business cases, Council data, and RTF incremental energy efficiency measure costs, including for equipment, labor, and operations and maintenance (O&M), but it does not attempt to forecast changes to these costs during the course of the study. For example, changes in incremental costs may impact some emerging technologies, which may then impact both the speed of adoption and the levelized cost of that measure (impacting the IRP levelized cost bundles).
- This potential study does not consider program implementation barriers. Although it includes a robust, comprehensive set of efficiency measures, it does not examine if these measures can be delivered through incentive programs or what incentive rate is appropriate. Many programs require strong trade ally networks or must overcome market barriers to succeed.

Acknowledging the fact that these considerations and limitations have an impact on the CPA, it is also worth noting that "RCW 80.28.380 Gas Companies—Conservation Targets"[11] requires PSE to complete and update a CPA every two years. PSE can address some of these considerations over time and mitigate

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11 Revised Code of Washington. Accessed 2022. "RCW 80.28.380 Gas Companies—Conservation Targets." https://app.leg.wa.gov/RCW/default.aspx?cite=80.28.380&pdf=true

short- and mid-term uncertainties by continually revising CPA assumptions to reflect changes in the market.

## *Energy Efficiency Potential - Results*

Table 4 shows the 2050 forecasted baseline natural gas sales and potential by sector.[12] Cadmus' analysis indicates that 232 MMTherm of technically feasible natural gas energy efficiency potential will be available by 2050, the end of the 27-year planning horizon, which translates to an achievable technical potential of 165 MMTherm for residential, commercial, and industrial sectors combined. Should all this achievable technical potential prove cost-effective and realizable, it will result in an 18% reduction in 2050 forecasted retail sales.

**Table 4. Natural Gas 27-Year Cumulative Energy Efficiency Potential**

| Sector | 2050 Baseline Sales (MMTherm) | Achievable Technical Potential | |
|---|---|---|---|
| | | MMTherm | Percentage of Baseline Sales |
| Residential | 617 | 111 | 18% |
| Commercial | 293 | 51 | 18% |
| Industrial | 18 | 3 | 18% |
| **Total** | **928** | **165** | **18%** |

Figure 5 shows each sector's relative share of the overall natural gas energy efficiency achievable technical potential. The residential sector accounts for roughly 67% of the total natural gas energy efficiency achievable technical potential, followed by the commercial (31%) and industrial (2%) sectors.

**Figure 5. 27-Year Achievable Technical Potential by Sector**

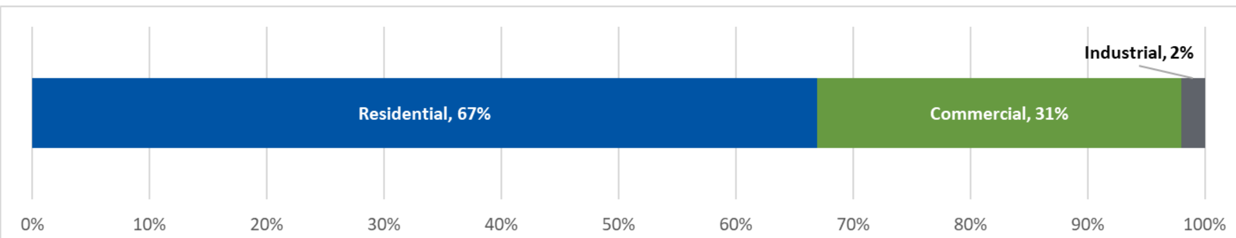


Figure 6 shows the relationship between each sector's cumulative (through 2050) natural gas energy efficiency achievable technical potential and the corresponding cost of conserved electricity.[13] For example, approximately 124 MMTherms of achievable technical potential exists, at a cost of less than $3.00 per therm.

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12 These savings derive from forecasts of future consumption, absent any utility program activities. Note that consumption forecasts account for the savings PSE has acquired in the past, but the estimated potential is inclusive of—not in addition to—current or forecasted program savings.

13 In calculating the levelized costs of conserved energy, non-energy benefits are treated as a negative cost. This means that some measures will have a negative cost of conserved energy, although incremental upfront costs would occur.

**Figure 6. Natural Gas 27-Year Cumulative Energy Efficiency Supply Curve by Sector**

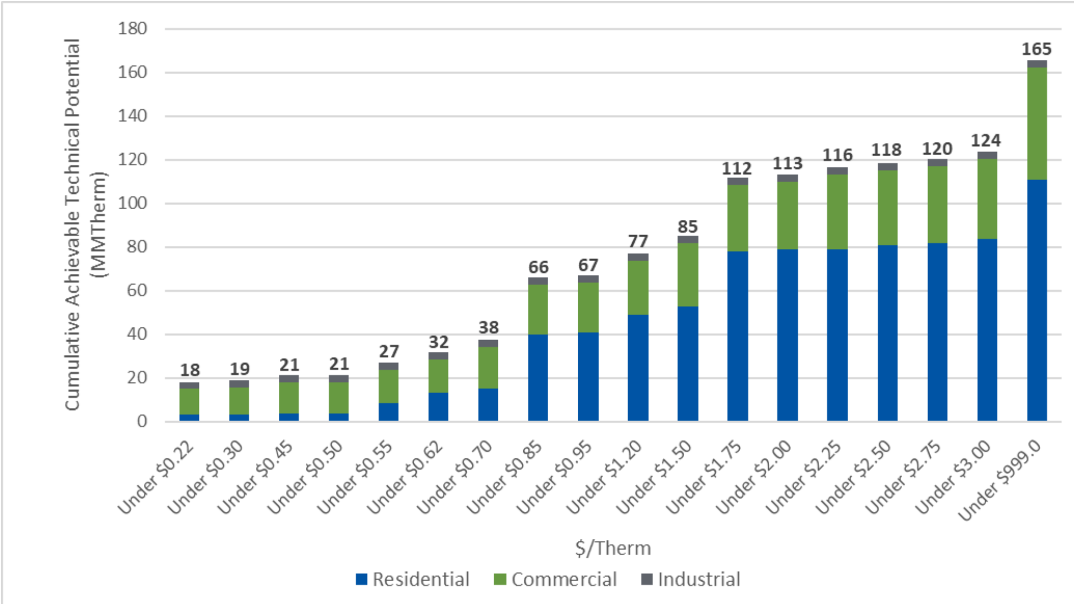



Figure 7 shows the relationship between cumulative natural gas energy efficiency achievable technical potential (through 2050) for discretionary and lost opportunity resources and the corresponding cost of conserved electricity.

**Figure 7. Natural Gas 27-Year Cumulative Energy Efficiency Supply Curve by Type of Resource (Discretionary vs. Lost Opportunity)**

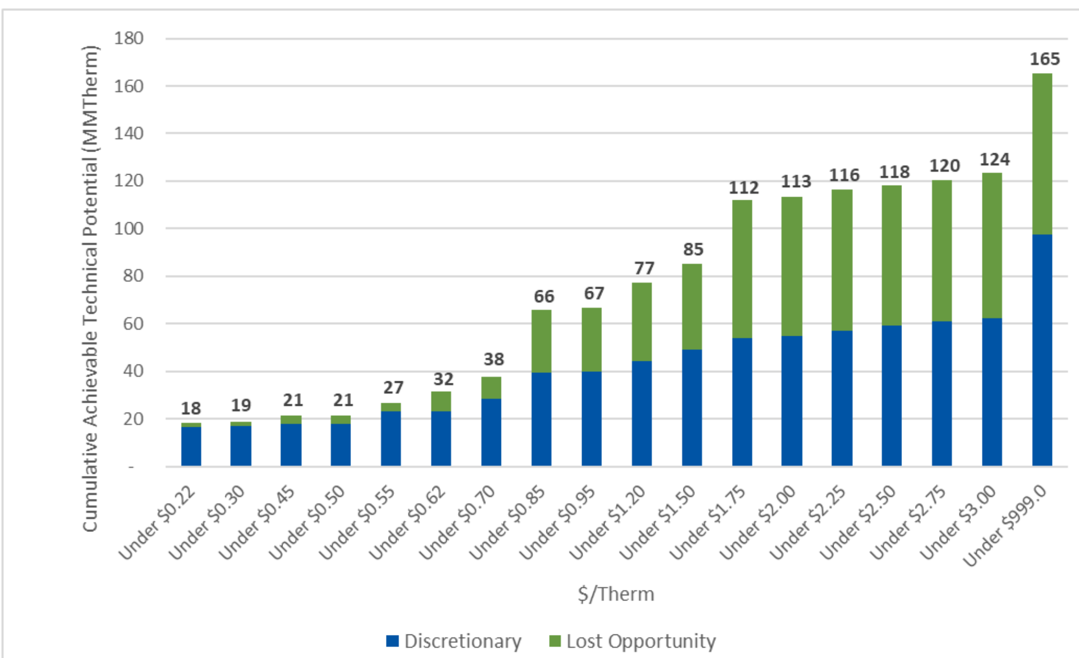
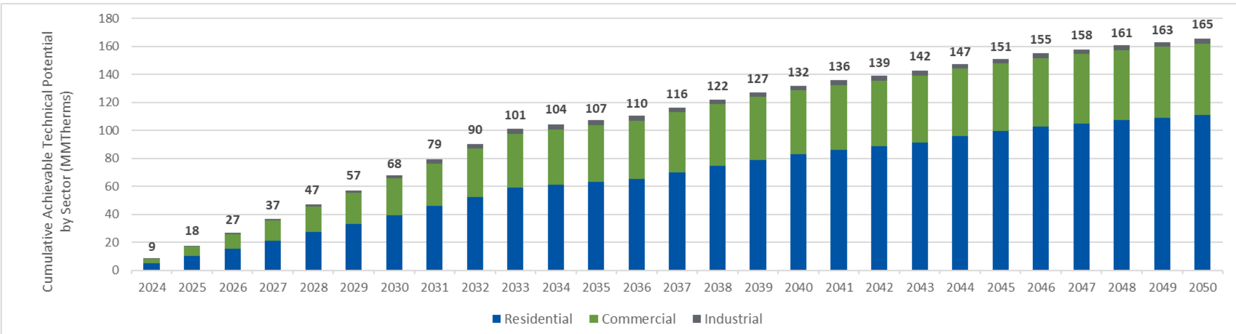


Figure 8 illustrates the cumulative achievable technical potential available annually in each sector. As shown in the figure, more savings are achieved in the first 10 years of the study (2024 through 2033) than in the remaining years. For this study, Cadmus assumed that discretionary measure potential savings are acquired in the first 10 years (for a selected set of measures that are retrofit in existing homes and businesses). The 10-year acceleration of discretionary resources will lead to the change in slope after 2033, at which point lost opportunity resources offer most of the remaining potential.

**Figure 8. Natural Gas Energy Efficiency Potential Forecast**



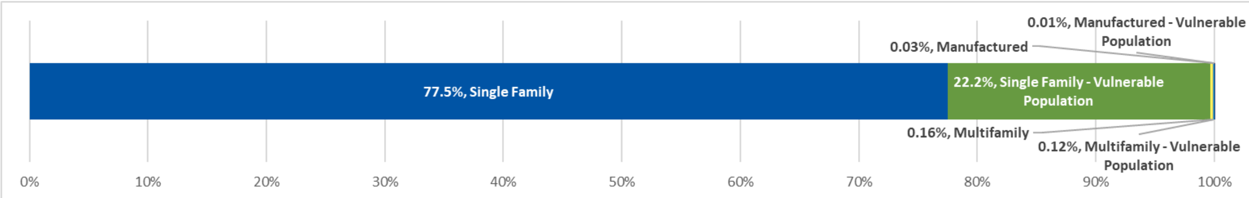

## Energy Efficiency Potential - Residential Sector

By 2050, residential customers in PSE's service territory will likely account for approximately 66% of forecasted natural gas retail sales in three sectors (residential, commercial, and industrial). The single-family, manufactured, and multifamily dwellings comprising this sector present a variety of potential savings sources, including equipment efficiency upgrades (such as boilers, furnaces, cooking ovens, and clothes dryers), improvements to building shells (including insulation, windows, and air sealing), and increases in domestic hot water efficiency (such as tankless water heaters).

As shown in Figure 9, single-family homes represent 99.7% of the total achievable technical residential natural gas potential, leaving only 0.3% from multifamily and manufactured homes, all including vulnerable populations.

Each home type's proportion of baseline sales is the primary driver of these results, but other factors such as heating fuel sources and equipment saturations are important for determining potential. For example, a very small percentage of manufactured homes use natural gas heat compared to other home types, which diminishes their relative share of the potential. Manufactured homes also tend to be smaller than detached single-family homes, and they experience lower per-customer energy; therefore, the same measure may save less in a manufactured home than in a single-family home.

**Figure 9. Residential Natural Gas Achievable Technical Potential by Segment**




Space heating end uses represent the largest portion (63%) of achievable technical potential, followed by water heating (36%) and dryer and cooking (0.4% each) end uses (Figure 10). The total achievable technical potential for residential increases to 111 MMTherms over the study horizon (Figure 11).

**Figure 10. Residential Natural Gas Achievable Technical Potential by End Use**

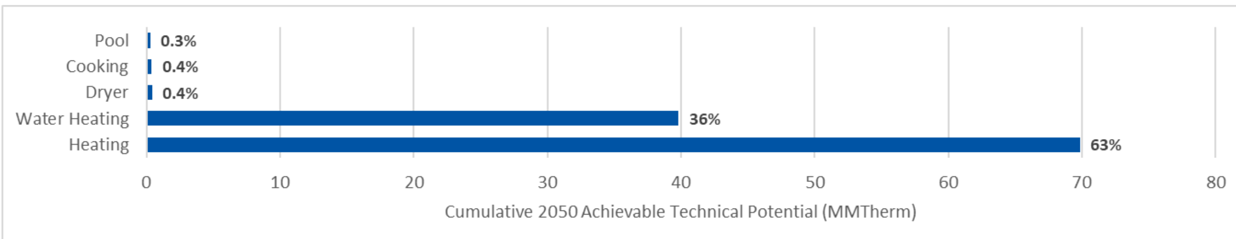



**Figure 11. Residential Natural Gas Achievable Technical Potential Forecast by End Use**

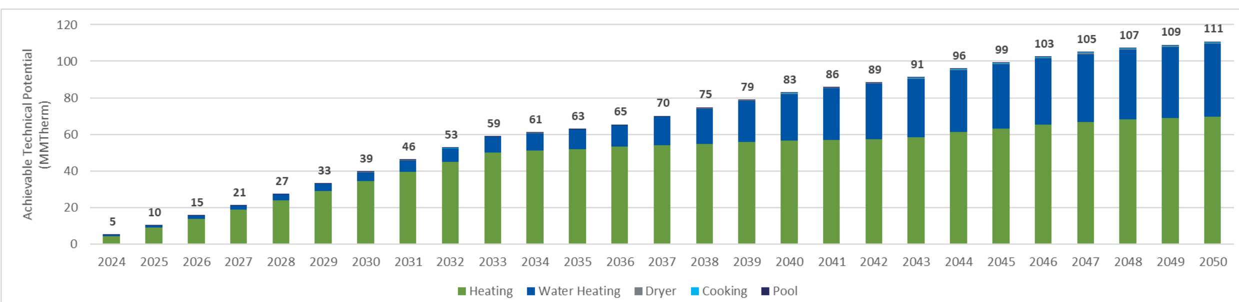



Table 5 lists the top 10 residential natural gas energy efficiency measures ranked in order of cumulative 27-year achievable technical potential. Combined, these 10 measures account for roughly 98 MMTherms, or approximately 89% of the total residential natural gas achievable technical potential. Premium efficiency furnaces represent the measure with the highest energy savings and all of the top 10 measures, except tankless water heaters, reduce natural gas heating loads: this includes an equipment measure (premium efficiency furnace) and retrofit measures (smart thermostat, insulation, and windows). This list represents both economic and non-economic measures.

**Table 5. Top Residential Natural Gas Measures**

| Measure Name | Cumulative 10-Year Achievable Technical Potential (MMTherm) | Cumulative 27-Year Achievable Technical Potential (MMTherm) |
|---|---|---|
| Furnace - Premium Efficiency | 8.6 | 26.3 |
| Water Heater - ENERGY STAR Tankless | 2.6 | 25.3 |
| Smart Thermostat | 10.6 | 11.3 |
| Integrated Space and Water Heating | 1.3 | 9.6 |
| Duct Sealing | 6.2 | 6.2 |
| Window - Storm Window | 5.2 | 5.2 |
| Insulation - Attic | 5.1 | 5.1 |
| Insulation - Wall | 4.8 | 4.8 |
| Windows | 2.7 | 2.8 |
| Duct Insulation | 1.8 | 1.8 |

In addition to estimating potential for each residential housing segment, Cadmus estimated potential for vulnerable population customers within PSE's natural gas service territory. Cadmus segmented PSE residential accounts (single family, multifamily, and manufactured) for vulnerable populations by county. As an approximation, Cadmus also used PSE 2021 RCS data to inform equipment saturations and fuel shares for vulnerable populations (based on income criterion with households having less than $49,000 gross annual income). Table 6 provides the percentage of vulnerable population customers in each county of PSE's natural gas service territory.

**Table 6. Percentage of Vulnerable Population Customers in Each County**

| County | Percentage of Vulnerable Population Customers |
|---|---|
| King County | 22% |
| Kittitas County | 11% |
| Lewis County | 51% |
| Pierce County | 42% |
| Snohomish County | 19% |
| Thurston County | 36% |

Cadmus derived UES estimates specifically for vulnerable population customers using low-income–specific measures from PSE's business cases:

- Weatherization: Attic, duct, floor, and wall insulation; air and duct sealing; and single-, double-, and triple pane windows
- Water heating: water heater pipe insulation, integrated space and water heating system
- Smart thermostats

Cadmus also apportioned savings from non-low-income–specific PSE business case measures to vulnerable population customers for other measures, including home energy reports, windows (single-, double-, and triple-pane with different U factors) and tub spouts.

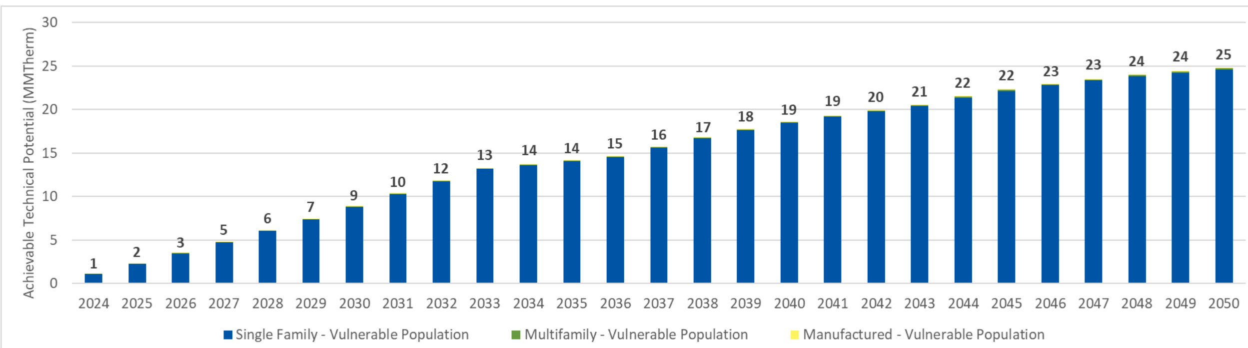
Table 7 shows the cumulative 10-year (through 2033) and 27-year (through 2050) achievable technical potential for PSE's vulnerable population customers by housing segment.

**Table 7. Residential Vulnerable Population Customer Potential – Natural Gas**

| Segment | Cumulative 10-Year Achievable Technical Potential (MMTherm) | Cumulative 27-year Achievable Technical Potential (MMTherm) |
|---|---|---|
| Single Family - Vulnerable Population | 13.170 | 24.603 |
| Multifamily - Vulnerable Population | 0.075 | 0.132 |
| Manufactured - Vulnerable Population | 0.005 | 0.008 |
| **Total** | **13.2** | **24.7** |

Figure 12 provides the cumulative residential vulnerable population natural gas achievable technical potential forecast by housing segment. The potentials shown above in Figure 11 include the vulnerable population customer potential shown in Figure 12.

**Figure 12. Residential Achievable Technical Potential Forecast for Vulnerable Populations**

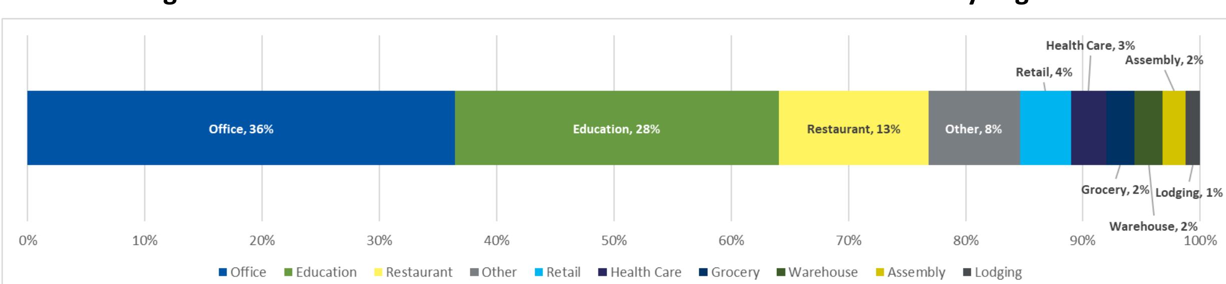



## Energy Efficiency Potential - Commercial Sector

Based on the energy efficiency measure resources used in this assessment, natural gas energy efficiency achievable technical potential in the commercial sector will likely be 51 MMTherms over 27 years, which is approximately an 18% reduction in forecasted 2050 commercial sales.

As shown in Figure 13, the office, education, and restaurant segments represent 36%, 28%, and 13%, respectively, of the total commercial achievable technical potential. The "other" segment, which includes customers who do not fit into any of the other categories and customers with insufficient information for classification, represents 8% of commercial achievable technical potential. Each of the remaining segments has less than 5% of commercial achievable technical potential.

**Figure 13. Commercial Natural Gas Achievable Technical Potential by Segment**



As shown in Figure 14, the heating end use represents the largest portion of achievable technical potential in the commercial sector (75%), followed by the cooking (16%) and water heat (9%) end uses. Figure 15 presents the annual cumulative natural gas commercial achievable technical potential by end use.

**Figure 14. Commercial Natural Gas Achievable Technical Potential by End Use**

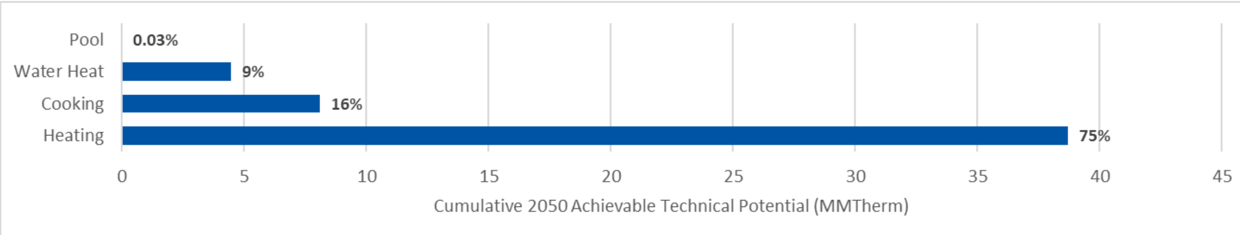



**Figure 15. Commercial Natural Gas Achievable Technical Potential Forecast**

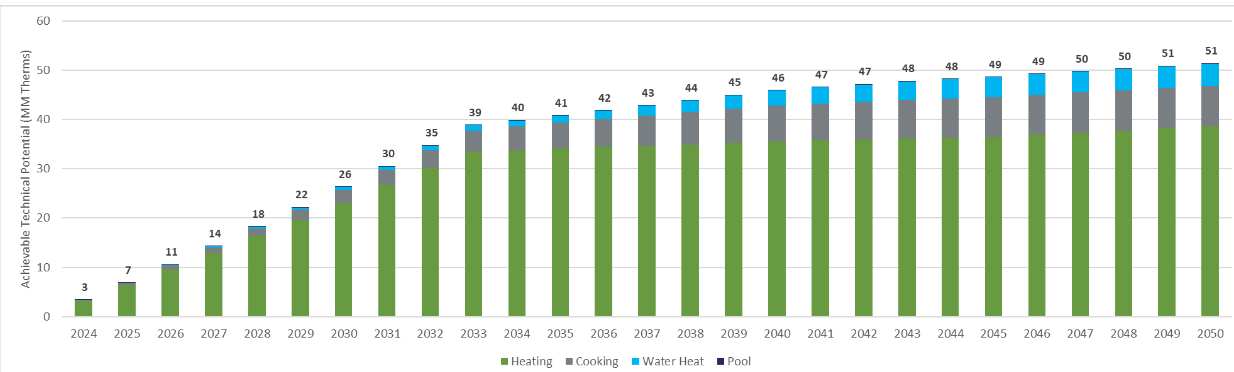



Table 8 lists the top 10 commercial natural gas energy efficiency measures ranked in order of cumulative 27-year achievable technical potential. Combined, these 10 measures account for 38 MMTherms, or approximately 74% of the total natural gas commercial achievable technical potential.

**Table 8. Top Commercial Natural Gas Measures**

| Measure Name | Cumulative 10-Year Achievable Technical Potential (MMTherm) | Cumulative 27-Year Achievable Technical Potential (MMTherm) |
|---|---|---|
| Re-Commissioning | 7.6 | 7.6 |
| Energy Management System | 5.6 | 5.6 |
| Space Heat - Natural Gas Furnace | 1.5 | 4.3 |
| Window - Secondary Glazing | 4.2 | 4.2 |
| Weatherization - Attic/Roof Insulation | 3.3 | 3.3 |
| Pipe Insulation - Space Heat | 3.0 | 3.0 |
| Water Heat LE 55 Gallon | 0.3 | 3.0 |
| Space Heat - Natural Gas Boiler | 1.2 | 2.8 |
| Kitchen Hood - Demand Controlled Ventilation | 2.0 | 2.0 |
| Fryer | 0.8 | 1.8 |

## Energy Efficiency Potential - Industrial Sector

Since electricity is the most commonly used energy source in industrial processes, the industrial sector represents a small portion of natural gas baseline sales and potential. Across all industries assessed, achievable technical potential is approximately 3 MMTherms over the 27-year planning horizon, corresponding to an 18% reduction of forecasted 2050 industrial natural gas retail sales.

Figure 16 shows 27-year natural gas industrial achievable technical potential by segment. Miscellaneous manufacturing represents 48% of the total 27-year natural gas industrial achievable technical potential followed by the other food (15%), transportation equipment (13%), metal fabrication (7%). and chemical (6%) industries. No other industry represents more than 5% of industrial natural gas achievable technical potential.

**Figure 16. Industrial Natural Gas Achievable Technical Potential Forecast**

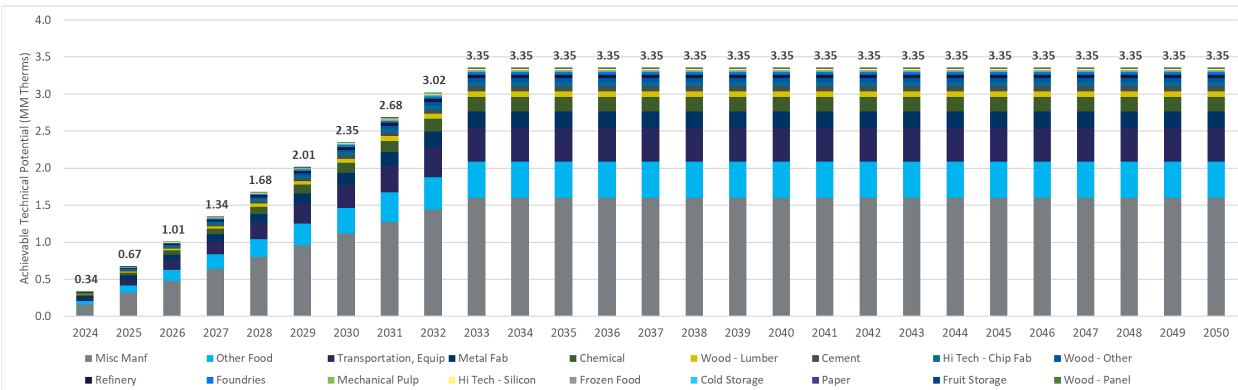



Table 9 presents natural gas cumulative 27-year achievable technical potential for the top 10 measures in the industrial sectors. The top 10 measures combined equal approximately 2.5 MMTherms of achievable technical potential, or roughly 74% of the industrial total.

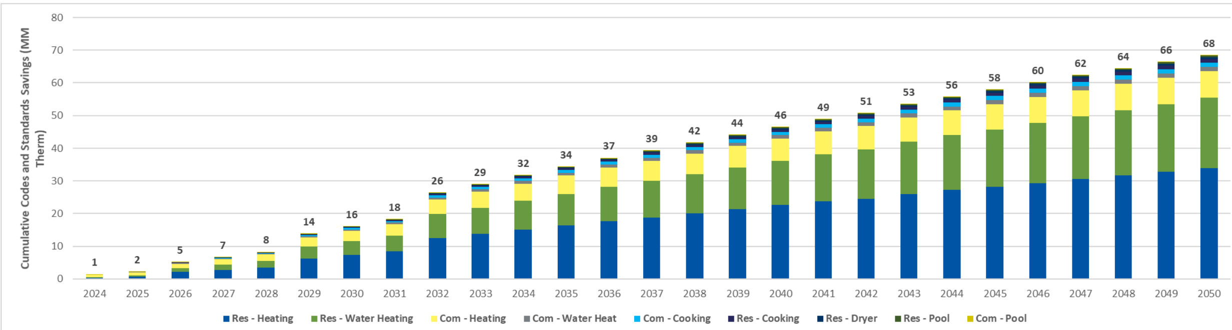
**Table 9. Top Industrial Natural Gas Measures**

| Measure Name | Cumulative 10-Year Achievable Technical Potential (MMTherm) | Cumulative 27-Year Achievable Technical Potential (MMTherm) |
|---|---|---|
| Waste Heat from Hot Flue Gases to Preheat | 0.37 | 0.37 |
| Improve Combustion Control Capability and Air Flow | 0.36 | 0.36 |
| Process Improvements to Reduce Energy Requirements | 0.32 | 0.32 |
| Install or Repair Insulation on Condensate Lines and Optimize Condensate | 0.31 | 0.31 |
| Heat Recovery and Waste Heat for Process | 0.31 | 0.31 |
| Optimize Heating System to Improve Burner Efficiency and Reduce Energy Requirements and Heat Treatment Process | 0.18 | 0.18 |
| Equipment Upgrade - Boiler Replacement | 0.17 | 0.17 |
| Thermal Systems Reduce Infiltration; Isolate Hot or Cold Equipment | 0.17 | 0.17 |
| Equipment Upgrade - Replace Existing HVAC Unit with High-Efficiency Model | 0.15 | 0.15 |
| Analyze Flue Gas for Proper Air/Fuel Ratio | 0.15 | 0.15 |

## Impacts of Codes and Standards

Figure 17 presents naturally occurring savings in PSE's service territory from the WSEC equipment standards and federal equipment standards, which is equal to 68 MMTherms in 2050.

**Figure 17. Natural Gas Codes and Standards Potential Forecast**




## Non-Energy Impacts

In addition to the Council and RTF measures with NEIs (limited to water savings, O&M, and lifetime replacement), this CPA incorporates additional NEI data to inform the IRP levelized cost bundles. Cadmus based the NEI data on PSE's recent program evaluation that included an assessment of program measure NEIs. Figure 18 shows a comparison of the cumulative 2050 achievable technical potential with and without the inclusion of these additional NEI data. The figure shows an increase in potential within the relatively lower-cost bundles with less of an impact in the high-cost bundles.

**Figure 18. Non-Energy Impacts on Levelized Cost, Cumulative 2050 Achievable Technical Potential**

# Chapter 2. Energy Efficiency Potential for Small Transport Customer Sector

## *Scope of the Analysis*

Per the Climate Commitment Act, PSE is including its small transport customer sector into this CPA as a compliance requirement. Small transport is a class of customers who had an average of less than 25,000 tonnes of annual carbon dioxide emission per Mscf of their natural gas consumption in 2015 through 2019. There were 309 small commercial and industrial (C&I) sites in PSE's service territory in this customer class.

## *Energy Efficiency Potential*

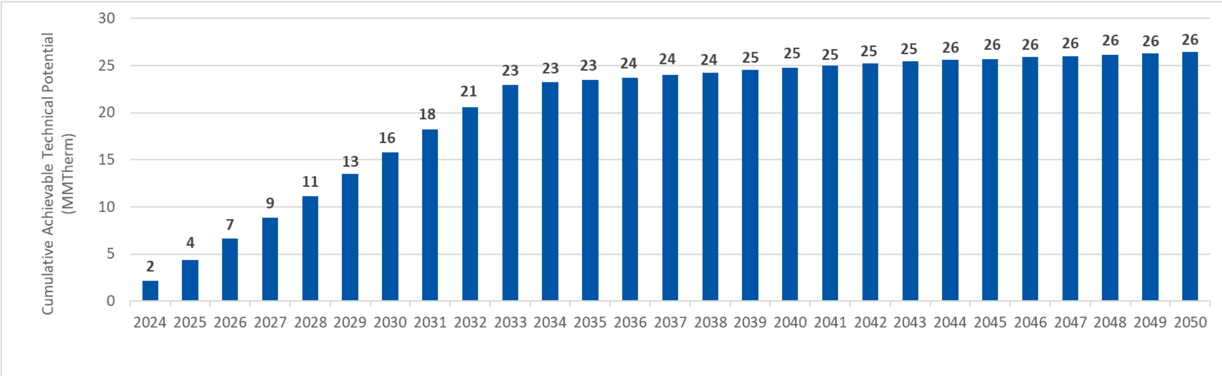
Cadmus estimated the energy efficiency potential for small transport customers using a methodology similar to the one used for standard C&I customers. The segments we included in the potential calculations are shown below. We excluded the small and medium office; small, medium, and large retail; mini-mart; university; and kraft pulp segments, as there were no small transport customer in these segments in PSE's service territory.

| **SMALL TRANSPORT - COMMERCIAL** | **SMALL TRANSPORT - INDUSTRIAL** |
|---|---|
| **ELEVEN SEGMENTS**<br>Large Office, Extra Large Retail, School K–12, Warehouse, Supermarket, Restaurant, Lodging, Hospital, Residential Care, Assembly, Other | **EIGHTEEN SEGMENTS**<br>Mechanical Pulp, Paper, Foundries, Food – Frozen, Food – Other, Wood – Lumber, Wood – Panel, Wood – Other, Cement, Hi Tech – Chip Fabrication, Hi Tech – Silicon, Metal Fabrication, Transportation Equipment, Refinery, Cold Storage, Fruit Storage, Chemical, Miscellaneous Manufacturing |

Across all modeled segments, achievable technical potential is approximately 26 MMTherms over the 27-year planning horizon, corresponding to a 15% reduction of forecasted 2050 small transport customer natural gas retail sales.

Figure 19 shows 27-year natural gas achievable technical potential for small transport customers. Cadmus assumed that all discretionary resources will be acquired on a 10-year schedule between 2024 and 2033. The 10-year acceleration of discretionary resources will lead to the change in slope after 2033, at which point lost opportunity resources offer the only remaining potential.

**Figure 19. Natural Gas Achievable Technical Potential Forecast for Small Transport Customers**




As shown in Figure 20, the boiler end use represents the largest portion of achievable technical potential in the small transport sector (34%), followed by process (26%) and heating (20%). All other end uses have less than a 10% share of the achievable technical potential.

**Figure 20. Natural Gas Achievable Technical Potential by End Use for Small Transport Customers**

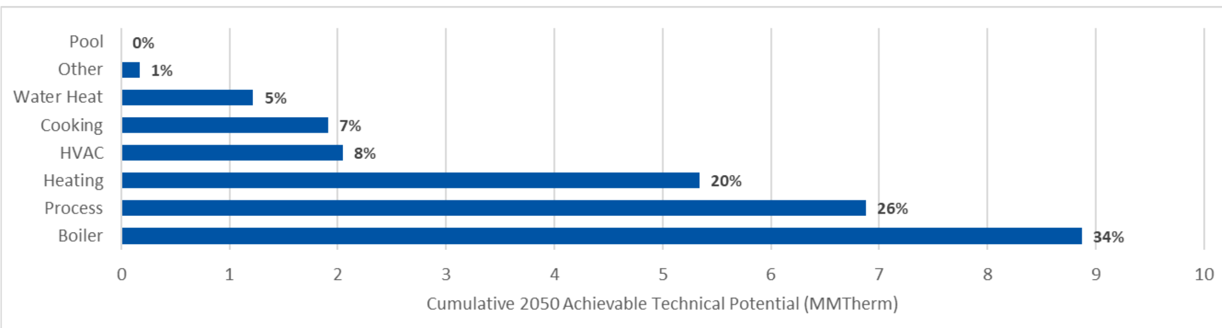



Figure 21 shows the relationship between the small transport sector's cumulative (through 2050) natural gas achievable technical potential and the corresponding cost of conserved electricity. For example, approximately 26 MMTherms of achievable technical potential exists at a cost of less than $3.00 per therm.

**Figure 21. Natural Gas 27-Year Cumulative Energy Efficiency Supply Curve for Small Transport Customers**

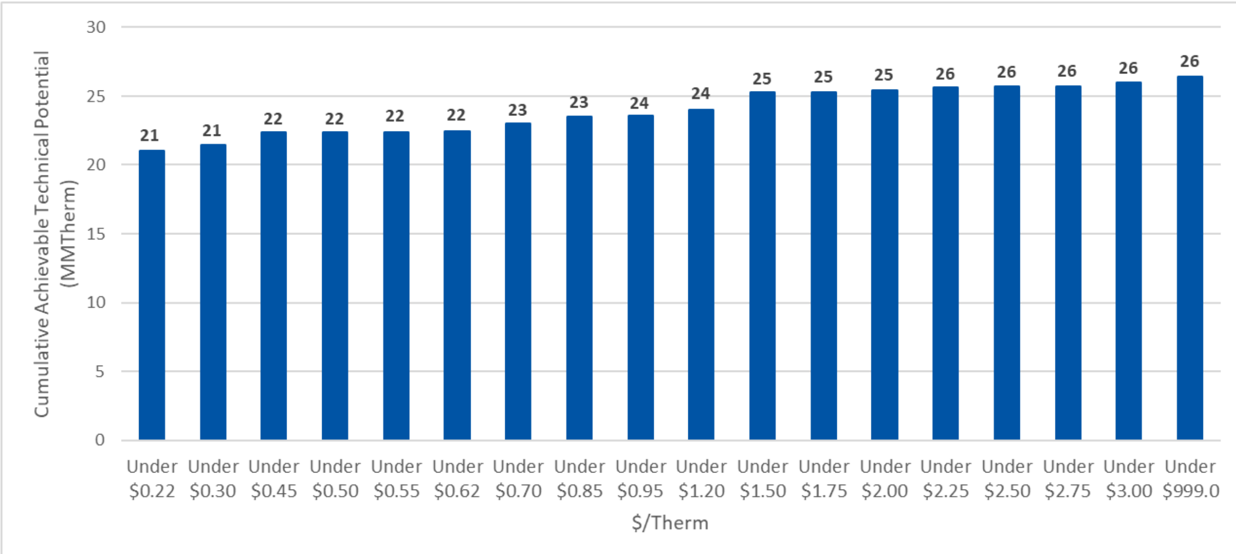



Table 10 presents natural gas cumulative 27-year achievable technical potential for the top 10 measures for small transport customers ranked in order of cumulative 27-year achievable technical potential. Combined, these 10 measures account for 14 MMTherms, or approximately 52% of the total natural gas achievable technical potential for small transport customers.

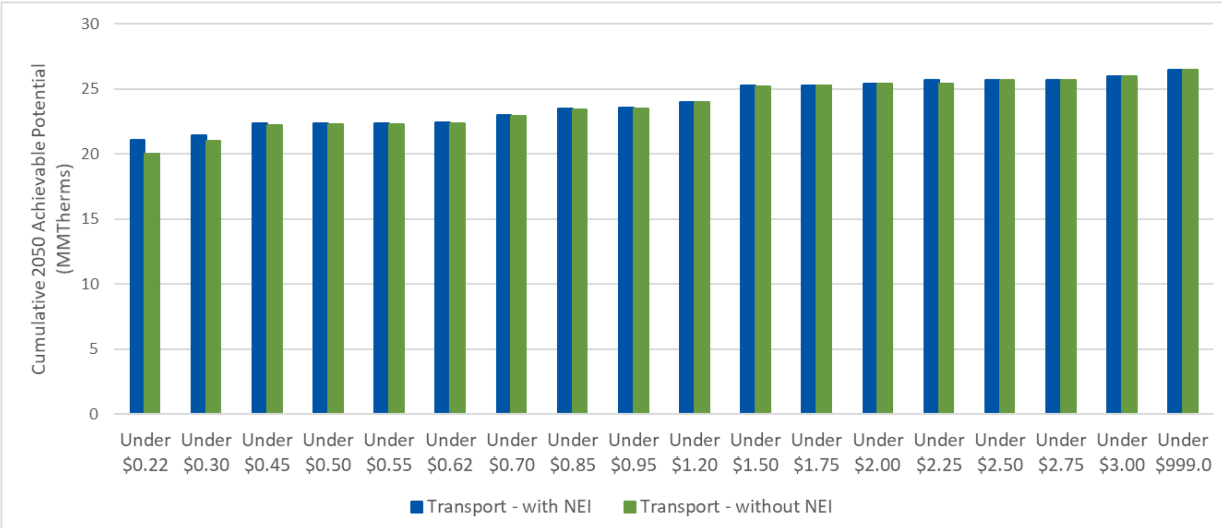
**Table 10. Top Natural Gas Measures for Small Transport Customers**

| Measure Name | Cumulative 10-Year Achievable Technical Potential (MMTherm) | Cumulative 27-Year Achievable Technical Potential (MMTherm) |
|---|---|---|
| Waste Heat from Hot Flue Gases to Preheat | 2.0 | 2.0 |
| Improve Combustion Control Capability and Air Flow | 1.9 | 1.9 |
| Process Improvements to Reduce Energy Requirements | 1.7 | 1.7 |
| Install or Repair Insulation on Condensate Lines and Optimize Condensate | 1.7 | 1.7 |
| Heat Recovery and Waste Heat for Process | 1.7 | 1.7 |
| Energy Management System | 1.1 | 1.1 |
| Optimize Heating System to Improve Burner Efficiency and Reduce Energy Requirements and Heat Treatment Process | 0.9 | 0.9 |
| Re-Commissioning | 0.9 | 0.9 |
| Equipment Upgrade - Boiler Replacement | 0.9 | 0.9 |
| Thermal Systems Reduce Infiltration; Isolate Hot or Cold Equipment | 0.9 | 0.9 |

## *Non-Energy Impacts*

Similar to the C&I sectors, Cadmus incorporated additional NEI data that was based on PSE's recent program evaluation to inform the IRP levelized cost bundles for the small transport customer sector. Figure 22 shows a comparison of the cumulative 2050 achievable technical potential with and without the inclusion of these additional NEI data. Overall, the impact of NEIs was less pronounced in transport sector compared to all other three sectors combined (as shown in Figure 18). As the figure shows, there is an increase in potential within the few lowest-cost bundles with less of an impact in the high-cost bundles.

**Figure 22. Non-Energy Impacts on Levelized Cost, Cumulative 2050 Achievable Technical Potential**



# Chapter 3. Natural Gas-to-Electric Potential Assessment

Public policies that are intended to help transition energy product and end uses away from fossil fuels are affecting electric and natural gas utilities across the country. The Climate Commitment Act[14] is for capping and reducing greenhouse gas emissions from Washington's largest emitting sources and industries with the limits 45% below 1990 levels by 2030, 70% below 1990 levels by 2040, and 95% below 1990 levels by 2050.

To address the impact of natural gas–to-electric conversion on PSE's system, Cadmus estimated the load impacts as well as the associated impacts of energy efficiency and demand response potential. To determine the load impacts, we evaluated three supply curve alternatives for PSE's IRP (hybrid heat pump – market, hybrid heat pump – policy, and full electrification – policy). To determine the impacts on energy efficiency and demand response potentials, we evaluated two policy supply curve alternatives (hybrid heat pump – policy and full electrification – policy). These supply curve alternatives (scenarios) were based on differences in heat pump technology as well as policy and market adoption criteria. For the residential sector, Cadmus conducted the natural gas–to-electric conversion potential analysis under three different scenarios:

**HYBRID HEAT PUMP – MARKET**

Cadmus analyzed the effects of a conversion from natural gas heating equipment (such as a natural gas furnace and ductless natural gas heating) to a heat pump (such as a ductless and ducted ASHP), while keeping the natural gas heating equipment as the backup. We obtained the market adoption rates for this scenario from the customer survey. The data will inform PSE's IRP, where technologies will be selected based on their cost-effectiveness in the natural gas portfolio model, where the customer adoption is limited by customer willingness to convert to electric equipment.

**HYBRID HEAT PUMP – POLICY**

Cadmus analyzed the effects of a conversion from natural gas heating equipment to a heat pump while keeping the natural gas heating equipment as the backup but, unlike in the previous scenario, we adjusted the market adoption rate to a maximum where 100% of applicable residential applications have a hybrid heat pump or ductless system with natural gas backup. This scenario represents a policy change where all residential customers are required to convert to a hybrid heat pump. Under this scenario the IRP will select all converted technologies regardless of costs, where the end-of-life replacement of natural gas equipment with hybrid heat pumps will reach 100% annual adoption within the study horizon based on future policy requirements.

**FULL ELECTRIFICATION – POLICY**

Cadmus analyzed the effects of a conversion from natural gas heating equipment to a heat pump without keeping the natural gas heating equipment and assumed full adoption (where the market adaption rate equals to 100%) to represent a policy change banning natural gas usage and forcing all customers to convert to heat pumps. Under this scenario the IRP will select all converted technologies regardless of costs, where the end-of-life replacement of natural gas equipment with electric heat pumps (with no natural gas backup) will reach 100% annual adoption within the study horizon based on future policy requirements.

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

[14] Washington State Legislature. 2021. *SB 5126 - 2021-22 Concerning the Washington climate commitment act.* https://app.leg.wa.gov/billsummary?billnumber=5126&year=2021

As part of this CPA, Cadmus estimated per-unit impacts—including reductions in natural gas usage and increased electric energy and peak demand—and customer costs for the full suite of electrification measures including space and water heating systems, stoves and cooktops, and clothes dryers for existing customers and new construction in the residential and commercial sectors.

Cadmus used data from PSE customer database, the PSE RCS, the CBSA, and other sources to calculate these potential impacts. Additionally, we conducted primary research by conducting a residential customer survey to determine the appropriate heat pump technologies (such as ductless heat pump partial- and full-load conversion, heat pumps with no supplement heating, and hybrid heat pumps) that customers would likely install if converting from a non-electric fuel. Furthermore, Cadmus conducted contractor and builder interviews to determine heat pump conversion costs (for hybrid, ductless, and ducted heat pumps) including any additional costs to convert to electric from non-electric equipment, such as electrical panel or wiring upgrades, duct reconfiguration, and added labor costs.

Table 11 details the natural gas–to-electric equipment being replaced and converted under the full electrification policy scenario.

**Table 11. Full Replacement Policy Scenario – Natural Gas–to-Electric Equipment**

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

For both the hybrid market and policy scenarios, Table 12 shows the natural gas-to-electric equipment being replaced and converted. Under these scenarios, 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.[15] Cadmus estimated 88% electric consumption and 12% natural gas consumption based on building simulations[16] using Seattle-area weather data.

**Table 12. Hybrid Policy and Market Scenarios – Gas to Electric Equipment**

| Sector | Electric – Converted To | Natural Gas – Converted From |
|---|---|---|
| Residential | DHP with Furnace Backup | Furnace - Partial Replacement |
| | Hybrid ASHP with Furnace Backup without Existing AC | Furnace - Partial Replacement without Existing AC |
| | Hybrid ASHP with Furnace Backup with Existing AC | Furnace - Partial Replacement with Existing AC |
| | DHP with Boiler Backup | Boiler - Partial Replacement |
| | DHP with Natural Gas Wall Unit Backup | Natural Gas Wall Unit - Partial Replacement |
| | Cooking Oven (Electric) | Cooking Oven (Natural Gas) |
| | Cooking Range (Electric) | Cooking Range (Natural Gas) |
| | Dryer (Electric) - Non-Heat Pump | Dryer (Natural Gas) |
| | Water Heat ≤55 Gal | Water Heat (Natural Gas) |
| | Water Heat >55 Gal | Water Heat (Natural Gas) |
| Commercial | ASHP/Variable Refrigerant Flow/DHP | Natural Gas Space Heat - Full Replacement |
| | Cooking (Electric) | Cooking (Natural Gas) |
| | Water Heat ≤55 Gal | Water Heat (Natural Gas) |
| | Water Heat >55 Gal | Water Heat (Natural Gas) |
| Industrial | Target Reduction Conversion of Natural Gas Load 30% Reduction | |

## *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 the purpose of this IRP and this natural gas–to-electric potential assessment, 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 this load into electric energy and peak demand.

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[15] Cadmus assumed a 35-degree auxiliary heat lock-out setpoint based on the 2018 WSEC (R403.1.2 Heat Pump Supplementary Heat).

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

## 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 equipment and new construction. We took PSE's customers counts and forecasts and applied equipment saturation rates 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, thereby aligning energy efficiency and natural gas–to-electric assumptions and producing alterative base case forecasts.

Cadmus used PSE customer counts and forecasts, residential equipment saturation and fuel share data from PSE's 2021 RCS, commercial equipment saturation data from the 2023 PSE CPA, and the 2019 CBSA to estimate natural gas equipment counts. Cadmus used PSE's current CPA to determine the energy impacts of equipment conversion. To assess the peak demand impacts, Cadmus used PSE's gas to electric IRP high load hour definition to determine the coincident peak impacts. To align with PSE's IRP modeling of gas to electric peak impacts, Cadmus defined each scenario differently rather than following the energy efficiency modeling peak hour definitions. For instance, the hybrid heat pump equipment scenarios assume zero electric peak impact under normal peak conditions (e.g., 28° Fahrenheit or lower) and conversely, there would be no reduction in natural gas peak. Under the full replacement scenario, the converted heat pumps would increase the electric peak load and remove the natural gas peak load. Table 13 lists the data sources we used to analyze conversion impacts in the residential and commercial sectors.

**Table 13. Data Sources for the Residential and Commercial Analysis**

| Analysis Component | Data Sources |
|---|---|
| Residential, Commercial, and Industrial Customer Counts | 2022 PSE customer counts, PSE customer forecasts |
| Residential Equipment Fuel Shares and Saturations | 2021 RCS, NEEA 2017 RBSA |
| Commercial Equipment Fuel Shares and Saturations | NEEA 2019 CBSA |
| Residential Electric Equipment Consumption | 2023 PSE CPA |
| Commercial Electric Equipment Consumption | 2023 PSE CPA |
| Residential Electric Equipment Peak Demand | 2023 PSE CPA, end-use load shapes |
| Commercial Electric Equipment Peak Demand | 2023 PSE CPA, end-use load shapes |
| Residential Electric Equipment Costs | 2023 PSE CPA, Cadmus' primary market research (contractor interviews) |
| Commercial Electric Equipment Costs | 2023 PSE CPA |

## Industrial Sector

Cadmus used the 2023 CPA methodology 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 CPA. We calculated potential for the industrial sector by converting a portion (~30%) of natural gas loads based on prior analysis by Cadmus. 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.[17] 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 prior analysis by Cadmus. 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 customer declines from year to year. Therefore, the industrial load analysis applied only to the existing construction conversion scenario.

## Market Research

As part of the natural gas–to-electric conversion potential assessment, Cadmus conducted a heat pump market research study and fielded an online customer survey (862 surveys completed by natural gas PSE customers) for measuring the residential sector's willingness to pay for natural gas conversions to heat pumps. We also interviewed contractors and builders (14 interviews completed) in PSE's service territory to determine heat pump (hybrid, ductless, ducted, and other) conversion costs, including any additional costs to convert to electric from non-electric equipment, such as electrical panel or wiring upgrades, duct reconfiguration, and added labor costs. The data we collected through the survey and interviews supported our analysis for determining the adaption rates and conversion costs.

### *Residential Customer Survey*

Cadmus assessed the market demand for natural gas conversions to heat pumps by measuring willingness to pay through an online customer survey. Survey respondents rated their likelihood to purchase a product, answering cascading questions about their willingness to buy at increasingly higher or lower price levels. These data then informed the demand curve for multiple heat pump products (such as hybrid, ductless, ducted, and cold climate). The results from the survey directly informed the potential adoption of these heat pump technologies. Supplemental questions also included the propensity of customer acceptance for converting to electric cooking equipment and electric water heating equipment.

The survey revealed that residential customers are more willing and influenced by incentives to install hybrid heat pump systems with natural gas backup. Figure 23 shows the customer market demand based on heat pump type and incentive level.

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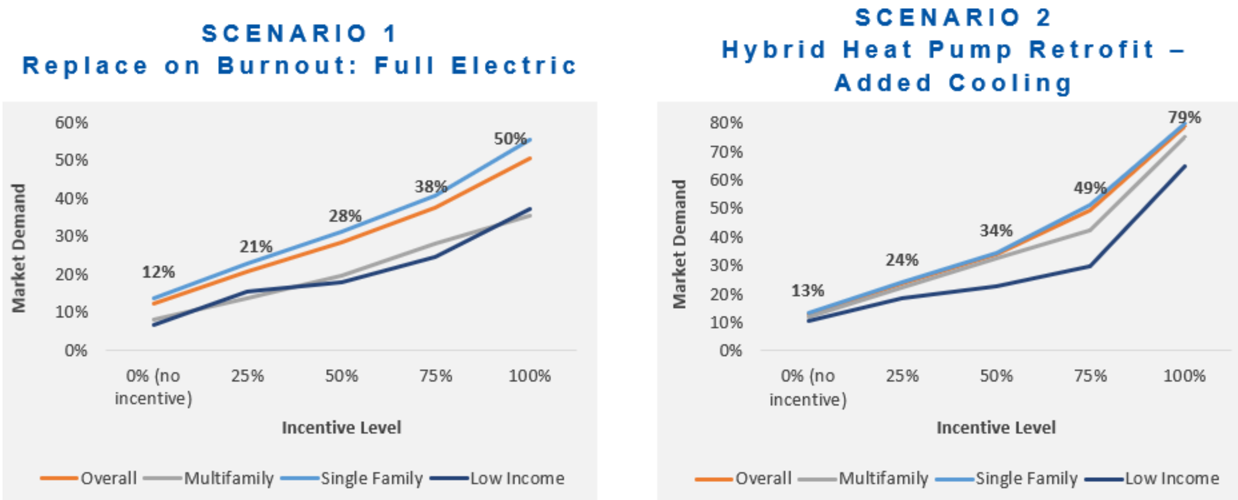
17 McKinsey & Company. May 28, 2020. "Plugging In: What Electrification Can Do for Industry." https://www.mckinsey.com/industries/electric-power-and-natural-gas/our-insights/plugging-in-what-electrification-can-do-for-industry

**Figure 23. Customers Willingness to Adopt Electric Equipment by Heat Pump Type and Incentive Level**




### *Contractor and Builder Interviews*

Cadmus conducted contractor and builder interviews to determine heat pump (hybrid, ductless, ducted, and cold climate) conversion costs, including any additional costs to convert to electric from non-electric equipment, such as electrical panel or wiring upgrades, duct reconfiguration, and added labor costs. We asked interview questions to find out what heat pump conversion equipment contractors and builders would recommend for specific non-electric heating systems (such as duct systems, boilers, and wall units) and to determine if there were certain barriers to converting to electric heating systems. The results directly informed the electrification costs and modeled equipment types.

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 wiring and conduit). More significant improvements are needed approximately 10% of the time (such as panel or 200-amp electrical service upgrades).

More details of the customer survey and constructor/builder interviews are available in ***Appendix A. Heat Pump Research Findings***.

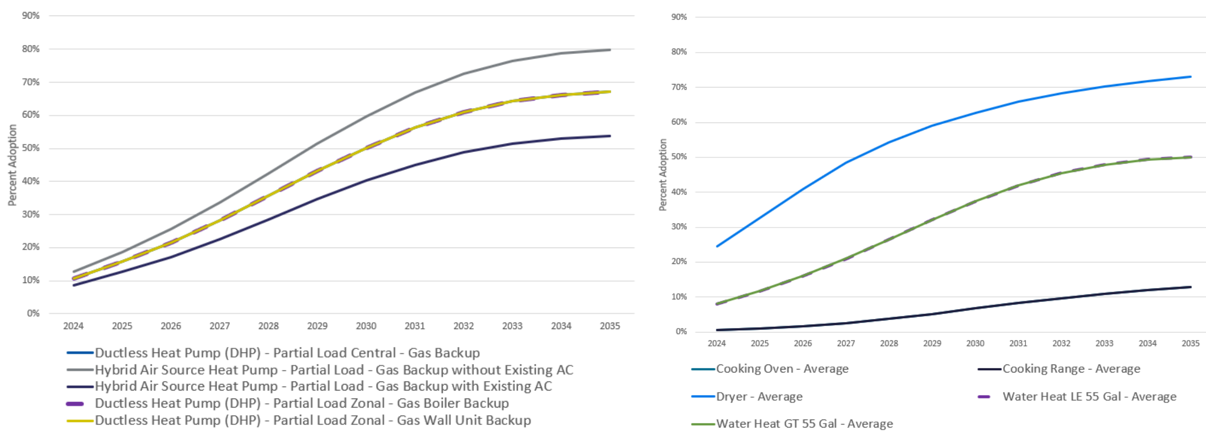
## Natural Gas–to-Electric Adoption Rates

Cadmus assessed each supply curve alternative 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. The data from the customer survey informed the hybrid heat pump – market scenario maximum achievability factor and varied for each technology and application (based on incentives representing 100% of the incremental costs). For the policy scenarios, we assumed the maximum achievability factor as 100%.

Ramp rate percentage are annual percentage values representing the proportion of technical annual potential that can be acquired in a given year (equipment/lost opportunity measures). For each supply curve alternative, equipment ramp rates are applied to the proportion of technical annual potential that can be acquired in a given year. Ramp rates are measure-specific and we based these on the ramp rates developed for the Council's draft *2021 Power Plan* supply curves, adjusted to account for the 2024 to 2050 study horizon. We assumed that, under the policy scenarios, there will be phase-in policies over time and customers will ramp-up to 100% adoption over the study horizon.

Figure 24 shows the residential hybrid heat pump – market scenario of annual ramp rate and maximum achievability factor for this technology. The heat pump ramp rate is based on the Council's heat pump adoption (Lost Opportunity 5 Medium). Cadmus estimated the maximum adoption of 75% for clothes dryers and assumed limited market barriers. For this scenario, we assumed water heat to have 50% maximum adoption, similar to ASHPs. We assumed cooking equipment to have 14% maximum adoption based on the customer survey (without incentives).

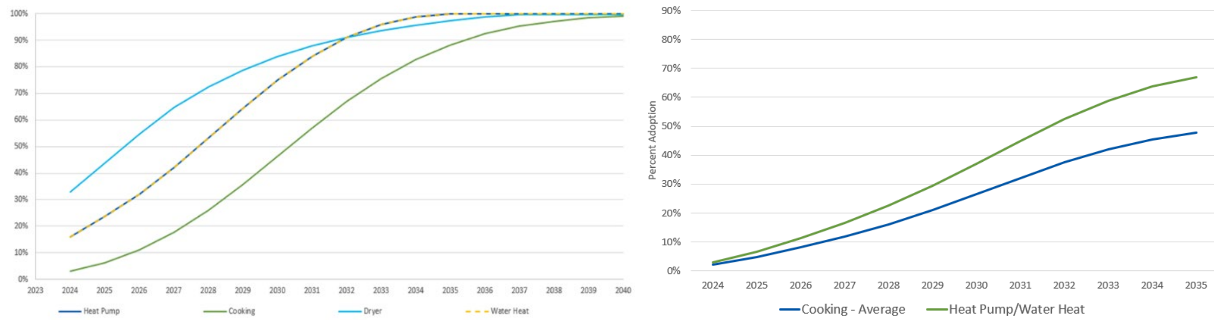
**Figure 24. Residential Adoption Curve Hybrid Heat Pump – Market Scenario (Single Family Example)**




In Figure 25 the residential policy scenarios (hybrid heat pump – policy and full electrification – policy) shows the maximum adoption reaching 100% in the latter half of the study horizon. For the commercial sector, the space heat and water heat maximum adoption was estimated to be 70% based on an ACEEE study.[18] We assumed cooking equipment to have 50% maximum adoption to account for market barriers in converting some natural gas cooking equipment.

18 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

**Figure 25. Residential Policy Scenarios (Left) and Commercial Adoption Curves (Right)**



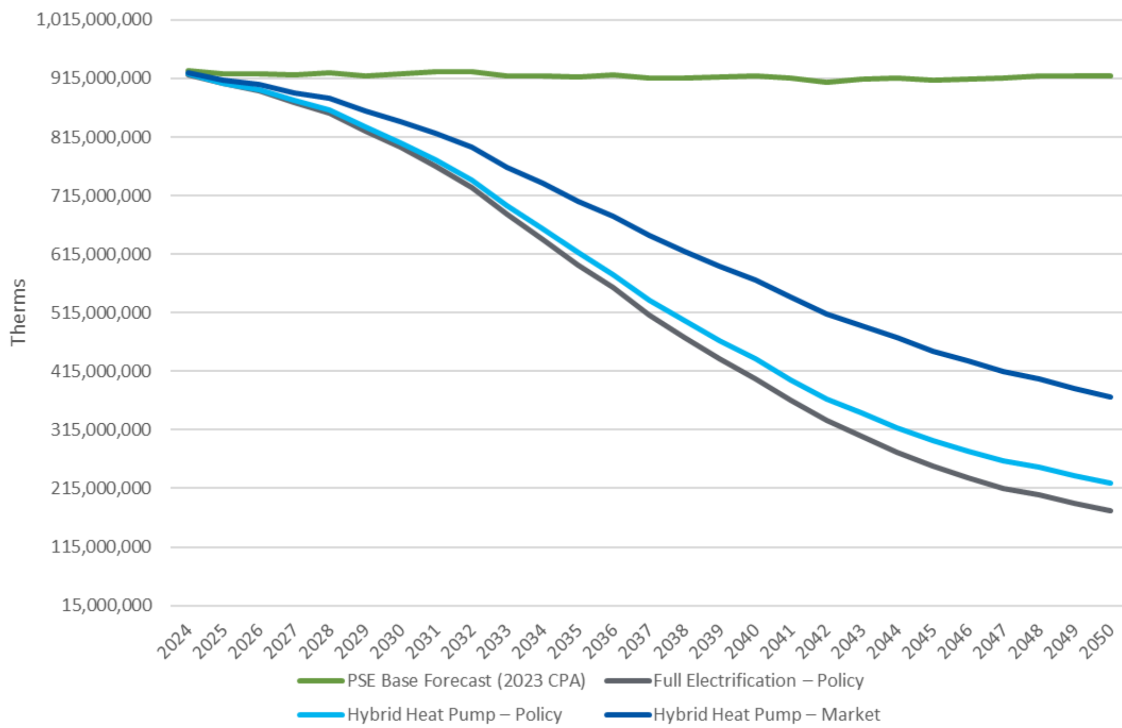

## *Load Impacts*

Cadmus used the natural gas-to-electric change in equipment saturation with the applied adoption rates 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 natural gas–to-electric supply curve alternatives. We used hourly end-use profiles from the draft *2021 Power Plan* and we estimated hourly profiles for hybrid and natural gas backup based on building simulations.

### Natural Gas Reduction Impacts

Cadmus calculated the associated natural gas reductions at the system level for each of the supply curve alternatives. The hybrid heat pump – market scenario is presented in figures below and represents the maximum impact if PSE's IRP portfolio model selects all measures (regardless of cost). We know that not all technologies will ultimately be selected within the IRP but this maximum market scenario provides additional context and comparison for the other scenarios. Figure 26 shows that the full electrification policy decreases the natural gas base sales forecast by 81% in 2050 from the PSE base forecast (2023 CPA), whereas the hybrid heat pump – policy scenario decreases the sales forecast by 76% and the hybrid heat pump – market scenario decreases the sales forecast by 60% (assuming all measures are found to be cost effective and selected in the IRP portfolio model). The C&I natural gas–to-electric supply curves do not change between each scenario. As a result, the change in natural gas reductions shown in Figure 26 comes from differences in the residential equipment (heat pump versus hybrid/backup).

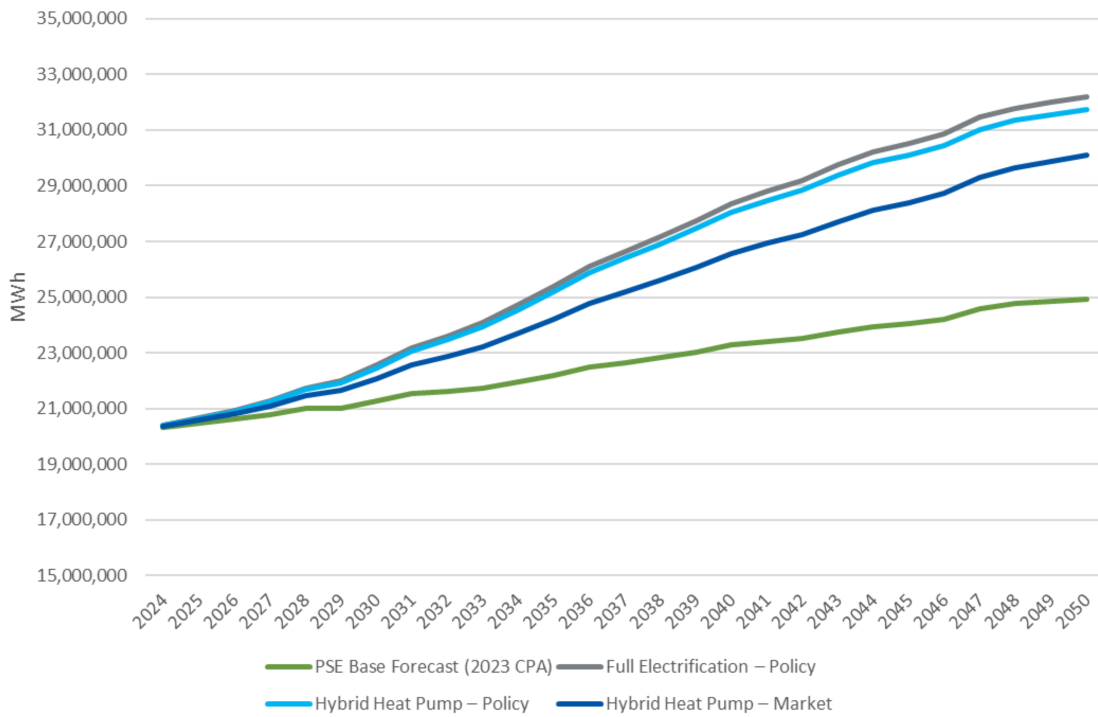
**Figure 26. Natural Gas Load Impact by Scenario 2024–2050 (Therms)**




## Electric Energy Impacts

Figure 27 shows the electric energy impacts by scenario of converting natural gas–to-electric equipment from 2024 to 2050. The full electrification policy increases the electric base sales forecast by 29% in 2050 from the PSE base forecast (2023 CPA), whereas the hybrid heat pump – policy scenario increases the sales forecast by 27% and the hybrid heat pump – market scenario increases the sales forecast by 21% (assuming all measures are found to be cost effective and selected in the IRP portfolio model).

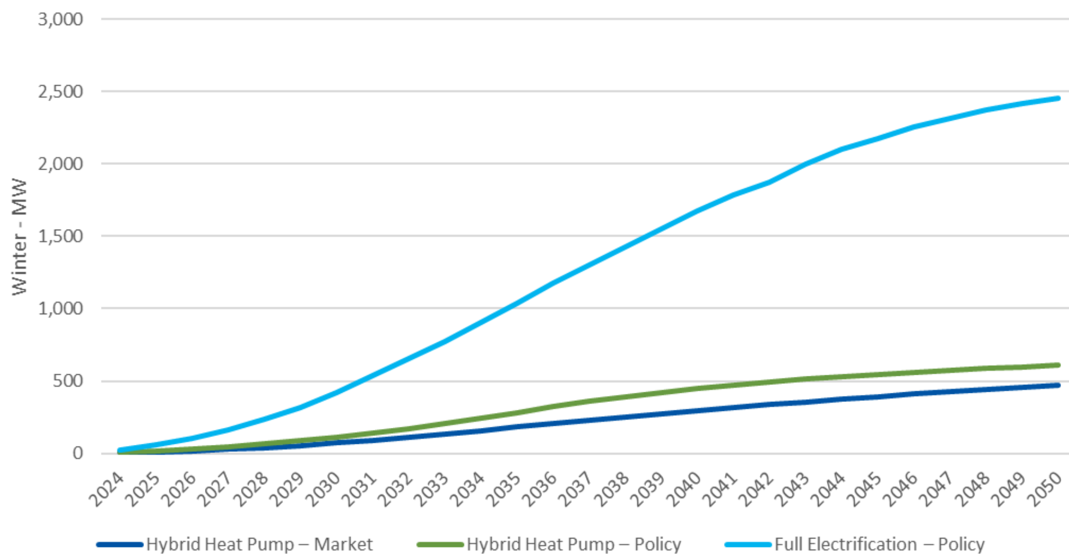
**Figure 27. Electric Load Impact by Scenario 2024–2050 (MWh)**




## Peak Demand Impacts

Cadmus calculated the cumulative peak winter demand impacts in PSE's electric service area as shown in Figure 28 by supply curve alternative from 2024 to 2050. The predominate increase in electric peak winter demand comes from the full electrification policy supply curve. This is due to heat pumps without natural gas backup operating during peak, whereas in the hybrid scenarios the natural gas heating equipment operates during peak and results in zero peak demand increases. The end uses represented in the hybrid scenarios peak demand are from water heaters, dryers, cooking, and commercial and industrial equipment. These end-uses are less coincident to PSE's winter peak (under extreme weather conditions).

**Figure 28. Cumulative Electric Winter Demand Impacts by Scenario (MW)**




## *Energy Efficiency Impacts*

Cadmus took the interaction with energy efficiency savings into account and assessed both electric and natural gas energy efficiency potential for both policy scenarios, as shown in Table 14. The market scenario was not evaluated for the energy efficiency impacts, since the cost effective amount of HHP will only be known after the gas portfolio analysis is complete.

**Table 14. Full Electrification and Hybrid Heat Pump Policy Scenario Impacts on Electric and Natural Gas Energy Efficiency Potential**

| Sector | Achievable Technical Potential, Cumulative 2050 | | |
|---|---|---|---|
| | 27-Year Base Energy Efficiency Potential | Full Electrification – Policy Scenario 27-Year Energy Efficiency Potential | Hybrid Heat Pump – Policy Scenario 27-Year Energy Efficiency Potential |
| **Electric (MWh)** | | | |
| Residential | 2,614,783 | 4,049,002 | 3,602,076 |
| Commercial | 2,020,415 | 2,303,609 | 2,303,609 |
| Industrial | 162,004 | 163,938 | 163,938 |
| **Total** | **4,797,202** | **6,516,549** | **6,069,624** |
| **Natural Gas (MMTherms)** | | | |
| Residential | 111 | 26 | 31 |
| Commercial | 51 | 19 | 19 |
| Industrial | 3 | 3 | 3 |
| **Total** | **165** | **48** | **53** |

The Full Electrification – Policy scenario has a 36% higher electric energy efficiency potential and 71% lower natural gas energy efficiency potential from equipment and retrofit measures compared to Hybrid Heat Pump – Policy scenario. The Hybrid Heat Pump – Policy scenario has a 27% higher electric energy efficiency potential and 68% lower natural gas energy efficiency potential than the base potential scenario.

## *Levelized Costs Calculations*

To incorporate the natural gas–to-electric 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 27-year period for the natural gas reductions. The 27-year natural gas levelized-cost calculations incorporate numerous factors, shown in Table 15.

**Table 15. Levelized Cost Components**

| Type | Component |
|---|---|
| Costs Included[1] | 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 |

[1]Costs for the electric energy generation and capacity are an output of 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 T&D costs for all non-hybrid heat pump systems (we modeled hybrid systems to have zero impact during winter peak).

In addition to the annual natural gas energy savings from converted away from natural gas, the total resource cost levelized-cost calculation incorporates several other 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.[19] Additional costs, besides 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 percent of incremental cost) from the energy efficiency potential

19 In this context, EUL refers to levelizing over the measure's useful life. This is equivalent to spreading incremental measure costs over its EUL in equal payments assuming a discount rate equal to PSE's weighted average cost of capital (6.80%). 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.

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

- ***Non-energy impacts.*** This study incorporated NEIs for residential customers who did not have existing cooling but received cooling comfort through the installation of the heat pump.
- ***The regional 10% conservation credit.*** The addition of this credit per the Northwest Power Act[20] is consistent with the Council's methodology and is effectively an adder to account for the unquantified external benefits of conservation when compared to other resources. This credit is only applied to the natural gas savings.

For more information on levelized costs calculations, see the *Integrated Resource Plan Input Development* section with details of the energy efficiency methodology.

## *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 the last step, Cadmus analyzed the magnitude of impacts of the natural gas–to-electric conversion on demand response potential. For this purpose, Cadmus focused on the same programs that were analyzed in "Demand-Side Electric Resource Potential Assessment"[21] 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*, with a few modifications to account for additional benchmarking. Details of these inputs can be found in a separate companion report titled *Comprehensive Assessment of Demand-Side Electric Resource Potential (2024–2050)*. To determine the impact of natural gas–to-electric conversion on demand response potential, Cadmus made some adjustments to the inputs. For the residential sector, we increased the number of ASHPs, DHPs, electric water heaters, dryers, and cooking equipment for each of three scenarios. Similarly, for commercial sector, we increased the number of ASHPs, water heaters, and

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

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

cooking equipment. In addition, we increased the total electric load (MWh) for each sector due to the additional load from natural gas–to-electric conversion.

| RESIDENTIAL | COMMERCIAL | INDUSTRIAL |
|---|---|---|
| • More increase in electric load in Full Electrification – Policy scenario than in Hybrid Heat Pump – Policy scenario<br>• Increase in equipment counts:<br>**Hybrid Heat Pump – Policy scenario**<br>Hybrid ASHPs, DHPs-partial load, DHPs-new construction full replacement, water heaters, dryers, stoves/cooktops<br>**Full Electrification – Policy scenario**<br>ASHPs, DHPs-full replacement, water heaters, dryesr, stoves/cooktops | • Increase in electric load at the same level for all scenarios<br>• Increase in equipment counts for ASHPs, water heaters, and cooking equipment | Increase in electric load at the same level for all scenarios |

After making these adjustments, we estimated the potential for two different natural gas–to-electric conversion scenarios, shown in Table 16. 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 17.

**Table 16. Comparison of Achievable Potential: Base Case and Policy Scenarios, Winter 2050**

| Program | Product Option | Base Case (MW) | Hybrid Heat Pump – Policy (MW) | Full Electrification – Policy (MW) |
|---|---|---|---|---|
| Residential DLC Water Heat | Residential ERWH DLC Switch | 0 | 0 | 0 |
| | Residential ERWH DLC Grid-Enabled | 32 | 63 | 63 |
| | Residential HPWH DLC Switch | 0 | 0 | 0 |
| | Residential HPWH DLC Grid-Enabled | 58 | 114 | 114 |
| Residential DLC HVAC | Residential HVAC DLC Switch | 97 | 102 | 173 |
| | Residential Bring-Your-Own Thermostat (BYOT) DLC | 108 | 122 | 356 |
| Residential DLC EVSE | Residential EVSE DLC Switch | 42 | 42 | 42 |
| Residential CPP | Residential CPP | 33 | 46 | 47 |
| | **Residential Sector Total** | **371** | **488** | **794** |
| Commercial DLC HVAC | Medium Commercial HVAC DLC Switch | 18 | 45 | 45 |
| | Small Commercial HVAC DLC Switch | 3 | 7 | 7 |
| | Small Commercial BYOT DLC | 3 | 18 | 18 |
| C&I Curtailment | Commercial Curtailment | 16 | 18 | 18 |
| Commercial CPP | Commercial CPP | 21 | 24 | 24 |
| | **Commercial Sector Total** | **61** | **112** | **112** |
| C&I Curtailment | Industrial Curtailment | 5 | 6 | 6 |
| Industrial CPP | Industrial CPP | 2 | 2 | 2 |
| | **Industrial Sector Total** | **7** | **8** | **8** |
| | **Total** | **439** | **607** | **913** |

**Table 17. Comparison of Achievable Potential: Base Case and Policy Scenarios, Summer 2050**

| Program | Product Option | Base Case (MW) | Hybrid Heat Pump – Policy (MW) | Full Electrification – Policy (MW) |
|---|---|---|---|---|
| Residential DLC Water Heat | Residential ERWH DLC Switch | 0 | 0 | 0 |
| | Residential ERWH DLC Grid-Enabled | 22 | 42 | 42 |
| | Residential HPWH DLC Switch | 0 | 0 | 0 |
| | Residential HPWH DLC Grid-Enabled | 29 | 57 | 57 |
| Residential DLC HVAC | Residential HVAC DLC Switch | 50 | 68 | 68 |
| | Residential BYOT DLC | 100 | 184 | 184 |
| Residential DLC EVSE | Residential EVSE DLC Switch | 42 | 42 | 42 |
| Residential CPP | Residential CPP | 74 | 101 | 101 |
| | **Residential Sector Total** | **316** | **493** | **493** |
| Commercial DLC HVAC | Medium Commercial HVAC DLC Switch | 77 | 116 | 116 |
| | Small Commercial HVAC DLC Switch | 5 | 8 | 8 |
| | Small Commercial BYOT DLC | 4 | 9 | 9 |
| C&I Curtailment | Commercial Curtailment | 20 | 23 | 23 |
| Commercial CPP | Commercial CPP | 26 | 30 | 30 |
| | **Commercial Sector Total** | **133** | **185** | **185** |
| C&I Curtailment | Industrial Curtailment | 5 | 6 | 6 |
| Industrial CPP | Industrial CPP | 2 | 2 | 2 |
| | **Industrial Sector Total** | **7** | **8** | **8** |
| | **Total** | **455** | **686** | **686** |

## Hybrid Heat Pump – Policy

Figure 29 shows the acquisition schedule for demand response achievable technical potential by product for winter. Product potential ramps up fast in the early years of the study and slows down once the market has become close to maturity. Residential HVAC makes up most of the available winter demand response potential due to the increased number of heat pumps. It should be noted that the demand response potential shown represents the achievable technical potential and includes both cost-effective and non-cost-effective demand response products.

**Figure 29. Demand Response Achievable Technical Potential Forecast by Program for Hybrid Heat Pump – Policy Scenario, Winter**

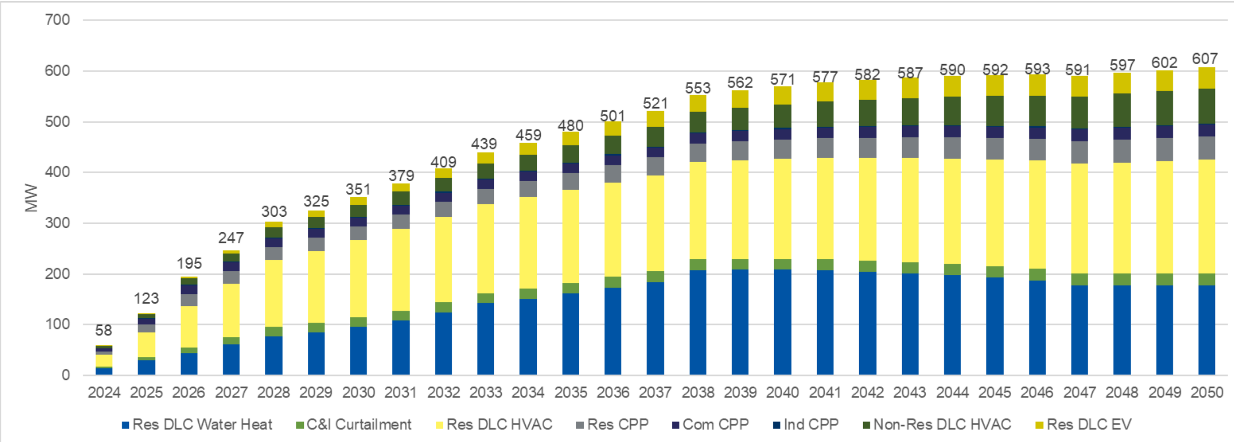
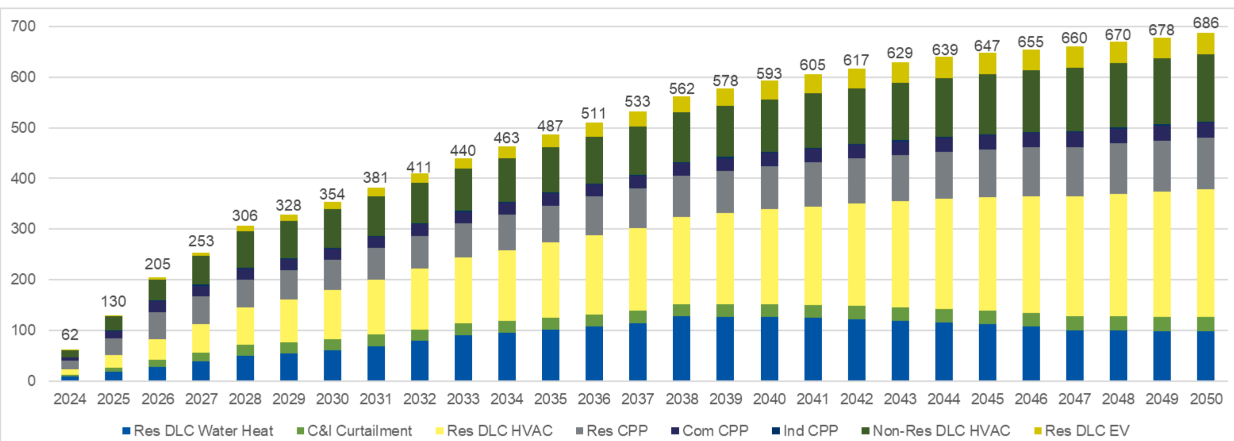



Figure 30 shows the acquisition schedule for demand response achievable technical potential by program for summer. The dynamics in the summer are similar to those seen in the winter, though the overall potential is higher.

**Figure 30. Demand Response Achievable Technical Potential Forecast by Program for Hybrid Heat Pump – Policy Scenario, Summer**




## Full Electrification – Policy

Figure 31 shows the acquisition schedule for demand response achievable technical potential by product for winter. Product potential ramps up fast in the early years of the study and slows down once the market has become close to maturity. Similar to the Hybrid Heat Pump – Policy scenario, residential HVAC makes up most of the available winter demand response potential due to the increased number of heat pumps. However, when compared to Hybrid Heat Pump – Policy scenario results (Figure 29), the Full Electrification – Policy scenario created more potential through Residential BYOT, Residential HVAC DLC Switch, and Residential CPP products due to not having backup natural gas heating.

**Figure 31. Demand Response Achievable Technical Potential Forecast by Program for Full Electrification – Policy Scenario, Winter**

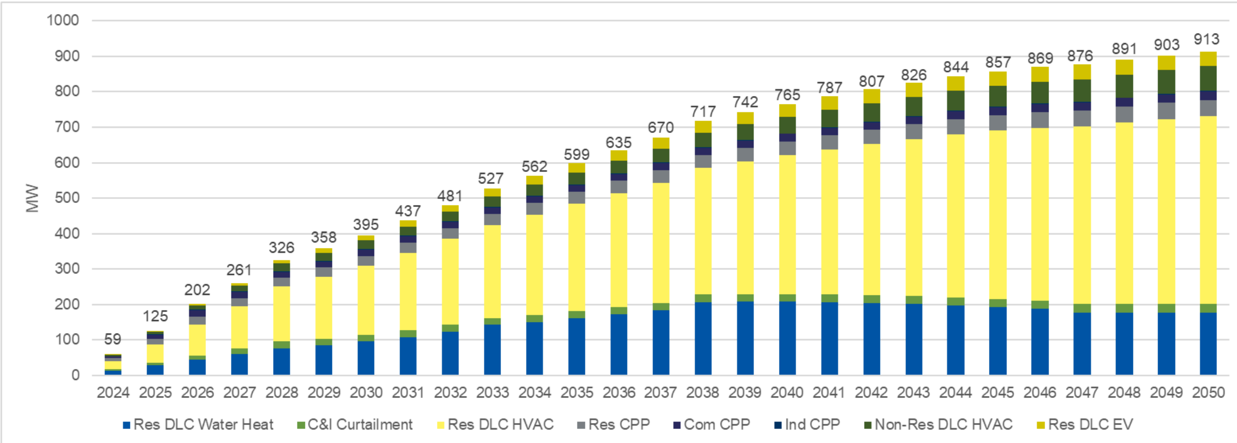
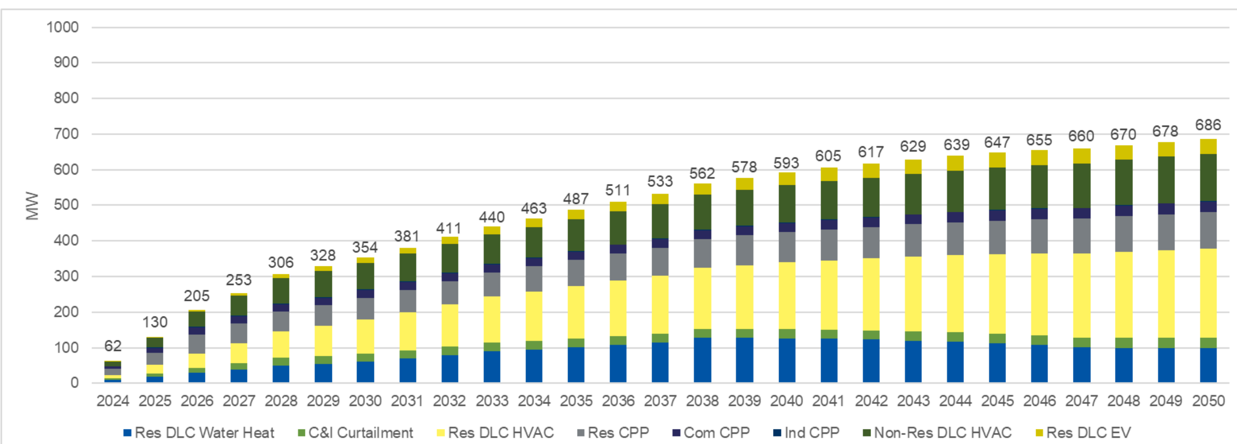



Figure 32 shows the acquisition schedule for demand response achievable technical potential by program for summer. For the Full Electrification – Policy scenario, demand response potential is the same as that for the Hybrid Heat Pump – Policy scenario because of having no difference in the number of equipment as well as no difference in per-unit impacts between these two scenarios.

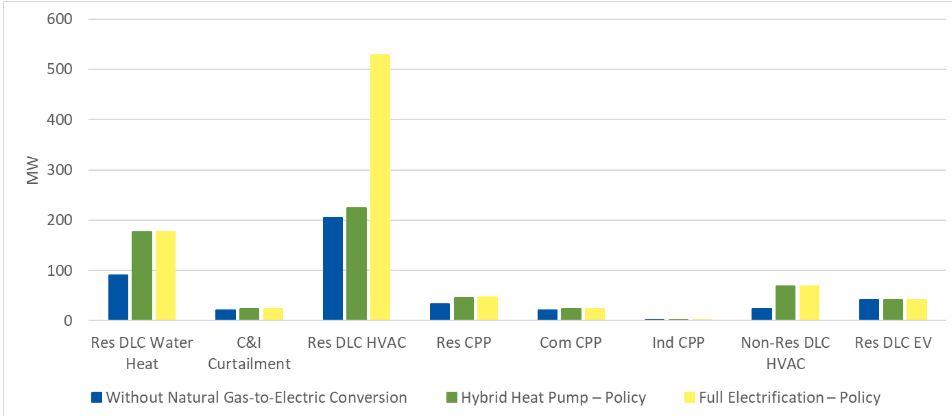
**Figure 32. Demand Response Achievable Technical Potential Forecast by Program for Full Electrification – Policy Scenario, Summer**




## Comparison of Natural Gas-to-Electric Conversion Scenarios with Base Case

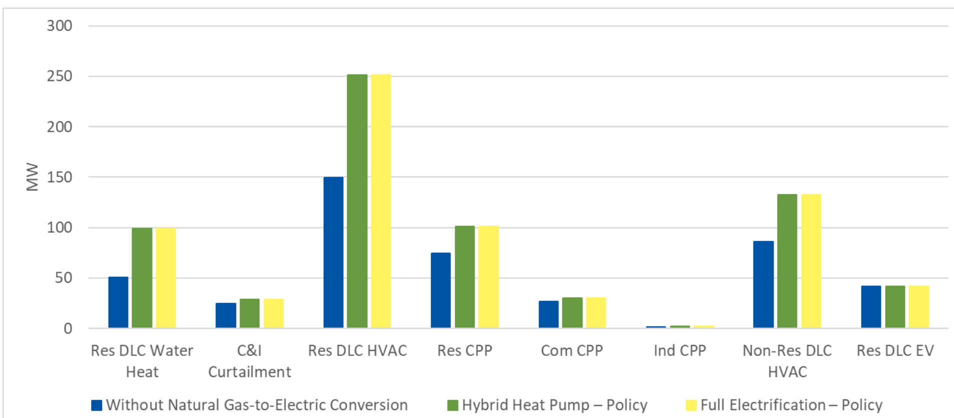
Figure 33 presents the impact of natural gas–to-electric conversion on winter demand response potential by comparing the base case (where there is no natural gas–to-electric conversion) with both scenarios.

**Figure 33. Comparison of Natural Gas-to-Electric Conversion Scenarios with the 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 demand, shown in Figure 34.

**Figure 34. Comparison of Natural Gas-to-Electric Conversion Scenarios with the Base Case, Summer 2050**




Except Residential DLC EV, all the products show the impact of natural gas–to-electric conversion on the base case to different extents. The most notable impact is between the base case and Full Electrification – Policy scenario in the Residential DLC HVAC program for winter due to the increasing electric heating load.

# Chapter 4. Energy Efficiency Methodology Details

This chapter describes Cadmus' methodology for estimating the potential of demand-side resources in PSE's service territory between 2024 and 2050 and for developing supply curves for modeling demand-side resources in PSE's IRP. We describe the calculations for technical and achievable technical potential, identify the data sources for components of these calculations, and discuss key global assumptions. To estimate the demand-side resource potential, Cadmus analyzed many conservation measures across many sectors, with each measure requiring nuanced analysis. This chapter does not describe the detailed approach for estimating a specific measure's UES or cost, but it does show the general calculations we used for nearly all measures.

Cadmus' methodology for calculating energy efficiency potential can be best described as a combined top-down, bottom-up approach. We began the top-down component with the most current load forecast, adjusting for building codes, equipment efficiency standards, and market trends that are not accounted for through the forecast. Cadmus then disaggregated this load forecast into its constituent customer sectors, customer segments, and end-use components and projected the results out 27 years. We calibrated the base year (2023) to PSE's sector-load forecasts produced in 2022.

For the bottom-up component, we considered potential technical impacts of various ECMs and practices on each end use. We then estimated impacts based on engineering calculations, accounting for fuel shares (the proportion of units using electricity versus natural gas), current market saturations, technical feasibility, and costs. The technical potential presents an alternative forecast that reflects the technical impacts of specific energy efficiency measures. Cadmus then determined the achievable technical potential by applying ramp rates and achievability percentages to technical potential. The CPA methodology is described in detail in the following sections.

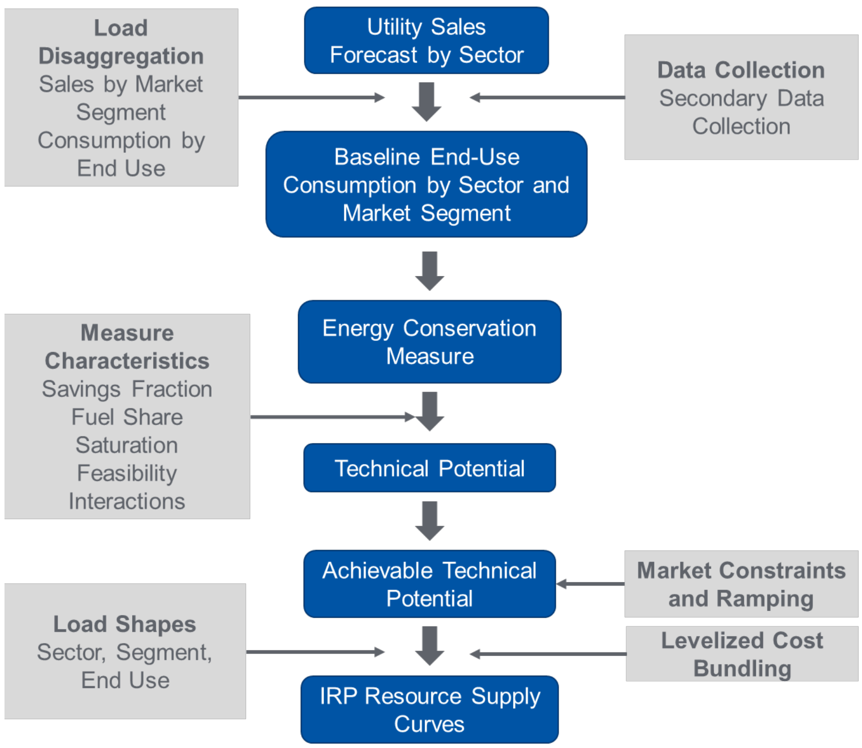
Cadmus followed a series of steps to estimate energy efficiency potential, described in detail in the subsections below:

- ***Market segmentation.*** Cadmus identified the sectors and segments for estimating energy efficiency potential. Segmentation accounts for variation across different parts of PSE's service territory and across different applications of energy efficiency measures.
- ***ECM characterization.*** Cadmus researched viable ECMs that can be installed in each segment. The description for this step below includes the components and data sources for estimating measure savings, costs, applicability factors, lifetimes, baseline assumptions, and the treatment of federal standards.
- ***Baseline end-use load forecast development.*** Cadmus developed baseline end-use load forecasts over the planning horizon and calibrated the results to the PSE's corporate forecast in the base year (2023).

- ***Conservation potential estimation.*** Cadmus forecasted technical potential, relying on the measure data compiled from prior steps and the achievable technical potential, which we based on technical potential and additional terms to account for market barriers and ramping.
- ***IRP input development.*** Cadmus bundled forecasts of achievable technical potential by levelized costs, so PSE's IRP modelers can consider energy efficiency as a resource within the IRP.

Figure 35 provides a general overview of the process and inputs required to estimate potential and develop conservation supply curves.

**Figure 35. Overview of Energy Efficiency Methodology**




## *Market Segmentation*

Market segmentation involved first dividing PSE's natural gas service territories into sectors and market segments. Careful segmentation accounts for variation in building characteristics and savings across the service territory. To the extent possible, energy efficiency measure inputs reflect primary data, such as the NEEA 2019 CBSA, the NEEA 2017 RBSA, and the PSE's RCS.

Considering the benefits and drawbacks of different segmentation approaches, Cadmus identified three parameters that produce meaningful and robust estimates:

- ***Service territories and fuel.*** PSE's natural gas service territory
- ***Sector.*** Residential, commercial, industrial, and small transport
- ***Industries and building types.*** Three residential segments (with the corresponding vulnerable population segments), 18 commercial segments, 18 industrial segments, and 29 small transport segments

Table 18 lists the sectors and associated segments modeled in this study.

**Table 18. Sectors and Segments Modeled**

| Residential | Commercial | Industrial | Small Transport | |
|---|---|---|---|---|
| | | | **Commercial** | **Industrial** |
| • Manufactured<br>• Manufactured - Vulnerable Population<br>• Multifamily<br>• Multifamily - Vulnerable Population<br>• Single Family<br>• Single Family - Vulnerable Population | • Assembly<br>• Extra Large Retail<br>• Hospital<br>• Large Office<br>• Large Retail<br>• Lodging<br>• Medium Office<br>• Medium Retail<br>• Mini-Mart<br>• Residential Care<br>• Restaurant<br>• School K–12<br>• Small Office<br>• Small Retail<br>• Supermarket<br>• University<br>• Warehouse<br>• Other | • Cement<br>• Chemical<br>• Cold Storage<br>• Food - Frozen<br>• Food - Other<br>• Foundries<br>• Fruit Storage<br>• Hi Tech - Chip Fabrication<br>• Hi Tech - Silicon<br>• Mechanical Pulp<br>• Metal Fabrication<br>• Miscellaneous Manufacturing<br>• Paper<br>• Refinery<br>• Transportation Equipment<br>• Wood - Lumber<br>• Wood - Other<br>• Wood - Panel | • Assembly<br>• Extra Large Retail<br>• Hospital<br>• Large Office<br>• Lodging<br>• Residential Care<br>• Restaurant<br>• School K–12<br>• Supermarket<br>• Warehouse<br>• Other | • Cement<br>• Chemical<br>• Cold Storage<br>• Food – Frozen<br>• Food – Other<br>• Foundries<br>• Fruit Storage<br>• Hi Tech – Chip Fabrication<br>• Hi Tech – Silicon<br>• Mechanical Pulp<br>• Metal Fabrication<br>• Miscellaneous Manufacturing<br>• Paper<br>• Refinery<br>• Transportation Equipment<br>• Wood – Lumber<br>• Wood – Other<br>• Wood – Panel |

## *Energy Efficiency Measure Characterization*

Technical potential draws upon an alternative forecast and should reflect installations of all technically feasible measures. To accomplish this, Cadmus chose the most robust set of appropriate ECMs by developing a comprehensive database of technical and market data that applied to all end uses in various market segments. Throughout this process, we calculated ECM savings as UES or measure percentage savings to estimate the end-use percentage savings. These measures' end-use percentage savings, when applied to the baseline end-use forecasts, produce estimates of energy efficiency potential.

The database included several measures:

- All measures in the PSE business case workbooks
- Active UES measures in the RTF
- Some dual fuel measures in the Council's draft *2021 Power Plan* conservation supply curve workbooks
- Industrial measures derived from the "Industrial Assessment Center Database (2000–2021)"
- Other Cadmus derived measures

Cadmus classified the natural gas energy efficiency measures applicable to PSE's service territories into two categories:

| LOST OPPORTUNITY | DISCRETIONARY |
|---|---|
| **High-efficiency equipment** measures directly affecting end-use equipment (such as high-efficiency boilers), which follow normal replacement patterns based on expected lifetimes | **Non-equipment (retrofit)** measures affecting end-use consumption without replacing end-use equipment (such as insulation). Such measures do not include timing constraints from equipment turnover—except for new construction—and should be considered discretionary, given that savings can be acquired at any point over the planning horizon. |

Cadmus assumed that all high-efficiency equipment measures would be installed at the end of the existing equipment's remaining useful life; therefore, we did not assess energy efficiency potential for early replacement.

Each measure type has several relevant inputs:

***Equipment and non-equipment measures:***

- Energy savings: Average annual savings attributable to installing the measure, in absolute (therm per unit) and/or percentage terms.
- Equipment cost: Full or incremental, depending on the nature of the measure and the application.
- Labor cost: The expense of installing the measure, accounting for differences in labor rates by region and other variables.
- Technical feasibility: The percentage of buildings where customers can install this measure, accounting for physical constraints.
- Measure life: The expected life of the measure equipment.
- Non-energy impacts: The annual dollar savings per year associated with quantifiable non-energy benefits.
- Savings shape. We assigned an hourly savings shape to each measure, which we then used to disaggregate annual forecasts of potential into monthly estimates.

***Non-equipment measures only:***

- Percentage incomplete: The percentage of buildings where customers have not installed the measure, but where its installation is technically feasible. This equals 1.0 minus the measure's current saturation.
- Measure competition: For mutually exclusive measures, accounting for the percentage of each measure likely installed to avoid double-counting savings.
- Measure interaction: Accounting for end-use interactions (for example, installing a high efficiency clothes washer serviced by a gas water heater reduces the remaining moisture content in clothing which in turn lowers the required natural gas dryer load required to dry the clothes).

Cadmus derived these inputs from various sources, though primarily through four main sources:

- NEEA CBSA IV, including PSE's oversample, where applicable
- NEEA RBSA II with PSE's oversample
- The RTF UES measure workbooks
- The Council's draft *2021 Power Plan* conservation supply curve workbooks

For many equipment and non-equipment inputs, Cadmus reviewed a variety of sources. To determine which source to use for this study, Cadmus developed a hierarchy for costs and savings:

1. PSE business cases
2. RTF UES measure workbooks
3. The Council's draft *2021 Power Plan* conservation supply curve workbooks (for some dual fuel measures)
4. Secondary sources, such as Simple Energy and Enthalpy Model building simulations, U.S. Department of Energy's "Industrial Assessment Center Database (2000–2021)," or various technical reference manuals

Cadmus also developed a hierarchy to determine the source for various applicability factors, such as the technical feasibility and the percentage incomplete. This hierarchy differed slightly for residential and commercial measure lists.

## Non-Energy Impacts

In this CPA, Cadmus included a wider range of NEIs (such as health and safety, comfort, and productivity) compared to the 2021 CPA, which resulted in additional NEIs for more measures. In 2021, PSE conducted an NEI evaluation study[22] to expand the NEIs; the full list is shown in Table 19.

[22] DNV Energy. September 30, 2021. *Puget Sound Energy Non-Energy Impacts Final Report*.

**Table 19. List of Non-Energy Impacts**

| NEI Name | NEI Type | Definition |
|---|---|---|
| **Residential** | | |
| Avoided Illness from Air Pollution | Societal | Modeled value of avoided particulate matter 2.5 microns or less (PM2.5) associated with electricity generation at power plant. Does not include carbon dioxide. |
| Bad Debt Write Offs | Utility | Reduction in cases of bad debt write offs. |
| Calls to Utility | Utility | Reduction in number of calls to utility from customers. |
| Carrying Cost on Arrearages | Utility | Reduced carrying cost on arrearages. |
| Ease of Selling or Leasing | Participant | Participant-reported improved ability to sell or lease property due to increased performance and desirability. |
| Fires/Insurance Damage | Participant | Avoided cost of fires based on insurance estimates. |
| Health and Safety | Participant | Participant-reported costs from time off and lost pay due to fewer missed days of work/school, less heat/cold stress, and similar, resulting from measures installed in the home. |
| Lighting Quality and Lifetime | Participant | Participant-reported value of improved lighting lumen levels, color, and steadiness. |
| Noise | Participant | Participant-reported value associated with reduced amount of outside noise that can be heard inside the home. |
| O&M | Participant | Modeled avoided time and costs associated with reduced maintenance, parts/repairs, service visits, and system monitoring |
| Other Impacts | Participant | Includes participant impacts not covered in the other categories such as reduced tenant turnover. |
| | Utility | Includes rate discounts and price hedging. |
| | | Includes low-income subsidies avoided. |
| Productivity | Participant | Participant-reported value resulting from improved rest, sleep, and living conditions associated with energy efficiency improvements. |
| Thermal Comfort | Participant | Increased comfort due to fewer drafts and more even temperatures throughout the building. |
| **Commercial and Industrial** | | |
| Administrative Costs | Participant | Participant-reported avoided overhead costs associated with invoice processing, parts/supplies procurement, contractor coordination, and customer complaints. |
| Avoided Illness from Air Pollution | Societal | Modeled value of avoided particulate matter 2.5 microns or less (PM2.5) from electric power generation associated with electricity generation at power plant. Does not include carbon dioxide. |
| Ease of Selling or Leasing | Participant | Participant-reported improved ability to sell or lease property due to increased performance and desirability. |
| Fires/Insurance Damage | Participant | Avoided cost of fires based on insurance estimates. |
| Lighting Quality and Lifetime | Participant | Participant-reported value of improved lighting lumen levels, color, and steadiness. |
| O&M | Participant | Avoided time and costs associated with reduced maintenance, parts/repairs, service visits, and system monitoring. |
| Other Impacts | Participant | Includes rent revenues, employee satisfaction, and other labor costs (defined as other labor at the company not covered in O&M, administrative costs, supplies, and materials). |
| | | Included modeled value of decreased usage of fuel, propane, and other sources. |

| NEI Name | NEI Type | Definition |
|---|---|---|
| Product Spoilage/Defects | Participant | Participant-reported value of avoided product losses (such as reduced food spoilage in grocery stores). |
| Productivity | Participant | Participant-reported value of improved workplace productivity resulting from improved rest and sleep related to improved living conditions. |
| Sales Revenue | Participant | Participant-reported increased sales resulting from improved product. |
| Supplies and materials | Participant | Includes changes in the type, amount, or costs of materials and supplies needed. |
| Thermal Comfort | Participant | Increased comfort due to fewer drafts and more even temperatures throughout the building. |
| Waste Disposal | Participant | Participant-reported costs to remove solid waste and pay landfill fees (such as fees to dispose of CFLs). |
| Water/ Wastewater | Participant | Reduced water usage due to efficient equipment. |

PSE has been incorporating these NEIs into some business cases; however, at the time of this study being conducted there were still some business cases without this new NEI evaluation embedded. In addition, as mentioned above, Cadmus used the RTF UES and draft *2021 Power Plan* workbooks when a business case was not available for a measure and some RTF and Council measures already had NEI as a water saving, O&M lifetime replacement. Therefore, Cadmus developed the methodological hierarchy presented in Table 20 to account for all available NEI data for all measures applicable.

**Table 20. Methodological Hierarchy for Non-Energy Impact Data Inclusion**

| Measure Type | CPA Action |
|---|---|
| PSE business case with existing NEI | Use existing business case NEI |
| PSE business case without existing NEI | Use NEI evaluation study data, if applicable |
| RTF/Council with existing NEI | Use RTF/Council data and NEI evaluation study data (excluding water saving, O&M lifetime replacements), if applicable |
| RTF/Council without existing NEI | Use NEI evaluation study data, if applicable |

## Measure Data Sources

By data input, Table 21 lists the primary sources referenced in the study.

**Table 21. Key Measure Data Sources**

| Data | Residential Source | Commercial Source | Industrial Source |
|---|---|---|---|
| Energy Savings [a] | PSE business cases; draft *2021 Power Plan* supply curve workbooks; RTF; Cadmus research | PSE business cases; draft *2021 Power Plan* supply curve workbooks; RTF; Cadmus research | U.S. Department of Energy's "Industrial Assessment Center Database (2000–2021)" |
| Equipment and Labor Costs | PSE business cases; draft *2021 Power Plan* supply curve workbooks; RTF; Cadmus research | PSE business cases; draft *2021 Power Plan* supply curve workbooks; RTF; Cadmus research | U.S. Department of Energy's "Industrial Assessment Center Database (2000–2021)" |
| Measure Life | PSE business cases; draft *2021 Power Plan* supply curve workbooks; RTF; Cadmus research | PSE business cases; draft *2021 Power Plan* supply curve workbooks; RTF; Cadmus research | Cadmus research |
| Technical Feasibility | NEEA RBSA; Cadmus research | NEEA CBSA; Cadmus research | Cadmus research |
| Percentage Incomplete | NEEA RBSA; PSE program accomplishments; Cadmus research | NEEA CBSA; PSE program accomplishments; Cadmus research | Cadmus research |

| Data | Residential Source | Commercial Source | Industrial Source |
|---|---|---|---|
| Measure Interaction | PSE business cases; draft *2021 Power Plan* supply curve workbooks; RTF; Cadmus research | PSE business cases; draft *2021 Power Plan* supply curve workbooks; RTF; Cadmus research | Cadmus research |
| Non-Energy Impacts | PSE business cases; PSE's NEI evaluation study; [b] draft *2021 Power Plan* supply curve workbooks; RTF | PSE business cases; PSE's NEI evaluation study; [b] draft *2021 Power Plan* supply curve workbooks; RTF | N/A |

[a] The draft *2021 Power Plan* does not have natural gas–only measures. Cadmus converted dual fuel measures, such as water heater applications, showerheads, and clothes washer, to represent natural gas impacts. Additionally, we benchmarked space and water heat consumptions for residential applications against both the RTF and draft *2021 Power Plan* consumptions to align electric and natural gas loads for these end uses.

[b] DNV Energy. September 30, 2021. *Puget Sound Energy Non-Energy Impacts Final Report.*

## Incorporating Federal Standards and State and Local Codes and Policies

Cadmus' assessment accounted for changes in codes, standards, and policies over the planning horizon. These changes affected customers' energy-consumption patterns and behaviors, and they determined which energy efficiency measures would continue to produce savings over minimum requirements. Cadmus captured current efficiency requirements, including those enacted but not yet in effect.

Cadmus reviewed all local codes, state codes, federal standards, and local and state policy initiatives that could impact this potential study. For the residential and commercial sectors, we considered the local energy code (2018 Seattle Energy Code, 2018 WSEC, and 2018 RCW) as well as current and pending federal standards.

Cadmus reviewed the following codes, standards, and policy initiatives:

- **Federal standards.** All technology standards for heating equipment, water heating, and appliances not covered in or superseded by state and local codes.[23]
- **2018 Seattle Energy Code.** The code prohibits new commercial and multifamily buildings from using electric resistance or fossil fuels for space heating effective June 1, 2021, and electric resistance or fossil fuels for water heating effective January 1, 2022. All other code provisions took effect on March 15, 2021.[24]

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23 U.S. Department of Energy, Office of Energy Efficiency & Renewable Energy. Accessed May 2022. "Standards and Test Procedures." https://www.energy.gov/eere/buildings/standards-and-test-procedures

24 City of Seattle, Office of the City Clerk. February 1, 2021. "Council Bill No: CB 119993. An Ordinance Relating to Seattle's Construction Codes." http://seattle.legistar.com/LegislationDetail.aspx?ID=4763161&GUID=A4B94487-56DE-4EBD-9BBA-C332F6E0EE5D

- **2018 Washington State Energy Code (WSEC).** The code provides requirements for residential and commercial new construction buildings, except in cases where the 2018 Seattle Energy Code supersedes Washington code. The effective date was February 1, 2021.[25]
- **2009 Washington State Senate Bill 5854 and Revised Code of Washington (RCW 19.27A.160).** This code requires "… residential and nonresidential construction permitted under the 2031 state energy code achieve a 70% reduction in annual net energy consumption, using the adopted 2006 Washington state energy code as a baseline."
- **2018 Revised Code of Washington (RCW 19.260.040).** These codes set minimum efficiency standards to specific types of products including steam cookers and fryers. The effective dates vary by product with the 2018 RCW signed on July 28, 2019.[26]
- **City of Shoreline Ordinance No. 948**. The "Ordinance of the City of Shoreline, Washington Amending Chapter 15.05, Construction and Building Codes, of the Shoreline Municipal Code, to Provide Amendments to the WSEC – Commercial, as Adopted by the State of Washington" adds a new section to Seattle Municipal Code 15.05 adopting the WSEC, as adopted by the Building Council in Chapter 51-11 of the Washington Administrative Code with amendments addressing reductions of carbon emissions in new commercial construction. The ordinance took effect on July 1, 2022.
- **City of Bellingham Ordinance.** The "Ordinance of the City of Bellingham Amending Bellingham Municipal Code Chapter 17.10 – Building Codes, to Provide Amendments to the WSEC – Commercial, Promoting Energy Efficiency and the Decarbonization of Commercial and Large Multifamily Buildings and Requiring Solar Readiness for New Buildings" took effect on August 7, 2022.

The following policy driven initiatives (Seattle's Energy Benchmarking program and the Clean Buildings Bill) do not mandate an energy code or baseline for specific measures, rather they inherently speed up the rate of the adoption of energy efficiency through energy reduction requirements. PSE can also claim energy impacts through these initiatives; therefore, removing measures or adjusting baselines may not be appropriate within the context of the CPA. Since PSE already incorporates a 10-year ramp rate for most discretionary measures, this accelerated adoption essentially accounts for the majority of these initiatives.

- **Seattle's Energy Benchmarking Program (SMC 22.920).** This program requires owners of commercial and multifamily buildings (20,000 square feet or larger) to track and annually report

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25 Washington State Building Code Council. Accessed May 2022. https://sbcc.wa.gov/

26 Washington State Legislature, Revised Code of Washington. December 7, 2020. "RCW 19.260.050 Limit on Sale or Installation of Products Required to Meet or Exceed Standards in RCW 19.260.040." https://app.leg.wa.gov/rcw/default.aspx?cite=19.260.050

energy performance to the city of Seattle. Though in effect since 2016, full enforcement of the program began on January 1, 2021.[27]

- **Clean Buildings Bill (E3SHB 1257).** The law requires the Washington State Department of Commerce to develop and implement an energy performance standard for the state's existing buildings, especially large commercial buildings (based on building square feet) and provide incentives to encourage efficiency improvements. The effective date was July 28, 2019, with the building compliance schedule set to begin on June 1, 2026. Early adopter incentive applications began in July 2021.[28]

## Treatment of Federal Standards

Cadmus explicitly accounted for several other pending federal codes and standards. For the residential and commercial sectors, these included appliance, HVAC, and water-heating standards. Figure 36 provides a comprehensive list of equipment standards considered in the study. However, Cadmus did not attempt to predict how energy standards might change in the future. At the time of this study's development, the proposed federal natural gas residential furnace standard (effective in 2029) had not been public and this study did not account for this proposed future standard.

**Figure 36. Natural Gas Federal and State Equipment Standards Considered**

| Equipment Electric Type | New Standard | Sectors Impacted | Study Effective Date |
|---|---|---|---|
| Clothes Washer (top loading) | Federal standard 2015 | Residential | March 7, 2015 |
| Clothes Washer (front loading) | Federal standard 2018 | Residential | January 1, 2018 |
| Clothes Washer (commercial sized) | Federal standard 2013 | Nonresidential | January 8, 2013 |
| | Federal standard 2018 | | January 1, 2018 |
| Dishwasher | Federal standard 2013 | Residential | May 30, 2013 |
| Dishwasher (commercial) | State standard 2019 | Nonresidential | January 1, 2021 |
| Dryer | Federal standard 2015 | Residential | January 1, 2015 |
| Boiler – Residential sized | Federal standard 2021 | Nonresidential/Residential | January 15, 2021 |
| Boiler – Commercial sized | Federal standard 2023 | Nonresidential | January 10, 2023 |
| Pre-Rinse Spray Valve | Federal standard 2019 | Nonresidential | January 28, 2019 |
| Showerhead | State standard 2019 | Nonresidential/Residential | January 1, 2021 |
| Water Heater >55 Gallons | Federal standard 2015 | Nonresidential/Residential | April 16, 2015 |
| Water Heater ≤55 Gallons | Federal standard 2015 | Nonresidential/Residential | April 16, 2015 |

## Additional Codes and Standards Considerations

Cadmus identified an additional consideration that impact the characterization of this potential study: residential and commercial new construction prescriptive and performance path requirement options, included in the 2018 WSEC. The CPA characterizes efficiency improvements on a measure basis that align with the prescriptive path. The performance path includes the HVAC total system performance

27 City of Seattle, Office of Sustainability and Environment. Accessed May 2022. "Energy Benchmarking." https://www.seattle.gov/environment/climate-change/buildings-and-energy/energy-benchmarking

28 Washington State Department of Commerce. Accessed July 2022. "Clean Buildings." https://www.commerce.wa.gov/growing-the-economy/energy/buildings/

ratio requirement, defined as the ratio of the sum of a building's annual heating and cooling load compared to the sum of the annual carbon emissions from the energy consumption of the building's HVAC systems. The variability in the HVAC total system performance ratio from building to building cannot be easily captured in the CPA. For this study, Cadmus followed the prescriptive requirements in the 2018 WSEC.

### Adapting Measures from PSE Business Cases and RTF and Draft *2021 Power Plan*

Cadmus prioritized PSE's program business cases in developing measure characterization inputs. In most cases, the program business cases relied on the RTF and Council workbooks tailored to PSE's territory and program delivery experience. In adapting ECMs for this study, Cadmus adhered to three principles:

- **PSE Developed Business Cases:** We used the PSE business cases as the primary data source for measure characterization inputs, where possible. Using these business cases creates better alignment between PSE program planning projections and potential estimates for applicable measures.
- **Deemed ECM savings in RTF or Council workbooks must be preserved:** PSE mainly relies on deemed savings estimates provided in RTF and Council workbooks. Therefore, Cadmus sought to preserve these deemed savings to avoid possible inconsistencies among estimates of potential, targets, and reported savings.
- **Use inputs specific to PSE's service territory:** Some RTF and Council workbooks relied on regional estimates of saturations, equipment characteristics, and building characteristics derived from the RBSA and CBSA. Cadmus updated regional inputs with estimates, calculated either from PSE's oversample of CBSA and RBSA or from estimates affecting the broader PSE area. This approach preserved consistency with Council methodologies while incorporating PSE-specific data.
- **Use the "Industrial Assessment Center Database":** Cadmus adapted industrial measures from the U.S. Department of Energy's "Industrial Assessment Center Database (2000–2021)" for inclusion in this study for measure savings (expressed as end-use percentage savings) and measure costs (expressed as dollars per therm saved). We sources industrial measure lifetimes (expressed in years) from technical reference manuals.

## *Baseline End-Use Load Forecast Development*

Creating a baseline forecast required multiple data inputs to accurately characterize energy consumption in PSE's service area. These are PSE's sector-level sales and customer forecasts, customer segments (business, dwelling, or facility types), end-use saturations (percentage of an end use [such as a furnace] present in a building), equipment saturations (such as the average number of units in a building), fuel shares (proportion of units using electricity versus natural gas), efficiency shares (the percentage of equipment below, at, and above standard), and annual end-use consumption estimates by efficiency levels.

PSE's sector-level sales and customer forecasts provided the basis for assessing energy efficiency potential. Prior to estimating potential, Cadmus disaggregated sector-level load forecasts by customer segment, building vintage (existing structures and new construction), and end use (all applicable end uses in each customer sector and segment).

After the market segmentation, Cadmus mapped the appropriate end uses to relevant customer segments. Upon determining appropriate customer segments and end uses for each sector, Cadmus determined how many units of each end use would be found in a typical home. End-use saturations represent the average number of units in a home and fuel shares represent the proportion of those units using electricity versus natural gas. For example, on average, a typical home has 0.9 clothes dryers (the saturation), and 15% of these units are natural gas (the fuel share).[29] Efficiency shares equal the current saturation of a specific type of equipment (of varying efficiency). Within an end use, these shares sum to 100%.

Next, Cadmus calculated annual end-use consumption for each end use in each segment in the commercial and residential sectors using the following equation:

$$TEUC_{ij} = \sum ACCTS_i \times UPA_i \times SAT_{ij} \times FSH_{ij} \times ESH_{ije} \times EUI_{ije}$$

where:

| | | |
|---|---|---|
| $TEUC_{ij}$ | = | The total energy consumption for end use $j$ in customer segment $i$ |
| $ACCTS_i$ | = | The number of accounts/customers in customer segment $i$ |
| $UPA_i$ | = | The number of units per account in customer segment $i$ ($UPA_i$ generally equals the average square feet per customer in commercial segments and 1.0 in residential dwellings, assessed at the whole-home level) |
| $SAT_{ij}$ | = | The share of customers in customer segment $i$ with end use $j$ |
| $FSH_{ij}$ | = | The share of end use $j$ of customer segment $i$ served by natural gas |
| $ESH_{ije}$ | = | The market share of efficiency level in equipment for customer segment $i$ and end use $j$ |
| $EUI_{ije}$ | = | The end-use intensity, or energy consumption per unit (per square foot for commercial and 1.0 for residential) for the natural gas equipment configuration $ije$ |

For each sector, we determined the total annual consumption as the sum of $TEUC_{ij}$ across the end uses, $j$, and customer segments, $i$.

Consistent with other conservation potential studies, and commensurate with industrial end-use consumption data, we allocated the industrial sector's loads to end uses in various segments based on

29 Saturations are less than 1.0 when some homes do not have the end use.

the *Manufacturing Energy Consumption Survey* data available from the U.S. Energy Information Administration.[30]

## Derivation of End-Use Consumption

End-use energy consumption estimates by segment, end use, and efficiency level ($EUI_{ije}$) provided one of the most important components in developing a baseline forecast. In the residential sector, Cadmus used estimates of unit energy consumption, representing annual energy consumption associated with an end use and represented by a specific type of equipment. We derived the basis for the unit energy consumption values from savings in the PSE business cases, most recent RTF UES workbooks, and the Council's draft *2021 Power Plan* workbooks and savings analysis to calculate accurate consumption wherever possible for all efficiency levels of an end-use technology. When PSE business cases and RTF and Council workbooks did not exist for certain end uses, Cadmus used results from NEEA's 2018 RBSA PSE oversample, including RBSA public data for the same heating and cooling zone as PSE's territory, or we conducted additional research.

For the commercial sector, Cadmus treated consumption estimates as end-use intensities that represented annual energy consumption per square foot served. To develop the end-use intensities, Cadmus developed electric energy intensities (total therms per building square foot) based on NEEA's 2019 CBSA (CBSA IV), based on PSE oversample and public data. Cadmus then benchmarked these electric energy intensities against various other data sources including the CBSA III, historical forecasted and potential study data from PSE, and historical end-use intensities developed by the Council and NEEA.

For the industrial sector, end-use energy consumption represented total annual industry consumption by end use, as allocated by the secondary data described above.

## PSE Forecast Climate Change Alignment

Cadmus worked with the PSE load forecast team to adjust the residential and commercial baseline forecast to account for climate change impacts. First we characterized the heating end-use consumptions using climate change adjustment factors based Council data (from TMY to Council-projected FMY) for any non-Council weather-sensitive RTF and PSE business case measures. For example, we based natural gas furnace end-use consumptions on PSE measure business case estimates, adjusted using HVAC FMY to TMY ratios from Council-developed building simulations, as shown in Table 22.

**Table 22. Residential Council Modeled HVAC FMY to TMY Ratio**

| Council Modeled Ratios | HVAC Ratio (FMY/TMY) |
|---|---|
| All Residential Heating – Heating Zone 1 | 0.80 |

[30] U.S. Department of Energy, Energy Information Administration. 2018. *Manufacturing Energy Consumption Survey.*

The resulting heating end-use consumption presents the upper bound of the climate adjustment (final year estimate). Next, we calibrated the annual change in residential and commercial heating end-use consumption with PSE's climate impacts within annual load forecasts to reflect climate change over the course of the study (where climate impacts increase over time). We followed a similar process to determine the climate impacts for the commercial heating end use.

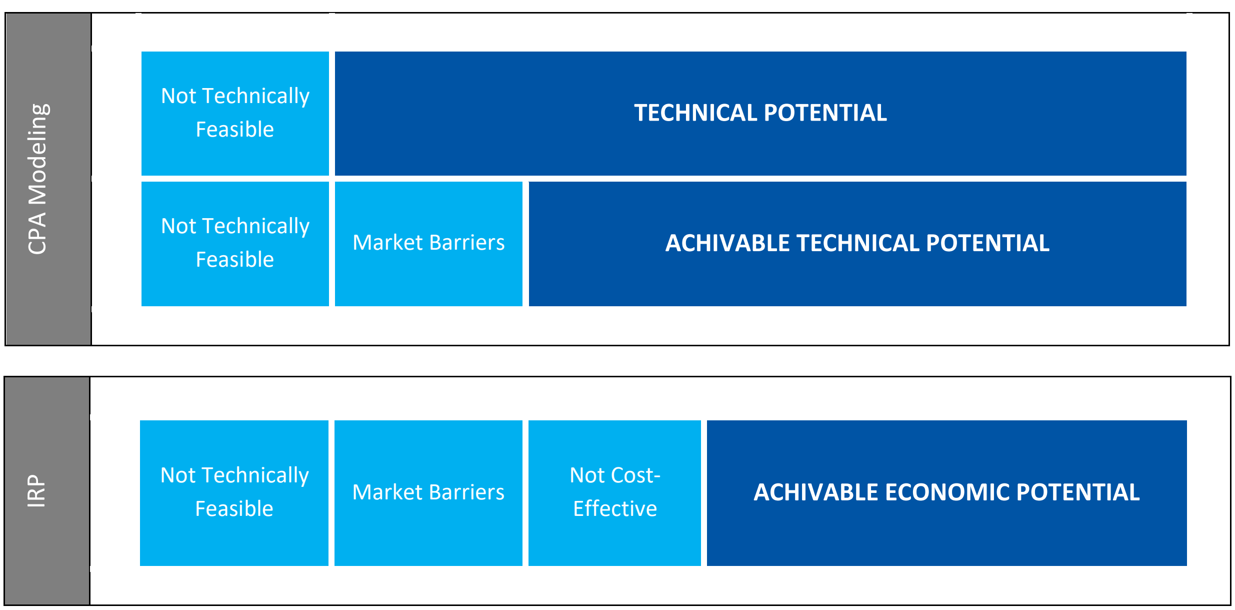
## Conservation Potential Estimation

Cadmus estimated two types of conservation potential, and PSE determined a third potential—achievable economic—through the IRP's optimization modeling, as shown in Figure 37:

- ***Technical potential*** assumes that all technically feasible resource opportunities may be captured, regardless of their costs or other market barriers. It represents the total energy efficiency potential in PSE's service territory, after accounting for purely technical constraints.
- ***Achievable technical potential*** is the portion of technical potential assumed to be achievable during the study forecast, regardless of the acquisition mechanism. For example, savings may be acquired through utility programs, improved codes and standards, and market transformation.
- ***Achievable economic potential*** is the portion of achievable technical potential determined to be cost-effective by the IRP's optimization modeling, in which either bundles or individual energy efficiency measures are selected based on costs and savings. The cumulative potential for these selected bundles constitutes achievable economic potential.

Cadmus provided PSE with forecasts of achievable technical potential, which PSE then entered as variables in the IRP's optimization model to determine achievable economic potential. The following sections describe Cadmus' approach for estimating technical and achievable technical potential.

**Figure 37. Types of Energy Efficiency Potential**



## Technical Potential

Technical potential includes all technically feasible ECMs, regardless of costs or market barriers. Technical potential divides into two classes: discretionary (retrofit) and lost opportunity (new construction and replacement of equipment on burnout).

- ***Discretionary resources*** are retrofit opportunities in existing facilities that, theoretically, are available at any point over the study period. Discretionary resources are also referred to as retrofit measures. Examples include weatherization, shell upgrades, and low-flow showerheads.
- ***Lost opportunity resources***, such as conservation opportunities in new construction and replacements of equipment upon failure (natural replacement), are nondiscretionary. These resources become available according to economic and technical factors beyond a program administrator's control. Examples of natural replacement measures include furnaces, water heaters, and appliances.

Another important aspect in assessing technical potential is, wherever possible, to assume installations of the highest-efficiency equipment that are commercially available. For example, there are two tiers of natural gas furnaces: 94% AFUE furnace and 96% AFUE furnace in residential applications. To assess technical potential, we assumed that, as equipment fails or new homes are built, customers will install 96% AFUE furnace wherever technically feasible, regardless of cost. Where applicable, we assumed that 94% AFUE furnace would be installed in homes ineligible for 96% AFUE furnace. Cadmus treated competing non-equipment measures in the same way, assuming installation of the highest-saving measures where technically feasible.

In estimating technical potential, it is inappropriate to merely sum savings from individual measure installations. Significant interactive effects can result from installations of complementary measures. For example, upgrading a furnace in a home where insulation measures have already been installed can produce less savings than upgrades in an uninsulated home. Our analysis of technical potential accounts for two types of interactions:

- ***Interactions between equipment (lost opportunity) and non-equipment (discretionary or retrofit) measures:*** As equipment burns out, technical potential is based on assuming that equipment will be replaced with higher-efficiency equipment, reducing average consumption across all customers. Reduced consumption causes non-equipment measures to save less than they would have if the equipment had remained at a constant average efficiency. Similarly, savings realized by replacing equipment decrease upon installation of non-equipment measures.
- ***Interactions between two or more non-equipment (discretionary or retrofit) measures:*** Two non-equipment measures that apply to the same end use may not affect each other's savings. For example, installing a low-flow showerhead does not affect savings realized from installing a faucet aerator. Insulating hot water pipes, however, causes water heaters to operate more efficiently, thus reducing savings from those water heaters. Cadmus accounted for such interactions by stacking interactive measures, iteratively reducing the baseline consumption as measures are installed, thus lowering savings from subsequent measures.

Although, theoretically, all retrofit opportunities in existing construction—often called discretionary resources—could be acquired in the study's first year, this would skew the potential for equipment measures and provide an inaccurate assessment of measure-level potential. Therefore, Cadmus assumed that these opportunities would be realized in equal annual amounts over the 27-year planning horizon. By applying this assumption, natural equipment turnover rates, and other adjustments described above, we could estimate the annual incremental and cumulative potential by sector, segment, construction vintage, end use, and measure.

Cadmus' technical potential estimates drew upon best-practice research methods and standard utility industry analytic techniques. Such techniques remained consistent with the conceptual approaches and methodologies used by other planning entities (such as by the Council in developing regional energy efficiency potential) and remained consistent with methods used in PSE's previous CPAs.

## Achievable Technical Potential

The achievable technical potential summarized in this report is a subset of the technical potential that accounts for market barriers. To subset the technical potential, Cadmus followed the approach of the Council and employed two factors:

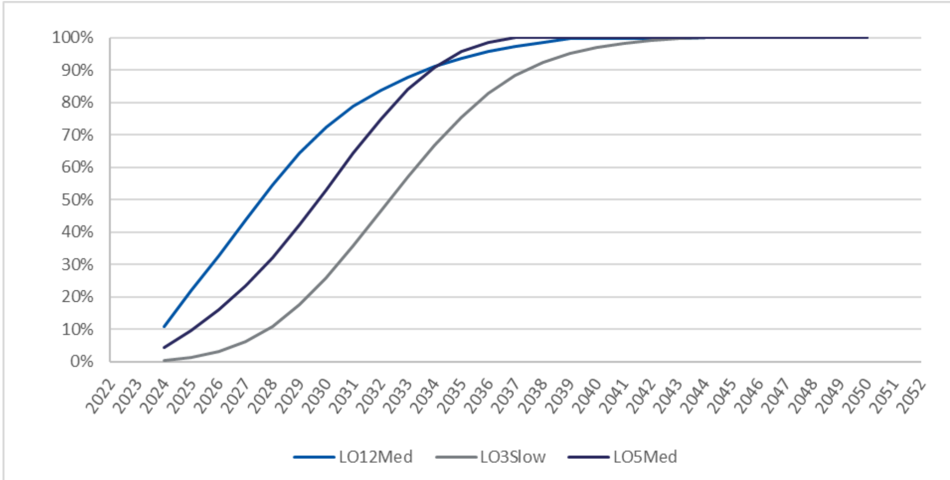
- **Maximum achievability factors** represent the maximum proportion of technical potential that can be acquired over the study horizon.
- **Ramp rates** are annual percentage values representing the proportion of cumulative 27-year technical potential that can be acquired in a given year (discretionary measures) or the proportion of technical annual potential that can be acquired in a given year (lost opportunity measures).

Achievable technical potential is the product of technical potential and both the maximum achievability factor and the ramp rate percentage. Cadmus assigned maximum achievability factors to measures based on the Council's draft *2021 Power Plan* supply curves. Ramp rates are measure-specific and we based these on the ramp rates developed for the Council's draft *2021 Power Plan* supply curves, adjusted to account for the 2024 to 2050 study horizon.

For most discretionary measures, Cadmus assumed that savings are acquired at an even rate over the first 10 years of the study. In other words, achievable technical potential for discretionary measures equals one-tenth of the total cumulative achievable technical potential in each of the first 10 years of the study (2024 through 2033). After 2033, most of the additional potential comes from loss opportunity measures. There were a few exceptions where we applied a custom rate (longer than 10 years) to discretionary measures based on PSE program data (such as for cooking measures).

For lost opportunity measures, we used the same ramp rates as those developed by the Council for its draft *2021 Power Plan* supply curves. However, the draft *2021 Power Plan* ramp rates cover only the 2024 to 2043 period of this study's horizon. Because nearly all lost opportunity ramp rates approach 100%, we set ramp values for 2044 through 2050 to equal the 2043 value from the Council's draft *2021 Power Plan*. Figure 38 illustrates the lost opportunity ramp rates used for natural gas measures in this study.

**Figure 38. Lost Opportunity Ramp Rates**




## *Integrated Resource Plan Input Development*

Cadmus developed energy efficiency supply curves to allow PSE's IRP optimization model to identify the cost-effective level of energy efficiency. PSE's optimization model required monthly forecasts of natural gas energy efficiency potential. To produce these monthly forecasts, we applied 8760-hour end-use load shapes to annual estimates of achievable technical potential for each measure. These hourly end-use load profiles are generally the same as those used by the Council in its draft *2021 Power Plan* supply curves and by the RTF in its UES measure workbooks (including generalized shapes that we expanded to hourly shapes).

Cadmus worked with PSE to determine the format of inputs into the IRP model. We grouped energy efficiency potential into the levelized costs bundles shown in Table 23. The number and delineating values of the levelized cost bundles has changed from the 2021 CPA. While there were 12 bundles in 2021 CPA, this CPA has 18 bundles.

**Table 23. Natural Gas Levelized Cost Bundles**

| Bundle | Natural Gas Bundle ($/therm) |
|---|---|
| 1 | ($999,999.00) to $0.22 |
| 2 | $0.22 to $0.30 |
| 3 | $0.30 to $0.45 |
| 4 | $0.45 to $0.50 |
| 5 | $0.50 to $0.55 |
| 6 | $0.55 to $0.62 |
| 7 | $0.62 to $0.70 |
| 8 | $0.70 to $0.85 |
| 9 | $0.85 to $0.95 |
| 10 | $0.95 to $1.20 |
| 11 | $1.20 to $1.50 |
| 12 | $1.50 to $1.75 |
| 13 | $1.75 to $2.00 |
| 14 | $2.00 to $2.25 |
| 15 | $2.25 to $2.50 |
| 16 | $2.50 to $2.75 |
| 17 | $2.75 to $3.00 |
| 18 | $3.00 to $999,999.00 |

Cadmus derived the levelized cost for each measure using the following formula.

$$\text{Levelized cost of electricity (LCOE)} = \frac{\sum_{t=0}^{n} \frac{Expenses_t}{(1+i)^t}}{\sum_{t=0}^{n} \frac{E_t}{(1+i)^t}}$$

where:

| | | |
|---|---|---|
| LCOE | = | The levelized cost of conserved energy for a measure |
| n | = | The lifetime of the analysis (27 years) |
| $Expenses_t$ | = | All net expenses in the year *t* for a measure using the costs and benefits outlined in Table 24 |
| i | = | The discount rate |
| $E_t$ | = | The energy conserved in year *t* |

Cadmus grouped the achievable technical potential by levelized cost over the 27-year study horizon, allowing PSE's IRP model to select the optimal amount of energy efficiency potential given various assumptions regarding future resource requirements and costs. The 27-year total resource levelized cost calculation incorporates numerous factors, which are consistent with the expense components shown in Table 24.

**Table 24. Levelized Cost Components**

| Type | Component |
|---|---|
| Costs | Incremental Measure Cost |
| | Incremental O&M Cost [a] |
| | Administrative Adder |
| Benefits | Present Value of NEIs |
| | Conservation Credit |
| | Secondary Energy Benefits |

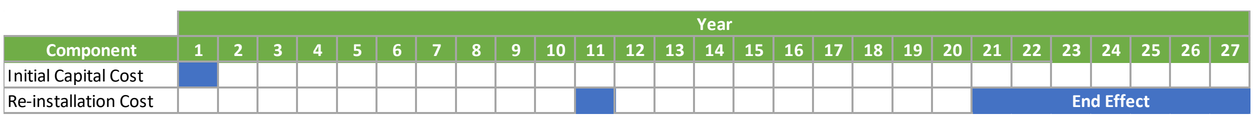
[a] Some measures may have a reduction in O&M costs, which is a benefit in the levelized cost calculation.

Cadmus' approach for calculating a measure's levelized cost of conserved energy aligned with the Council's approach and incorporated several factors:

- ***Incremental measure cost.*** Cadmus considered the costs required to sustain savings over a 27-year horizon, including reinstallation costs for measures with EULs 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.[31]

  For example, Figure 39 shows the timing of initial and reinstallation costs for a measure with a 10-year lifetime in the context of the 27-year study horizon. The measure's final lifetime in this study ends after the study horizon, so the final seven years (Year 21 through Year 27) are treated differently by leveling measure costs over its 10-year EUL and treating these as annual reinstallation costs.

**Figure 39. Illustration of Capital and Reinstallation Cost Treatment**




- ***Incremental O&M benefits or costs.*** As with incremental measure costs, we considered O&M costs annually over the 27-year horizon. Cadmus used the present value to adjust the levelized cost upward for measures with costs above baseline technologies and downward for measures that decrease O&M costs.
- ***Administrative adder.*** Cadmus assumed a program administrative cost equal to 21% of incremental measure costs across all sectors.
- ***Non-energy impacts.*** We treated these impacts as a reduction in levelized costs for measures that save resources, such as water, or that provide other benefits to users or the utility. For

31 In this context, EUL refers to levelizing over the measure's useful life. This is equivalent to spreading incremental measure costs over its EUL in equal payments assuming a discount rate equal to PSE's weighted average cost of capital (6.80%). 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.

example, the value of reduced water consumption due to the installation of a low-flow showerhead reduces the levelized cost of that measure. The details of how we accounted for the NEIs are outlined in the *Energy Efficiency Measure Characterization* section.

- ***The regional 10% conservation credit.*** The addition of this credit per the Northwest Power Act[32] is consistent with the Council's methodology and is effectively an adder to account for the unquantified external benefits of conservation when compared to other resources.
- ***Secondary energy benefits.*** We treated these benefits as a reduction in levelized costs for measures that save energy on secondary fuels. This treatment was necessitated by Cadmus' end-use approach to estimating technical potential. For example, consider the cost for R-60 ceiling insulation for a home with a natural gas furnace and an electric central cooling system. For the heating end use, Cadmus considered the energy savings that R-60 insulation produces for central cooling system, conditioned on the presence of gas heating, as a secondary benefit that reduces the levelized cost of the measure. This adjustment only impacts the measure's levelized costs: the magnitude of energy savings for the R-60 measure is not impacted by considering secondary energy benefits.

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

# Glossary of Terms

Cadmus compiled these definitions mostly from the *National Action Plan for Energy Efficiency Guide for Conducting Energy Efficiency Potential Studies and the State and Local Energy Efficiency Action Network*.[33]

**Achievable economic potential:** The subset of achievable technical potential that is economically cost-effective compared to conventional supply-side energy resources.

**Achievable technical potential:** The amount of energy that efficiency can realistically be expected to displace.

**Benefit/cost ratio:** The ratio (as determined by the total resource cost test) of the discounted total benefits of the program to the discounted total costs over some specified time period.

**Conservation potential assessment (CPA):** A quantitative analysis of the amount of energy savings that exists, proves cost-effective, or could potentially be realized by implementing energy-efficient programs and policies.

**Cost-effectiveness:** A measure of relevant economic effects resulting from implementing an energy efficiency measure. If the benefits of this selection outweigh its costs, the measure is considered cost-effective.

**End use:** A category of equipment or service that consumes energy (such as lighting, refrigeration, heating, and process heat).

**End-use consumption:** Used for the residential sector, this represents per-UEC consumption for a given end use, expressed in annual kilowatt-hours per unit.

**End-use intensities:** Used in the C&I sectors, this is the energy consumption per square foot for a given end use, expressed in annual kilowatt-hours per square foot per unit.

**Energy efficiency:** The use of less energy to provide the same or an improved service level to an energy consumer in an economically efficient way.

**Effective useful life (EUL):** An estimate of the duration of savings from a measure. EUL is estimated through various means, including the median number of years that energy efficiency measures installed under a program remain in place and operable. EUL is also sometimes defined by the date at which 50% of installed units remain in place and operational.

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[33] Schiller Consulting, Inc. (Schiller, Steven R.). 2012. *Energy Efficiency Program Impact Evaluation Guide. NAPEE Guide for Conducting Energy Efficiency Potential Studies and the State and Local Energy Efficiency Action Network.* www.seeaction.energy.gov

**Levelized cost:** The result of a computational approach used to compare the cost of different projects or technologies. The stream of each project's net costs is discounted to a single year using a discount rate (creating a net present value), divided by the project's expected lifetime output (in megawatt-hours).

**Lost opportunity:** Refers to an efficiency measure or efficiency program seeking to encourage the selection of higher-efficiency equipment or building practices than that typically chosen at the time of a purchase or design decision.

**Measure:** Installation of equipment, subsystems, or systems, or modifications of equipment, subsystems, systems, or operations on the customer side of the meter, designed to improve energy efficiency.

**Portfolio:** Either (a) a collection of similar programs addressing the same market, technology, or mechanisms or (b) the set of all programs conducted by one organization.

**Program:** A group of projects with similar characteristics and installed in similar applications.

**Retrofit:** An efficiency measure or efficiency program intended to encourage the replacement of functional equipment before the end of its operating life with higher-efficiency units (also called early retirement) or the installation of additional controls, equipment, or materials in existing facilities for reducing energy consumption (such as increased insulation, lighting occupancy controls, and economizer ventilation systems).

**Resource adequacy***:* Having sufficient resources, generation, energy efficiency, storage, and demand-side resources to serve loads across a wide range of conditions.

**Technical potential:** The theoretical maximum amount of energy use that could be displaced by efficiency, disregarding all non-engineering constraints (such as cost-effectiveness or the willingness of end users to adopt the efficiency measures).

**Total resource cost test:** A cost-effectiveness test that assesses the impacts of a portfolio of energy efficiency initiatives on the economy at large. The test compares the present value of efficiency costs for all members of society (including costs to participants and program administrators) compared to the present value of benefits, including avoided energy supply and demand costs.

**Utility cost test:** A cost-effectiveness test that evaluates the impacts of efficiency initiatives on an administrator or an energy system. It compares administrator costs (such as incentives paid, staff labor, marketing, printing, data tracking, and reporting) to accrued benefits, including avoided energy and demand supply costs. Also called the program administrator cost test.

# Appendix A. Heat Pump Market Research Findings


## AGENDA

- Research Approach
- Customer Survey Findings
- Contractor and Builder Interview Findings
- Key Research Takeaways

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# RESEARCH APPROACH



## INTERVIEW APPROACH

| Contractors | Builders |
| --- | --- |
| **Research Objective:** Understand contractor perspectives on heat pump sales by system type, attitudes towards cold climate heat pumps, and barriers to electrification | **Research Objective:** Understand builder perspectives on heat pumps in all-electric and dual-fuel homes, market trends, and customer interest |
| **Completed 12 contractor interviews** Installed a total of 3,021 HVAC systems (2,801 heat pumps) in existing single-family homes within PSE's service territory in the last 12 months | **Completed 2 builder interviews** Built a total of 20 new, single-family homes in PSE's service territory in the last 12 months (30% all-electric, 70% electric and gas connected homes) |

# INTERVIEW APPROACH

| Category | Total Contacted | Targeted Completes | Achieved Completes |
|---|---|---|---|
| Contractors | 83 | ≤ 15 | 12 |
| Builders | 38 | ≤ 5 | 2 |
| **Total** | **121** | **≤ 20** | **14** |

### Response Rate by Contact Mode

**Phone Call**
7% response rate

**Email**
13% response rate

### Response Rate by Category

| | |
|---|---|
| Contractors | 14% |
| Builders | 5% |

### Eligibility

HVAC contractors that have installed heat pumps in PSE service territory

Builders that have developed new homes using heat pumps around PSE service territory

### Incentive

$150 Amazon gift card to each interviewed contractor and builder

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# SURVEY APPROACH

Completed **862** online surveys with eligible PSE customers

5 winners selected for a $100 Amazon gift card

- Gas-only or combination PSE customers
- Homeowners with gas as primary heating fuel
- Familiarity with air source heat pumps

**Research Objectives**
- Assess general awareness of and interest in heat pump technology
- Understand barriers and opportunities for adoption
- Measure willingness to purchase heat pumps among gas-heated homes (market demand)

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## SURVEY APPROACH

| 5 Willingness-to-Pay Scenarios | Baseline Equipment |
|---|---|
| Ductless Replace On Burn-out: Full Electrification | Ductless gas heat, Cooling or no cooling |
| Ductless Partial Displacement: DHP with Existing Gas Backup | Ductless gas heat, Cooling or no cooling |
| Ducted Replace on Burnout: Full Electric | Gas furnace, Cooling or no cooling |
| Ducted Hybrid (Dual-Fuel) Heat Pump Retrofit – Added Cooling | Gas furnace, No central cooling |
| Ducted Replace on Burnout: Hybrid Heat Pump | Gas furnace, Central cooling |

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## SURVEY APPROACH

| Housing Strata | Total Contacted | Targeted Completes | Achieved Completes |
|---|---|---|---|
| Multifamily | 9,179 | 200 | 135 |
| Single Family | 34,768 | 200 | 579 |
| Low-Income | 27,719 | 200 | 148 |
| **Total** | **71,666** | **600** | **862** |

**Response Rate by Contact Mode**

**Postcard**
4% response rate

**Email**
6% response rate

**Response Rate by Housing Strata**

| | |
|---|---|
| Multifamily | 4% |
| Single Family | 11% |
| Low-Income* | 3% |

*200% below Federal Poverty Level

*Response rate includes partial responses.

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# CUSTOMER SURVEY

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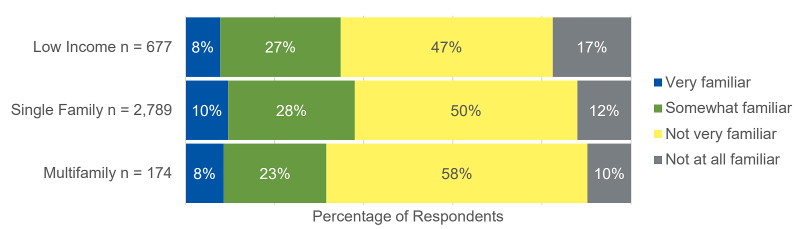
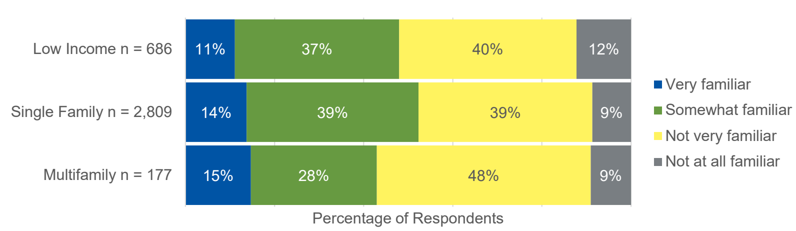
## HEAT PUMP ATTITUDES AND AWARENESS

PSE customers are more familiar with ducted air source heat pumps compared to ductless

Ductless Air Source Heat Pump Awareness




Ducted Air Source Heat Pump Awareness

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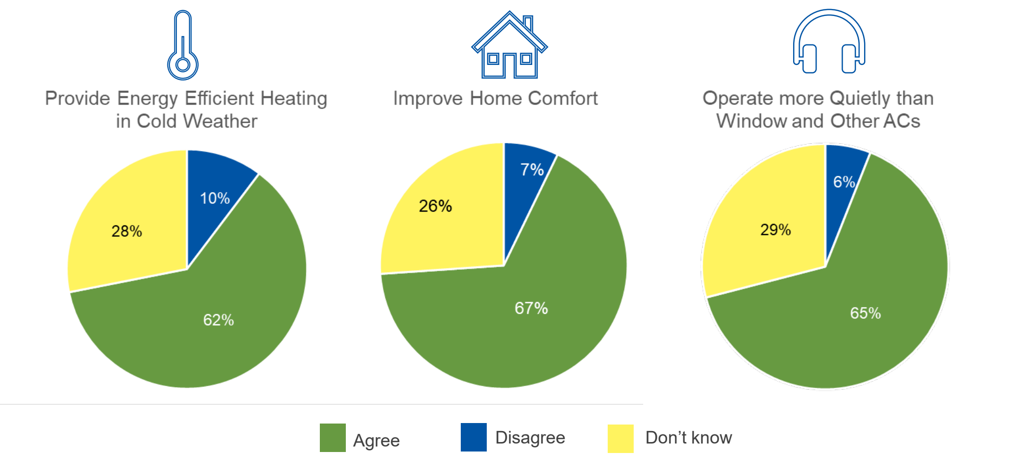
CADMUS

## HEAT PUMP ATTITUDES AND AWARENESS

The majority of respondents agreed that performance, comfort, and noise reduction are benefits of air source heat pumps

### AIR SOURCE HEAT PUMPS OF ANY TYPE CAN…

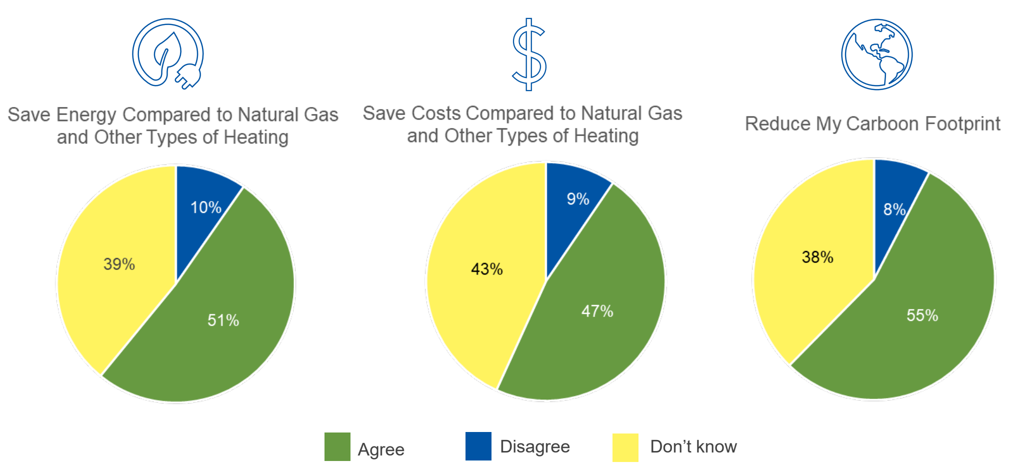



11 CADMUS

## HEAT PUMP ATTITUDES AND AWARENESS

Respondents were much less sure about energy saving, cost saving, and climate benefits

### AIR SOURCE HEAT PUMPS OF ANY TYPE CAN…

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# HEAT PUMP ATTITUDES AND AWARENESS

| Barrier Statements<br>*Air source heat pumps…* | % Having Heard About Barrier | | | |
|---|---|---|---|---|
| | Overall | Multifamily | Single Family | Low-Income |
| *Might have difficulty keeping a home warm enough in a Washington winter without a backup heating source* | 14% | 10% | 15% | 12% |
| *Might cost more to install than other heating or cooling equipment* | 14% | 10% | 14% | 12% |
| *Might disrupt the aesthetic of a room with wall-mounted indoor units* | 9% | 10% | 9% | 8% |
| *Might cost more to run than a traditional heating/cooling system* | 7% | 6% | 7% | 7% |
| *Might be more complicated to operate than a traditional heating/cooling system* | 6% | 5% | 6% | 4% |

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# WILLINGNESS TO PAY

## Ductless HP

| SCENARIO SUMMARY | INCREMENTAL COST |
|---|---|
| **Replace On Burn-out: Full Electrification** | |
| 1. Your current primary heating system is about to fail. A new ductless heat pump with 4 indoor units would provide efficient heating and cooling to your whole home without requiring ductwork. $150/year in energy bill savings. | $4,000 |
| **Partial Displacement: DHP with Existing Gas Backup** | |
| 2. Your current primary heating system is working. A new ductless heat pump with 3 indoor units would add cooling, improve comfort, and provide most of your heating. $100/year in energy bill savings. | $10,000 |

Note: Ductless respondents answered both scenarios, regardless of existing cooling.

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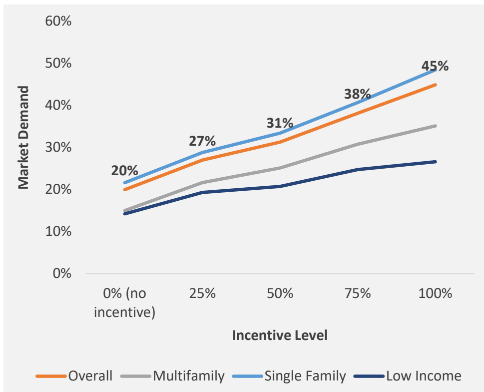
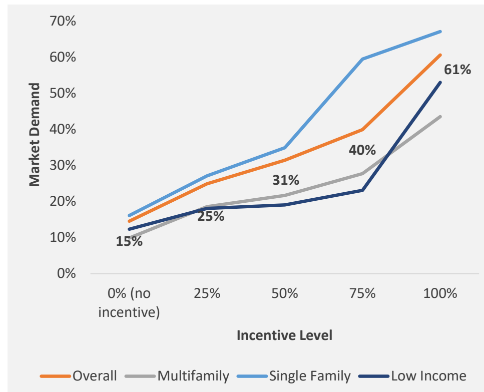
# WILLINGNESS TO PAY

## Ductless HP

### SCENARIO 1
### Replace On Burn-out: Full Electrification




### SCENARIO 2
### Partial Displacement: DHP with Existing Gas Backup




Note: Data labels represent “Overall” market demand (orange curve)

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# WHY NOT INSTALL?

## Replace on Burn-out: Full Electrification

### SINGLE FAMILY

- Concerned about how the DHP would look in my home (43%)
- Initial costs too high (35%)

### LOW-INCOME

- Initial costs too high (40%)
- Don’t believe monthly energy bill would go down (40%)
- Don’t plan to stay in home long enough (25%)
- Would rather trust a technology I’m more familiar with (25%)

### MULTIFAMILY

- Concerned about how the DHP would look in my home (29%)
- Don’t plan to stay in home long enough (29%)
- Building restrictions such as HOAs (24%)

## Partial Displacement: DHP with Existing Gas Backup

### ALL HOUSING TYPES

- Satisfied with my current systems and do not need to supplement my heating or cooling with a DHP
- Other top reasons similar to ROB

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## WILLINGNESS TO PAY

### Ducted HP

| SCENARIO SUMMARY | INCREMENTAL COST |
|---|---|
| **Replace on Burnout: Full Electric** | |
| 1. Your current primary heating system is <u>about to fail</u>. A new heat pump would use your existing ductwork and provide efficient heating and cooling to your whole home. $150/year in energy bill savings. | $4,500 |
| **Hybrid Heat Pump Retrofit – Added Cooling** | |
| 2. Your current primary heating system <u>is working</u>. A new heat pump would add cooling and operate in place of your furnace until the temperature reached around 35 degrees Fahrenheit and add central cooling. $100/year in energy bill savings. | $8,000 |
| **Replace on Burnout: Hybrid Heat Pump** | |
| 3. Your current heating system and cooling system are <u>both about to fail.</u> A new heat pump with natural gas back-up heat would provide efficient heating and cooling to your whole home. $100/year in energy bill savings. | $1,200 |

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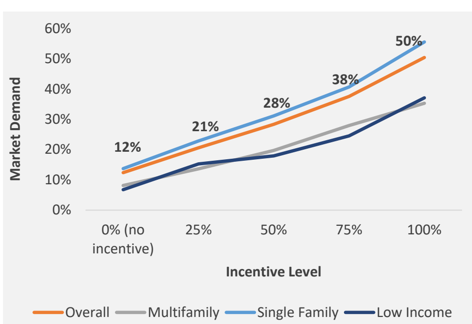
## WILLINGNESS TO PAY

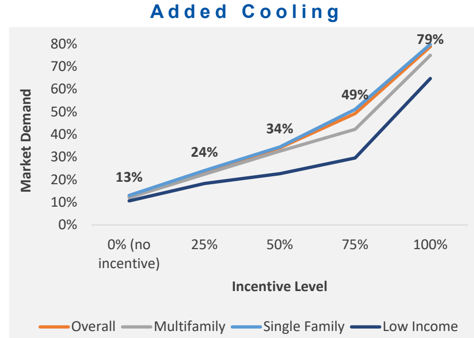
### Ducted HP

**SCENARIO 1**
**Replace on Burnout: Full Electric**




Presented to anyone regardless of cooling.

**SCENARIO 2**
**Hybrid Heat Pump Retrofit – Added Cooling**




Presented to respondents without central cooling. Emphasized added cooling and back-up heat at 35°

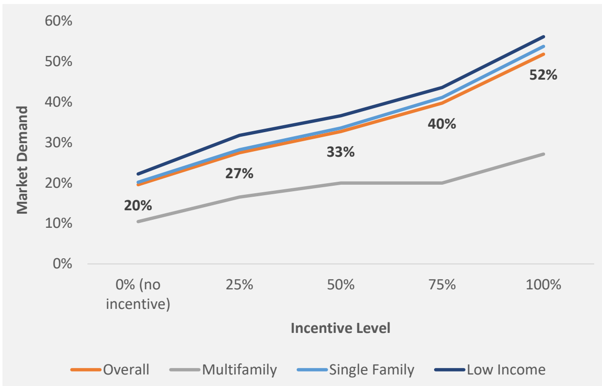
Note: Data labels represent "Overall" market demand (orange curve)

18 CADMUS

# WILLINGNESS TO PAY

## Ducted HP

**SCENARIO 3**
**Replace on Burnout: Hybrid Heat Pump**




Heating and cooling system failure and replacement with a hybrid system. Presented to respondents with central cooling.

**Why is MF curve so low?**

Only 11 MF customers responded to Scenario 3

5 of them would not install at all, reasons being:

- Building restrictions such as HOAs (2)
- Initial costs too high (1)
- Recently upgraded their system (1)
- Did not feel it was realistic to consider both systems failing at once (1)

Note: Data labels represent "Overall" market demand (orange curve)

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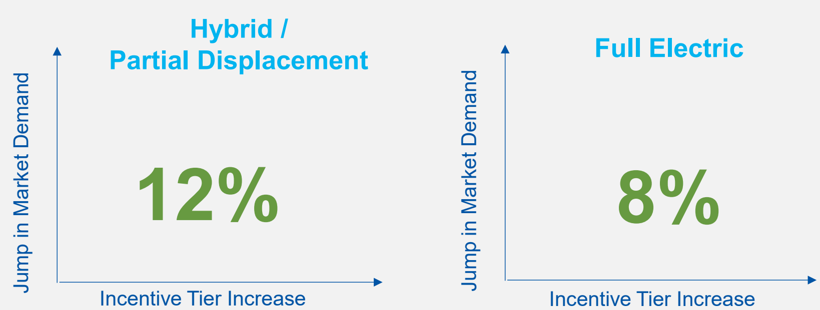
# WILLINGNESS TO PAY

## Incentives

**Most "bang for the buck" (highest market share per dollar) is at 25% incentive tier**

- 1:1 ratio. On average, 25% of respondents would participate if 25% of incremental costs are covered (In any situation)
- Ratio shrinks as incentive tiers grows (not a linear relationship)
- Market share gains at each tier are highest for hybrid or partial displacement scenarios

**Average Increase in Market Share Per Incentive Tier**

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# WHY NOT INSTALL?

## Replace on Burn-out: Full Electric

### SINGLE FAMILY

- Initial costs too high (34%)
- Don't believe monthly energy bill would go down (29%)

### LOW-INCOME

- Don't believe monthly energy bill would go down (32%)
- Initial costs too high (26%)

### MULTIFAMILY

- Don't plan to stay in home long enough (28%)
- Building restrictions such as HOAs (28%)

## Hybrid Heat Pump Retrofit

### ALL HOUSING TYPES

- Satisfied with my current systems and do not need to supplement my heating or cooling with an ASHP
- Other top reasons similar to ROB

## Replace on Burn-out: Hybrid

### SINGLE FAMILY

- Initial costs too high (31%)
- Don't believe monthly energy bill would go down (40%)
- **Concerns about performance (26%)**

### LOW-INCOME

- Don't believe monthly energy bill would go down (57%)
- **Concerns about performance (43%)**
- **Unsure of how to apply for incentives (43%)**

### MULTIFAMILY

- Building restrictions such as HOAs (40%)

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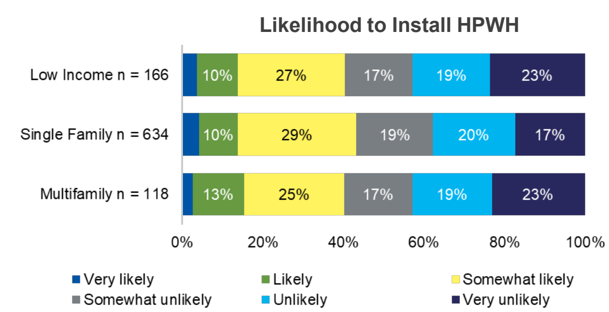
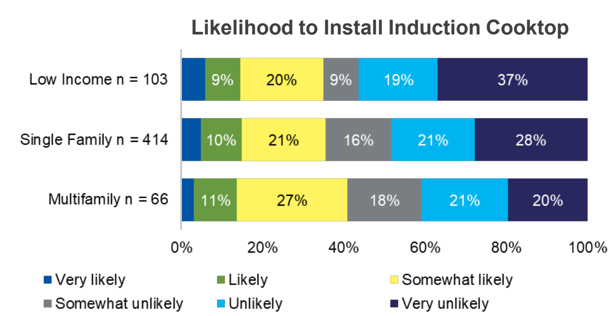
# OTHER LOW-CARBON TECHNOLOGY




Most customers are "somewhat likely" to install a heat pump water heater if their current system needs replacement in the next two years.

**Market Demand: 16%**




Customers are slightly less likely to install an induction cooktop than a HPWH if their current system needs replacement in the next two years.

**Market Demand: 14%**

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# CONTRACTOR AND BUILDER INTERVIEWS

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## HEAT PUMP INCREMENTAL COSTS

Incremental costs of heat pumps range from 7-17% of the combined cost of a gas heating system and central AC

| Appliance | Avg Cost per Unit | Incremental Cost |
|---|---|---|
| Gas Furnace + Central AC | $13,830 | - |
| Ductless Heat Pump | $15,223 | $1,393 |
| Ducted Heat Pump | $14,800 | $970 |
| Ducted Heat Pump + Gas Furnace (Hybrid/Dual-Fuel) | $16,250 | $2,420 |

**Avg Central AC and Dual Fuel Heat Pump capacities were reported at 2.79 tons*
***Avg Ductless and Ducted Heat Pump capacities were reported at 2.94 tons*
****Many applications for each baseline and measure combination (e.g. replace on burnout, partial displacement retrofit, new construction, etc.) were integrated into the potential analysis. System and incremental costs provided are intended to be illustrative for one set of replace on burnout scenarios analyzed. Full dataset will be used for the CPA.*

Incremental costs for ENERGY STAR, dual stage, and cold climate equipment ranged from 9%-50%. Half of contractors noted they only install ENERGY STAR ductless heat pumps

Contractors estimated that installing central AC for the first time added nearly $1,400 to the cost of the installation

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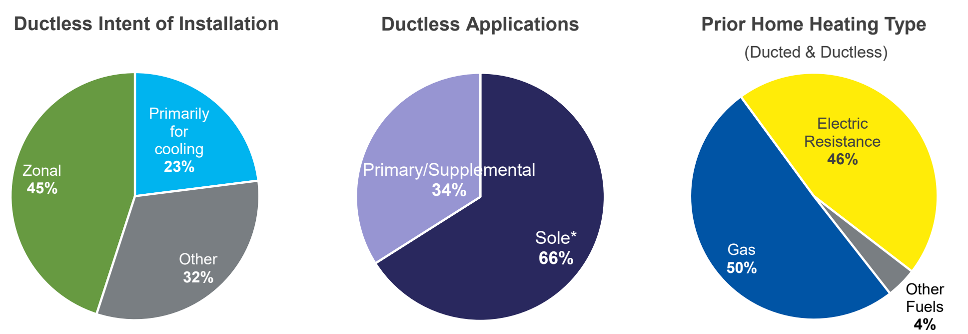
# HEAT PUMP APPLICATIONS AND USAGE

Contractors surveyed installed 1,095 ductless heat pumps and 1,706 ducted heat pumps in the past 12 months.




*Contractors considered ductless installations in zonal applications (e.g. new additions, previously-unheated spaces) as sole source installations. These buildings may have a separate heating system for the remainder of the home. Contractors reported a ductless heat pump as primary/supplemental or sole based primarily on whether there was another heating system present in the space the unit was installed in (whether one zone or the whole home).*

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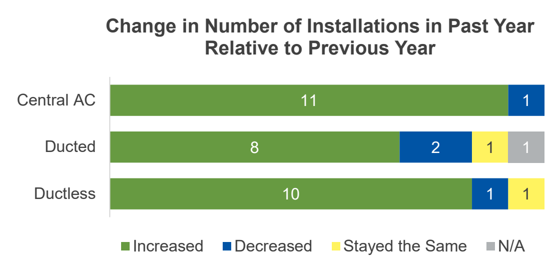
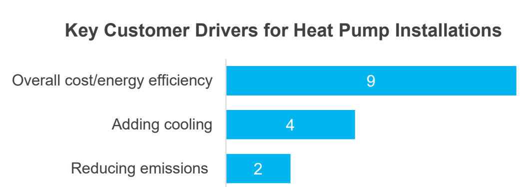
# CUSTOMER INTEREST IN HEAT PUMPS AND CENTRAL AC

While energy efficiency and the COVID-19 pandemic have encouraged increasing installations of heat pumps, contractors also reported a significant increase in customers installing central AC for the first time due to recent heat waves




**2 of 12** contractors differentiated between standalone and hybrid/dual-fuel ducted heat pumps, both saying that hybrid/dual-fuel installations increased less than standalone systems, while others reported no difference

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# COVID-19 IMPACTS ON HEAT PUMP INSTALLATIONS AND INTEREST

**How COVID-19 impacted installations of ducted heat pumps**

**4 of 12** contractors reported challenging supply chain issues

**5 of 12** contractors reported increased installations due to higher rates of working from home, customers wanting higher comfort levels, and increased interest in secure air filtration systems

**How COVID-19 impacted installations of ductless heat pumps**

**6 of 12** contractors reported challenging supply chain issues

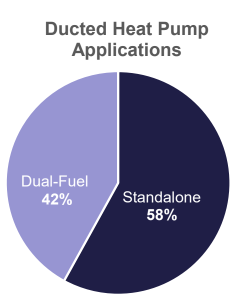
**5 of 12** contractors reported increased installations due to higher rates of working from home and customers wanting higher levels of comfort

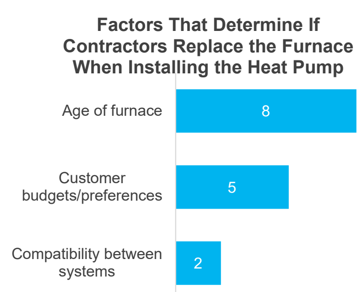


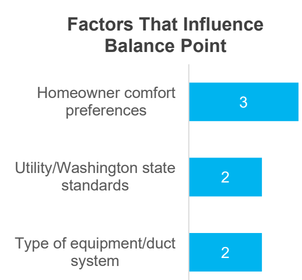
# HYBRID/DUAL-FUEL HEAT PUMP CONFIGURATION

Most contractors reported replacing the furnace when installing ducted HPs in dual-fuel configurations, which increases the overall project cost.

A large majority stated that they use pre-set numbers or balance point calculators to determine **switchover temperatures between the furnace and the heat pump**. One contractor noted that newer systems can sense switchover temperatures using controls.



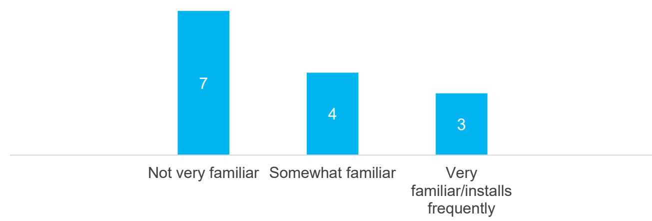



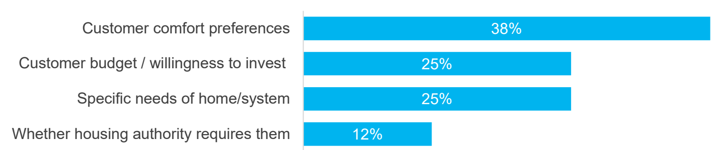
# ATTITUDES AND AWARENESS OF COLD CLIMATE HEAT PUMPS

Contractors ranged widely in frequency of installation of cold climate ASHPs; contractors that don't typically install cold climate heat pumps stated the weather in their area is not cold enough to justify doing so

**Contractor/Builder Familiarity with Cold Climate Heat Pumps**




**Factors Influencing Whether a Cold Climate Heat Pump is Installed**

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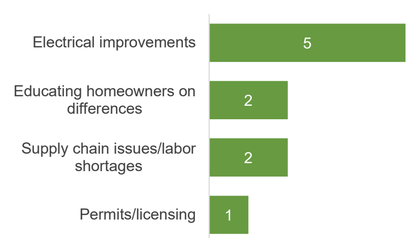
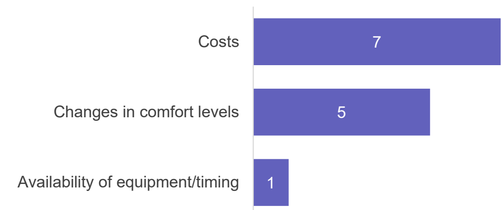
# FUEL CONVERSION CHALLENGES

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

**Primary Challenges Contractors Face Converting from Gas to Heat Pumps**




**Primary Challenges Customers Face Converting from Gas to Heat Pumps**

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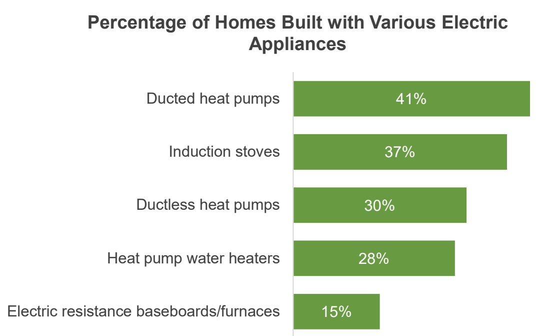
# BUILDER INTERVIEW HIGHLIGHTS

The primary factors that make builders more likely to choose a heat pump for a new home include the overall energy package/energy efficiency of the new home and building code changes




**Homebuyer interest in all-electric vs. electric & gas homes**

*"Clients are shifting towards all-electric for environmental reasons"*

*"It's mostly client-driven; it's a combination of cost-effectiveness and a lot of people shying away from natural gas"*

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# KEY RESEARCH TAKEAWAYS

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## KEY FINDINGS SUMMARY

**Customer demand for heat pumps is increasing, with a similar number of heat pumps being installed in gas-heated and electric-heated homes**

- Demand for central AC is also increasing but contractors do not see this as a primary driver for customers' heat pump demand
- Some contractors noted that hybrid heat pumps were not growing as rapidly as ASHP-only installations, though others did not see a significant difference.
- The COVID-19 pandemic increased demand for heat pumps, though supply chain issues have constrained growth
- Most contractors are not familiar with or do not see the need for cold climate heat pumps in WA

**While heat pump installations often have modest incremental costs compared to baseline equipment, additional costs may constrain market adoption**

- Many gas homes require at least minor electrical improvements when converting to all-electric; high costs are a primary barrier to adoption.

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## KEY FINDINGS SUMMARY

**Market demand for hybrid replacements or partial displacement is higher than full electric HPs (at almost every incentive level). Added cooling is important.**

- Maximum adoption scenario: 79% for hybrid heat pump retrofit on an existing gas furnace for customers without existing central cooling
- Optimal Incentive Level for any scenario: 25% of incremental cost
- Market demand is higher at the same incentives tiers for replace on burnout for a ducted hybrid system compared to a full electric HP*

*At tiers ≤50% of incremental cost

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## KEY FINDINGS SUMMARY

Despite higher market demand for hybrid/dual-fuel, more people surfaced performance concerns when asked why they would not install a hybrid/dual-fuel (ducted) system

Other barriers to installation:

- "Happy with current system"
- Cost concerns (both initial and ongoing energy costs)

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## NEXT STEPS

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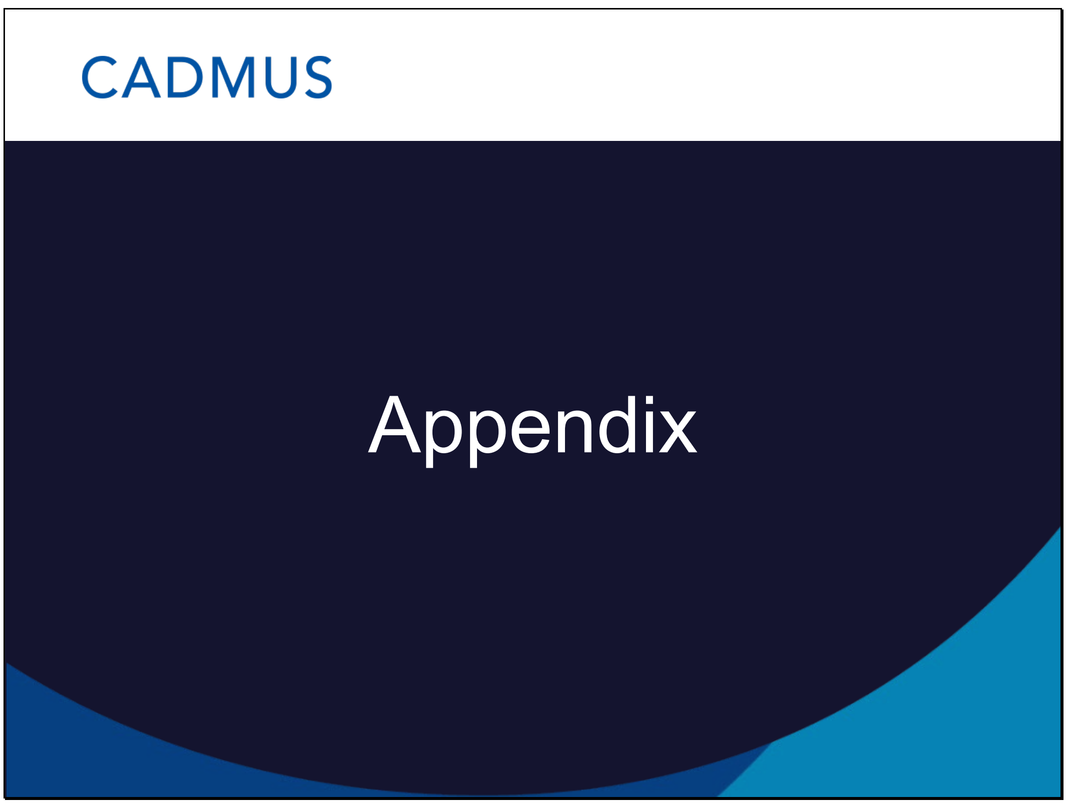
Thank You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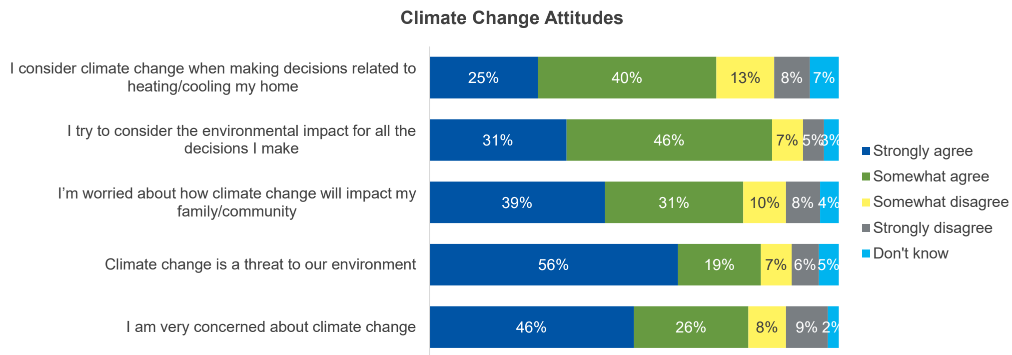
Appendix

# CLIMATE CHANGE ATTITUDES

In many cases, there was a positive correlation between a customer's climate change attitudes and their willingness to install an ASHP with no utility incentive




**Statements positively correlated with "very likely" to install:**

- *I consider climate change when making decisions related to heating/cooling my home*
- *I am very concerned about climate change*

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# Appendix B. Residential Heat Pump Adoption Survey

Cadmus will program the survey into an online format using the Qualtrics platform. The table below presents the research objectives and the corresponding survey questions.

| Research Objectives | Corresponding Question Numbers |
|---|---|
| Establish and screen for baseline conditions of space heating and space cooling equipment | A1–A9 |
| Gauge consumer awareness of air source heat pump technologies, benefits and perceived challenges | B1–B8 |
| Identify barriers to installing heat pumps among homeowners upgrading their systems | C1–C5 |
| Quantify consumers' willingness to purchase air source heat pumps at varying price points | D1–E18 |
| Identify customers' willingness to adopt other low-carbon technology | F1–F4 |
| Understand customers' attitudes about climate change | G1 |
| Gather demographic information and housing, system characteristics for respondents | H1–H9 |

**Target Audience:** Residential gas heat homeowners within PSE's service territory in Washington who have familiarity with heat pump technology.

**Expected number of completions:** 600 total: 200 Gas Heat single-family homeowners (≥ 200% FPL), 200 Gas Heat multifamily homeowners (≥ 200% FPL), 200 Gas Heat homeowners (≤ 200% FPL).

**Estimated timeline for fielding**: 10 to 15 minutes

**Survey and Sampling Design**

- NOTE: Respondents will not answer all questions in this survey
- Survey recruitment will be through email and postcard distributions. Postcards will be sent out to customers who have a Digital Engagement Score of 0 or 1. Email invitations will be sent to customers who have a Digital Engagement Score of 2–10.

**Variables to be pulled into Survey**

- FIRSTNAME
- LASTNAME
- EMAIL
- DIGITAL ENGAGMENT SCORE

## *Survey Introduction and Screener*

Welcome! Thank you for participating in this survey for Puget Sound Energy about your heating and cooling system. If you qualify and finish the survey, you will be eligible to enter a raffle for a chance to win a $100 Visa gift card. Please be sure to enter your contact information at the end of the survey. This survey is for research purposes only; it is not to sell a product of any kind. Please note that not all respondents will be eligible to complete the study.

If you'd like to pause your survey and come back to it at any time, simply close out of the survey, re-click on the link in your email, and pick up where you left off.

Open drop-down menus by clicking on this icon [ ▼ ] within the survey.

Click on the Next and Back buttons at the bottom of each page to navigate through the survey.

[SCREEN OUT TERMINATION MESSAGE:] Unfortunately, you don't qualify for this survey. Those are all the questions we have. Thank you.

## A. Screener

To start, we have a few questions to confirm your eligibility for the survey.

A1. Do you own or rent your home?

1. Own
2. Rent [TERMINATE]

A2. What type of home do you live in?

1. Mobile or manufactured home
2. Single family detached house
3. Single family attached house such as a duplex, townhouse, or rowhouse
4. Apartment building or condominium building
5. Other [THANK AND TERMINATE]

A3. Do you have one or multiple sources of heating in your home? [SINGLE RESPONSE]

1. One
2. Multiple

A4. [IF A3=1] What is the type of fuel used for heating your home? [SINGLE RESPONSE]

1. Electricity [THANK AND TERMINATE]
2. Natural gas
3. Propane (bottled gas), fuel oil (delivered fuel), or kerosene (delivered fuel) [THANK AND TERMINATE]
4. District steam [THANK AND TERMINATE]
5. Wood/wood pellets [THANK AND TERMINATE]

98. Don't know [THANK AND TERMINATE]

A5. [IF A3=2] What is the primary type of fuel used for heating your home? [SINGLE RESPONSE]

1. Electricity [THANK AND TERMINATE]
2. Natural gas
3. Propane (bottled gas), fuel oil (delivered fuel), or kerosene (delivered fuel) [THANK AND TERMINATE]
4. District steam [THANK AND TERMINATE]
5. Wood/wood pellets [THANK AND TERMINATE]
98. Don't know [THANK AND TERMINATE]

A6. [IF A3=2] What is the supplementary type of fuel used for heating your home? [SINGLE RESPONSE]

1. Electricity
2. Natural gas
3. Propane (bottled gas), fuel oil (delivered fuel), or kerosene (delivered fuel)
4. District steam
5. Wood/wood pellets
98. Don't know

A7. What type of primary natural gas heating system do you have in your home? [SINGLE RESPONSE]

1. Central forced air furnace with vents in individual rooms
2. Steam/hot water system with radiators or baseboards in each room (central boiler)
3. Something else:_____________

A8. What type of equipment do you currently use for your home's primary cooling system? [SINGLE RESPONSE]

1. Central air conditioning system
2. Wall/room/window air conditioner unit(s)
3. Air source heat pump or ductless heat pump [THANK AND TERMINATE]
4. None
5. Ceiling or room fans
6. Something else:____________

A9. [IF A8=2,4, 5 or 6] Are you interested in installing central AC in the next two years?

1. Yes
2. No
98. Don't know

## *B. ASHP Awareness and Attitudes*

B1. Prior to this survey, how familiar were you with ducted air source heat pumps, also called central air source heat pumps?

1. Very familiar [SKIP TO B3]
2. Somewhat familiar [SKIP TO B3]
3. Not very familiar
4. Not at all familiar

98. Don't know

B2. An electric ducted (or central) air source heat pump is a central heating and air conditioning system that uses electricity to transfer heat between your house and the outside air, providing heating in winter and cooling in the summer. It includes indoor and outdoor equipment and distributes heating and cooling into your home through ducts, similar to a central air conditioner and central furnace.

After this description, are you now familiar with ducted air source heat pumps?

1. Yes
2. No

B3. **Prior** to this survey, how familiar were you with **ductless** air source heat pumps, also called ductless mini-splits?

1. Very familiar [SKIP TO B5]
2. Somewhat familiar [SKIP TO B5]
3. Not very familiar
4. Not at all familiar

98. Don't know

B4. This is an electric ductless mini-split heat pump. Like a central ducted air source heat pump, a ductless heat pump uses electricity to provide both heating and cooling, however ductless heat pumps do not require ductwork to deliver heated or cooled air. Ductless systems consist of an outdoor unit and one or more indoor units. Indoor units are typically mounted high on a wall, which are connected to an outside unit which is typically installed next to the house.

After this description, are you now familiar with ductless air source heat pumps?

1. Yes
2. No

[IF B2=2 AND B4=2, THANK AND TERMINATE BECAUSE RESPONDENT NOT AWARE OF HEAT PUMPS]

Please rate your level of agreement with the following benefits of ducted and ductless air source heat pumps: [1=STRONGLY DISAGREE, 2=SOMEWHAT DISAGREE, 3=SOMEWHAT AGREE, 4=STRONGLY AGREE, 98=DON'T KNOW] [RANDOMIZE ORDER]

B5. Air source heat pumps of any type can…

1. Improve home comfort
2. Provide energy efficient heating in cold weather
3. Help reduce my carbon footprint
4. Operate more quietly than window and other air conditioners
5. Save energy compared to natural gas and other types of heating
6. Save costs compared to natural gas and other types of heating

B6. Have you ever heard of any challenges or drawbacks to air source heat pumps?

1. Yes
2. No

B7. [ASK IF B7=1] What challenges or drawbacks to air source heat pumps have you heard of? Please select all that apply. [RANDOMIZE ORDER OF 1–5]

1. Air source heat pumps might cost more to run than a traditional heating/cooling system.
2. Air source heat pumps might have difficulty keeping a home warm enough in a Washington winter without a backup heating source
3. Air source heat pumps might cost more to install than other heating or cooling equipment
4. Air source heat pumps might disrupt the aesthetic of a room with wall-mounted indoor units
5. Air source heat pumps might be more complicated to operate than a traditional heating/cooling system

B8. Please rate your level of agreement with the challenge: "[PIPE IN ANSWER FROM B6]" [1=STRONGLY DISAGREE, 2=SOMEWHAT DISAGREE, 3=SOMEWHAT AGREE, 4=STRONGLY AGREE, 98=DON'T KNOW]

[ASK FOR EACH SELECTED B6 THAT WAS 1–5]

## C. HVAC System Upgrades and Barriers

Now, we'd like to talk more about your home's heating and cooling systems.

C1. Have you considered making improvements to your home's heating/cooling system (either a specific component or installing an entirely new system, including if your system failed) **in the past three years**? This would include if you've completed this work, it's in progress, or if you've considered it but haven't done any work.

1. Yes, I've considered or completed a whole system upgrade
2. Yes, I've considered or completed upgrading a specific component of the system
3. No [SKIP TO D1]

C2. [ASK IF C1=1 OR 2] You mentioned you've considered or made improvements to your home's heating/cooling system. Have you considered, or did you consider at any point, switching from a natural gas heating system to an electric air source heat pump?

1. Yes
2. No [SKIP TO D1]

C3. [ASK IF C2=1] Are you planning to install an air source heat pump?

1. Yes [SKIP TO D1]
2. No
3. Not sure [SKIP TO D1]

C4. [ASK IF C3=2] Which of the following are reasons why you considered, but decided not to install an air source heat pump? Please select all that apply. [RANDOMIZE ORDER OF 1–9]

1. The initial cost of an air source heat pump was too high (i.e. too expensive)
2. I didn't know enough about air source heat pumps

C5. I was concerned about the system's performance

1. I was concerned about the look of an air source heat pump installation
2. I don't plan to stay in home long enough for it to pay off
3. I went with a technology I was more familiar with
4. I didn't have enough time or resources to pursue upgrading my home's heating system at all
5. I was concerned that it would cost more on my monthly energy bill
6. I was concerned about switching to a different fuel source (i.e. switch to electric)
7. Something else, please specify [TEXT ENTRY BOX]

## *D. Willingness to Pay – Ductless Air Source Heat Pumps*

[ONLY ASK SECTION D IF A7=2 AND B3=1 or 2, OR A7=2 AND B4=1]

**Programming Note: Ductless heating system respondents are asked *both* Ductless ASHP Scenarios due to anticipated small population**

The next section will ask you how likely you would be to install an electric ductless mini-split heat pump in your home. Some people install an electric ductless mini-split heat pump to provide more cost-effective and efficient heating and cooling than their current system, to add cooling, and/or to improve their comfort, for all or some areas of their home. As a reminder, this is not to sell you anything, this is for research purposes only.

[RANDOMZIE ORDER OF BLOCKS D1–D6 (Scenario 1) AND D7–D13 (Scenario 2)]

**Scenario 1: Ductless ASHP – Full Replacement**

Assume that you live in an 1,800 sq ft home and that **your current primary heating system is about to fail**. On average, installing a ductless mini-split heat pump to replace your current failing heating system would cost approximately $13,000—about $4,000 more than a new natural gas boiler. The system would have four indoor units, typically mounted up high on a wall like in the picture below and would provide heating and cooling to your whole home without requiring ductwork.

Switching to a ductless mini-split heat pump will decrease your gas bill while increasing your electric bill. Overall, you would save up to $150 a year on your energy costs. The system would also provide quiet, efficient heating and cooling throughout your home while being environmentally friendly and energy efficient.

D1. How likely would you be to install a ductless mini-split heat pump if your current primary heating system is about to fail and you received no utility incentive (i.e. paid the full cost out of pocket)? As a reminder, a ductless mini-split heat pump would cost about $4,000 more than a new natural gas boiler.

| | | | | | |
|---|---|---|---|---|---|
| Very likely (6) | Likely (5) | Somewhat likely (4) | Somewhat unlikely (3) | Unlikely (2) | Very Unlikely (1) |

D2. [ASK IF D1=1–4] How likely would you be to install a ductless mini-split heat pump if you received an incentive of $1,000 from your utility (i.e. reduce the total installation cost by $1,000)? This would reduce the difference in cost between a ductless mini-split heat pump and a new natural gas boiler to about $3,000.

| | | | | | |
|---|---|---|---|---|---|
| Very likely (6) | Likely (5) | Somewhat likely (4) | Somewhat unlikely (3) | Unlikely (2) | Very Unlikely (1) |

D3. [ASK IF D2=1–4] How likely you would be to install a ductless mini-split heat pump if you received an incentive of $2,000 from your utility (i.e. reduce the total installation cost by $2,000)? This would reduce the difference in cost between a ductless mini-split heat pump and a new natural gas boiler to about $2,000.

| | | | | | |
|---|---|---|---|---|---|
| Very likely (6) | Likely (5) | Somewhat likely (4) | Somewhat unlikely (3) | Unlikely (2) | Very Unlikely (1) |

D4. [ASK IF D3=1–4] How likely you would be to install a ductless mini-split heat pump if you received an incentive of $3,000 from your utility (i.e. reduce the total installation cost by $3,000)? This would reduce the difference in cost between a ductless mini-split heat pump and a new natural gas boiler to about $1,000.

| | | | | | |
|---|---|---|---|---|---|
| Very likely (6) | Likely (5) | Somewhat likely (4) | Somewhat unlikely (3) | Unlikely (2) | Very Unlikely (1) |

D5. [ASK IF D4=1–4] How likely you would be to install a ductless mini-split heat pump if you received an incentive of $4,000 from your utility (i.e. reduce the total installation cost by $4,000)? This would make the cost of installing a ductless mini-split heat pump about the same as a new natural gas boiler.

| | | | | | |
|---|---|---|---|---|---|
| Very likely (6) | Likely (5) | Somewhat likely (4) | Somewhat unlikely (3) | Unlikely (2) | Very Unlikely (1) |

D6. [ASK IF D5=1–3] Why would you be unlikely to install a ductless mini-split heat pump if your gas heating system failed? Please select all that apply. [RANDOMIZE ORDER 1–7]

1. The initial cost of a the ductless mini-split heat pump is too high (i.e. too expensive)
2. I don't know enough about ductless mini-split heat pumps
3. Don't plan to stay in home long enough for it to pay off
4. Would rather trust a technology I am more familiar with
5. I'm concerned about how the ductless mini-split heat pump would look in my home
6. I don't believe my monthly energy bill would go down
7. I'm concerned about the system's performance
8. Something else, please specify [TEXT ENTRY BOX]

[TRANSITION LANGUAGE AFTER FIRST SCENARIO]: Great. We have just one more scenario for you to consider, that's slightly different than the last.

**Scenario 2: Ductless ASHP – Partial Displacement**

Assume you live in an 1,800 sq ft home and that **your current primary heating system is working fine**. Some people install an electric ductless mini-split heat pump to provide more cost-effective and efficient heating and cooling than their current system, to add cooling, and/or to improve their comfort, for all or some areas of their home. On average, installing a ductless mini-split heat pump to supplement your current gas heating system would cost approximately $10,000. This system would have three indoor units, typically mounted up high on a wall like in the picture below. Each indoor unit would provide heating and cooling to an open living area or room, and the system would provide a majority of your heating and cooling at lower cost than does your current system.

When used for heating, a ductless mini-split heat pump will decrease your gas bill while increasing your electric bill. Overall, you would save up to $100 a year on your energy bill. The system would provide quiet, efficient heating and cooling throughout your home while being environmentally friendly and energy efficient.

D7. How likely would you be to install a ductless mini-split heat pump in conjunction to supplement your existing system if you received no utility incentive (i.e. paid the full cost out of pocket)? As a reminder, a ductless mini-split heat pump would cost about $10,000 to supplement your current gas heating system.

| | | | | | |
|---|---|---|---|---|---|
| Very likely (6) | Likely (5) | Somewhat likely (4) | Somewhat unlikely (3) | Unlikely (2) | Very Unlikely (1) |

D8. [ASK IF D7=1–4] How likely would you be to install a ductless mini-split heat pump in conjunction with your existing system if you received an incentive of $2,500 from your utility (i.e. reduce the total installation cost by $2,500)? This would reduce the cost of the ductless mini-split heat pump to about $7,500.

| | | | | | |
|---|---|---|---|---|---|
| Very likely (6) | Likely (5) | Somewhat likely (4) | Somewhat unlikely (3) | Unlikely (2) | Very Unlikely (1) |

D9. [ASK IF D8=1–4] How likely would you be to install a ductless mini-split heat pump in conjunction with your existing system if you received an incentive of $5,000 from your utility (i.e. reduce the total installation cost by $5,000)? This would reduce the cost of the ductless mini-split heat pump to about $5,000.

| | | | | | |
|---|---|---|---|---|---|
| Very likely (6) | Likely (5) | Somewhat likely (4) | Somewhat unlikely (3) | Unlikely (2) | Very Unlikely (1) |

D10. [ASK IF D9=1–4] How likely would you be to install a ductless mini-split heat pump in conjunction with your existing system if you received an incentive of $7,500 from your utility (i.e. reduce the total installation cost by $7,500)? This would reduce the cost of the ductless mini-split heat pump to about $2,500.

| | | | | | |
|---|---|---|---|---|---|
| Very likely (6) | Likely (5) | Somewhat likely (4) | Somewhat unlikely (3) | Unlikely (2) | Very Unlikely (1) |

D11. [ASK IF D10=1–4] How likely would you be to install a ductless mini-split heat pump in conjunction with your existing system if you received an incentive of $10,000 from your utility? This means the system would be installed at no cost to you.

| | | | | | |
|---|---|---|---|---|---|
| Very likely (6) | Likely (5) | Somewhat likely (4) | Somewhat unlikely (3) | Unlikely (2) | Very Unlikely (1) |

D12. [ASK IF D11=1–3] Why would you be unlikely to install a ductless mini-split heat pump in this scenario? Please select all that apply. [RANDOMIZE ORDER 1–8]

1. I'm satisfied with my current systems and do not need to supplement my heating or cooling with a ductless mini-split heat pump
2. The initial cost of a the ductless mini-split heat pump is too high (i.e. too expensive)
3. I don't know enough about ductless mini-split heat pumps
4. Don't plan to stay in home long enough for it to pay off
5. Would rather trust a technology I am more familiar with
6. I'm concerned about how the ductless mini-split heat pump would look in my home
7. I don't believe my monthly energy bill would go down
8. I'm concerned about the system's performance
9. Something else, please specify [TEXT ENTRY BOX]

## *E. Willingness to Pay – Ducted Air Source Heat Pumps*

[ONLY ASK SECTION E IF A7=1 AND B1=1 or 2 OR A7=1 and B2=1]

The next section will ask you how likely you would be to install an electric ducted air source heat pump in your home. Some people install a ducted air source heat pump to provide more cost-effective and efficient heating and cooling than their current system, to add or replace a central air conditioner, and/or to improve their comfort. As a reminder, this is not to sell you anything, this is for research purposes only.

**Programming Note: Respondents are asked *one* Ducted ASHP Scenario depending on existing cooling.**

- **IF A8=1, RANDOMIZE TO E1 OR D13**
- **IF A8=2,4, 5 or 6 RANDOMIZE TO E1 OR E7**
- **Ducted Scenario 1: Ducted ASHP – Full Replacement/Replace on Burnout**

Assume that you live in an 1,800 sq ft home and **that your current primary heating system is about to fail**. On average, installing a ducted air source heat pump to replace your current failing heating system would cost approximately $9,000—about $4,500 more than a new gas furnace. This system would reuse the existing ductwork in your home previously used by your old furnace to provide heating and cooling.

The ducted air source heat pump will decrease your gas bill while increasing your electric bill. Overall, you would save up to $150 a year on your energy bill. The system would provide quiet, efficient heating cooling throughout your home while being environmentally friendly and energy efficient.

E1. How likely would you be to install a ducted air source heat pump if you received no utility incentive (i.e. paid the full cost out of pocket)? As a reminder, a ducted air source heat pump would cost about $4,500 more than a new natural gas furnace.

| Very likely (6) | Likely (5) | Somewhat likely (4) | Somewhat unlikely (3) | | Unlikely (2) | Very Unlikely (1) |
|---|---|---|---|---|---|---|

E2. [ASK IF E1=1–4] Please indicate how likely you would be to install a ducted air source heat pump if you received an incentive of $1,150 from your utility (i.e. reduce the total installation cost by $1,150)? This would reduce the difference in cost between an air source heat pump and a new natural gas furnace to about $3,350.

| Very likely (6) | Likely (5) | Somewhat likely (4) | Somewhat unlikely (3) | Unlikely (2) | Very Unlikely (1) |
|---|---|---|---|---|---|

E3. [ASK IF E2=1–4] How likely would you be to install a ducted air source heat pump if you received an incentive of $2,250 from your utility (i.e. reduce the total installation cost by $2,250)? This would reduce the difference in cost between an air source heat pump and a new natural gas furnace to about $2,250.

| Very likely (6) | Likely (5) | Somewhat likely (4) | Somewhat unlikely (3) | Unlikely (2) | Very Unlikely (1) |
|---|---|---|---|---|---|

E4. [ASK IF E3=1–4] How likely would you be to install a ducted air source heat pump if you received an incentive of $3,375 from your utility (i.e. reduce the total installation cost by $3,375)? This would reduce the difference in cost between an air source heat pump and a new natural gas furnace to about $1,125.

| Very likely (6) | Likely (5) | Somewhat likely (4) | Somewhat unlikely (3) | Unlikely (2) | Very Unlikely (1) |
|---|---|---|---|---|---|

E5. [ASK IF E4=1–4] How likely would you be to install a ducted air source heat pump if you received an incentive of $4,500 from your utility? This would make the cost of installing a ducted air source heat pump about the same as a new natural gas furnace.

| Very likely (6) | Likely (5) | Somewhat likely (4) | Somewhat unlikely (3) | Unlikely (2) | Very Unlikely (1) |
|---|---|---|---|---|---|

E6. [ASK IF E5=1–3] Why would you be unlikely to install a ducted air source heat pump? Please select all that apply. [RANDOMIZE ORDER 1–7]

1. The initial cost of an air source heat pump is too high (i.e. too expensive)
2. Unsure of how to apply for incentives and/or special financing for air source heat pumps
3. I don't know enough about air source heat pumps
4. Don't plan to stay in home long enough for it to pay off
5. Would rather trust a technology I am more familiar with
6. I don't believe my monthly energy bill would go down
7. I'm concerned about the system's performance
8. Something else, please specify [TEXT ENTRY BOX]

**Scenario 2: Ducted ASHP – Dual Fuel Early Replacement**

Assume that you live in an 1,800 sq ft home and **that your current primary heating system is older but still working.** On average, installing a ducted air source heat pump to supplement your current natural gas furnace and add the benefit of central cooling would cost approximately $8,000. This system would use the same ductwork in your home used by your furnace, and operate in place of your furnace until the temperature reached around 35 degrees Fahrenheit.

The ducted air source heat pump would decrease your gas bill while increasing your electric bill. Overall, you would save up to $100 a year on your energy bill. The system would provide quiet, efficient heating and cooling throughout your home while being more environmentally friendly and energy efficient.

E7. How likely would you be to install a ducted air source heat pump if you received no utility incentive (i.e. paid the full cost out of pocket)? As a reminder, a ducted air source heat pump would cost about $8,000 to supplement your current gas heating system and add central cooling.

| Very likely (6) | Likely (5) | Somewhat likely (4) | Somewhat unlikely (3) | Unlikely (2) | Very Unlikely (1) |
|---|---|---|---|---|---|

E8. [ASK IF E7=1–4] Please indicate how likely you would be to install a ducted air source heat pump if you received an incentive of $2,000 from your utility (i.e. reduce the total installation cost by $2,000)? This would reduce the cost to approximately $6,000.

| Very likely (6) | Likely (5) | Somewhat likely (4) | Somewhat unlikely (3) | Unlikely (2) | Very Unlikely (1) |
|---|---|---|---|---|---|

E9. [ASK IF E8=1–4] How likely would you be to install a ducted air source heat pump if you received an incentive of $4,000 from your utility (i.e. reduce the total installation cost by $4,000)? This would reduce the cost to approximately $4,000.

| Very likely (6) | Likely (5) | Somewhat likely (4) | Somewhat unlikely (3) | Unlikely (2) | Very Unlikely (1) |
|---|---|---|---|---|---|

E10. [ASK IF E9=1–4] How likely would you be to install a ducted air source heat pump if you received an incentive of $6,000 from your utility (i.e. reduce the total installation cost by $6,000)? This would reduce the cost to approximately $2,000.

| Very likely (6) | Likely (5) | Somewhat likely (4) | Somewhat unlikely (3) | Unlikely (2) | Very Unlikely (1) |
|---|---|---|---|---|---|

E11. [ASK IF E10=1–4] How likely would you be to install a ducted air source heat pump if you received an incentive of $8,000 from your utility (i.e. the system would be installed at no cost to you)?

| Very likely (6) | Likely (5) | Somewhat likely (4) | Somewhat unlikely (3) | Unlikely (2) | Very Unlikely (1) |
|---|---|---|---|---|---|

E12. [ASK IF D11=1–3] Why would you be unlikely to install a ducted air source heat pump? Please select all that apply. [RANDOMIZE ORDER 1–8]

1. I'm satisfied with my current systems and do not need to supplement my heating or add cooling with an air source heat pump
2. The initial cost of an air source heat pump is too high (i.e. too expensive)
3. Unsure of how to apply for incentives and/or special financing for air source heat pumps
4. I don't know enough about air source heat pumps
5. Don't plan to stay in home long enough for it to pay off
6. Would rather trust a technology I am more familiar with
7. I don't believe my monthly energy bill would go down
8. I'm concerned about the system's performance
9. Something else, please specify [TEXT ENTRY BOX]

### SCENARIO 3 – ROB Dual Fuel

Assume your existing central air conditioner is about to fail *and* your heating system is about to fail. The cost of the ducted air source heat pump, with natural gas back-up heat, is approximately $1,200 more than installing a new central air conditioner and new furnace separately.

The ducted air source heat pump with natural gas back-up heat would decrease your gas bill while increasing your electric bill. Overall, you would save up to $100 a year on your energy bill. The system would provide quiet, efficient heating and cooling throughout your home while being more environmentally friendly and energy efficient.

E13. How likely would you be to install a ducted air source heat pump if you received no utility incentive (i.e. paid the full cost out of pocket), knowing that it will provide cooling like an air conditioner while also reducing your heating bill by approximately $100 annually? As a reminder, a ducted air source heat pump with natural gas back-up heat would cost about $1,200 more than installing a new gas furnace and new central air conditioner.

| Very likely (6) | Likely (5) | Somewhat likely (4) | Somewhat unlikely (3) | Unlikely (2) | Very Unlikely (1) |
|---|---|---|---|---|---|

E14. [ASK IF E13=1–4] How likely would you be to install a ducted air source heat pump if you received an incentive of $300 from your utility (i.e. reduce the total installation cost by $300). This would reduce the difference in cost between an air source heat pump and a new natural gas furnace and new air conditioner to about $900. more than installing a new gas furnace and new central air conditioner.

| Very likely (6) | Likely (5) | Somewhat likely (4) | Somewhat unlikely (3) | Unlikely (2) | Very Unlikely (1) |
|---|---|---|---|---|---|

E15. [ASK IF E14=1–4] How likely would you be to install a ducted air source heat pump if you received an incentive of $600 from your utility (i.e. reduce the total installation cost by $600)? This would reduce the difference in cost between an air source heat pump and a new natural gas furnace and new air conditioner to about $600.

| Very likely (6) | Likely (5) | Somewhat likely (4) | Somewhat unlikely (3) | Unlikely (2) | Very Unlikely (1) |
|---|---|---|---|---|---|

E16. [ASK IF E15=1–4] How likely would you be to install a ducted air source heat pump if you received an incentive of $900 from your utility (i.e. reduce the total installation cost by $900)? This would reduce the difference in cost between an air source heat pump and a new natural gas furnace and new air conditioner to about $300.

| | | | | | |
|---|---|---|---|---|---|
| Very likely (6) | Likely (5) | Somewhat likely (4) | Somewhat unlikely (3) | Unlikely (2) | Very Unlikely (1) |

E17. [ASK IF E16=1–4] How likely would you be to install a ducted air source heat pump with natural gas back-up heat if you received an incentive of $1,200 from your utility (This would make the cost of installing a ducted air source heat pump about the same as a new natural gas furnace and new air conditioner).

| | | | | | |
|---|---|---|---|---|---|
| Very likely (6) | Likely (5) | Somewhat likely (4) | Somewhat unlikely (3) | Unlikely (2) | Very Unlikely (1) |

E18. [ASK IF E17=1–3] Why would you be unlikely to install a ducted air source heat pump? Please select all that apply. [RANDOMIZE ORDER 1–7]

1. The initial cost of an air source heat pump is too high (i.e. too expensive)
2. Unsure of how to apply for incentives and/or special financing for air source heat pumps
3. I don’t know enough about air source heat pumps
4. Don’t plan to stay in home long enough for it to pay off
5. Would rather trust a technology I am more familiar with
6. I don’t believe my monthly energy bill would go down
7. I’m concerned about the system’s performance
8. Something else, please specify [TEXT ENTRY BOX]

## *F. Willingness to Pay – Other Low-Carbon Technology*

The next section will ask you how likely you would be to install other low-carbon technologies.

F1. What kind of water heater do you currently have?

1. Gas water heater
2. Electric water heater
3. Other, please specify [TEXT ENTRY BOX]

F2. [ASK IF F1=1] An electric, heat pump water heater provides several benefits compared to a gas water heater, including improved energy efficiency and lower water heating costs. Consider a scenario in which you need to replace your gas water heater within the next two years. How likely would you be to replace your gas water heater with an electric heat pump water heater? Heat pump water heaters cost approximately $1,000 more than new gas water heater on average, and could save $80–$120 annual on your energy bill.

| | | | | | |
|---|---|---|---|---|---|
| Very likely (6) | Likely (5) | Somewhat likely (4) | Somewhat unlikely (3) | Unlikely (2) | Very Unlikely (1) |

F3. What type of cooktop do you currently have?

1. Gas cooktop
2. Electric cooktop
3. Other

F4. [ASK IF F3=1] An electric, induction cooktop provides several benefits compared to gas cooktop, including a more even and precise heating surface, lower energy usage, and improved indoor air quality and safety. Consider a scenario in which you are considering updating your stove or cooktop within the next two years. How likely you would be to install an induction cooktop? Assume your energy costs remain approximately the same and the cost to purchase an induction cooktop is $300 more than a new gas cooktop, on average.

| Very likely (6) | Likely (5) | Somewhat likely (4) | Somewhat unlikely (3) | Unlikely (2) | Very Unlikely (1) |
|---|---|---|---|---|---|

## G. Climate Change

G1. Please rate how much you agree or disagree with the following statements: [1=STRONGLY DISAGREE, 2=SOMEWHAT DISAGREE, 3=SOMEWHAT AGREE, 4=STRONGLY AGREE, 98=DON'T KNOW] [RANDOMIZE ORDER]

1. I am very concerned about climate change
2. Climate change is a threat to our environment
3. I'm worried about how climate change will impact my family/community
4. I try to consider the environmental impact for all the decisions I make
5. I consider climate change when making decisions related to heating/cooling my home

## H. Demographics

To close, we have a few questions about your household. These will be kept strictly confidential and will only be used in aggregate with other responses.

H1. Which of the following categories best represents your approximate annual household income from all sources in 2021 before taxes?

1. < $30,000
2. Between $30,000 and $49,999
3. Between $40,000 and $49,999
4. Between $50,000 and $59,999
5. Between $60,000 and $79,999
6. Between $80,000 and $99,999
7. Between $100,000 and $119,999
8. $120,000 or more

98. Don't know
99. Prefer not to answer

H2. What is the highest level of education you've completed so far?

1. Some high school, no diploma
2. High school diploma or GED
3. Associates degree
4. Some college, no degree
5. Bachelor's degree
6. Graduate or professional degree

99. Prefer not to answer

H3. What year was your home built?

1. 2010 or later
2. 2000 to 2009
3. 1990 to 1999
4. 1980 to 1989
5. 1970 to 1979
6. 1960 to 1969
7. 1950 to 1959
8. 1940 to 1949
9. Earlier than 1940

98. Don't know
99. Prefer not to answer

H4. Approximately how may years old is your heating system? Please estimate the age of your system in the drop-down menu. [DROP DOWN NUMERIC 1–20]

H5. How many years have you lived in your current home?

1. Less than 1 year
2. 1 year to less than 5 years
3. 5 years to less than 10 years
4. 10 years or more

99. Prefer not to answer

H6. How many people, including yourself, live in your home full time?

1. 1
2. 2
3. 3
4. 4
5. 5
6. 6
7. 7 or more people

98. Don't know
99. Prefer not to answer

H7. Is English your first language?
1. Yes
2. No, please specify what your first language is [TEXT ENTRY BOX]

H8. What is your race? Please select all that apply. [RANDOMIZE ORDER]
1. White
2. Black or African American
3. American Indian or Alaska Native
4. Asian
5. Native Hawaiian or Other Pacific Islander
6. Other: [TEXT ENTRY BOX]

H9. What is your ethnicity?
1. Hispanic or Latino or Spanish Origin
2. Not Hispanic or Latino or Spanish Origin
3. Other: [TEXT ENTRY BOX]

## *Gift Card*

Those are all of our questions! Please verify your contact information to be entered into the drawing to win one of five $100 Amazon.com gift cards. Your information will only be used to email you a gift card; PSE will not use it for marketing purposes, and they will not update any of your billing or emailing preferences with this information. Please note that if you do not complete your email address, or only fill in some of the fields below, you will not be entered to win a gift card.

Name: [TEXT ENTRY BOX]

Best Email: [TEXT ENTRY BOX]

## *End of Survey Message*

Thank you for your responses and your time!

PSE offers a variety of energy efficiency programs that could help you save energy and manage your monthly bills. For more information on other ways to save, please visit https://www.pse.com/rebates.

# Appendix C. Heat Pump Cost and Market Barriers Interview Guide (HVAC Contractors)

**Interview Overview:** The purpose of these interviews is to collect data from HVAC contractors and builders active in Puget Sound Energy's service territory to determine the costs to install different configurations of air source heat pumps across a variety of different gas-heated homes. Additionally, these interviews seek to collect information about use of cold climate heat pumps and additional barriers to electrifying heating systems from PSE gas customers.

| Research Objectives | Corresponding Question Numbers |
|---|---|
| Understand contractor perspective on heat pump sales by system type, attitudes towards cold climate heat pumps, and barriers to electrification | A1–A8 |
| Assess costs for primary baseline heating and cooling equipment configurations | B1–B5 |
| Assess costs per ton and by scenario for various heat pump configurations | C1–C13 |

**Target Audience:** Residential service providers (HVAC contractors) that have ideally installed at least 50 air source heat pumps in and around PSE's service territory in 2021

**Target:** Up to 15 contractors

**Estimated time:** 30 to 45 minutes

## A. *Company and Heat Pump Market Overview*

A1. What geographic areas does your company serve?

A2. In the past 12 months, about how many HVAC systems has your business installed in existing single-family homes in PSE's service territory, which includes King, Kittitas, Thurston, Pierce, and Snohomish Counties? [Follow-on: Please note that all questions we are asking about sales and costs are focused on PSE's service territory, though we realize it may be difficult to consider just these areas. Where possible, please consider PSE's territory or jobs within a 50-mile radius of Seattle]

A3. In the past 12 months, about how many **ductless mini-split heat pumps** has your business installed in **existing single-family homes**?

1. Thinking about the homes in which your company installed ductless mini-split heat pumps, approximately what percentage of these ductless mini-split heat pumps were installed in homes heated with gas, what percentage were installed in homes heated with electric resistance, and what percentage were installed in homes heated with other fuels?
2. Approximately what percentage of these systems were installed as **sole sources of heating to the home**, what percentage were installed as **primary or supplemental sources of heating**, what percentage were installed as **zonal sources of heating, and what percentage were installed primarily for providing cooling**?
   (1) [Definition: For this question, we are considering installations to be primary or supplemental sources of heating as systems that are installed with the intent of being operated in conjunction with an existing heating system that is used as a backup source of heating. We are considering installations to be zonal source of heating if they are installed as the sole source of heating in a previously unheated space like a new addition or bonus room where the home is otherwise served by a separate system]
   (2) [Probe: If percentages do not add up to 100%, ask about alternative applications]
3. What are the primary reasons why customers are interested in installing ductless mini-split heat pumps? [Probe: Replacing old system, saving energy, adding cooling, reducing greenhouse gas emissions]

A4. How has the number of **ductless mini-split heat pumps** you've installed changed in the past 12 months relative to the previous 12 months? [Probe: increased, decreased, stayed the same]

1. How did the COVID-19 pandemic impact your installations of **ductless mini-split heat pumps**?

A5. In the past 12 months, about how many centrally ducted or unitary air source heat pumps has your business installed in existing single-family homes?

1. Approximately what percentage of these ducted air source heat pumps were installed in homes heated with gas, what percentage were installed in homes heated with electric resistance, and what percentage were installed in homes heated with other fuels?
2. Thinking about the homes in which your company installed centrally ducted air source heat pumps, approximately what percentage of these systems were installed as **sole sources of heating** vs. installed in **dual-fuel configuration** with an existing or new natural gas furnace? [Probe: If percentages do not add up to 100%, ask about alternative applications]
3. What are the primary reasons why customers are interested in installing centrally ducted air source heat pumps? [Probe: Replacing old furnace, replacing old air conditioner, saving energy, adding cooling, reducing greenhouse gas emissions] Do these reasons differ between standalone centrally ducted ASHPs and dual-fuel systems?

4. When you install centrally ducted heat pumps in dual-fuel configurations, how do you typically determine switchover temperatures between the furnace and heat pump? What factors influence what balance point you use?
5. When you install centrally ducted heat pumps in dual-fuel configurations, do you typically replace the furnace as well? What factors determine whether you replace the furnace when installing the heat pump?

A6. How has the number of **centrally ducted air source heat pumps** you've installed changed in the past 12 months relative to the previous 12 months? [Probe: increased, decreased, stayed the same]

1. Does this differ between standalone centrally ducted ASHPs and dual-fuel systems?
2. How did the COVID-19 pandemic impact your installations of **centrally ducted air source heat pumps?**

A7. How familiar are you with **cold climate air source heat pumps?** [Prompt: The Northeast Energy Efficiency Partnerships certifies air source heat pumps as "cold climate" if they include a variable-speed compressor, have an HSPF of 9 or higher, and are able to maintain a COP of at least 1.75 at 5°F]

1. How frequently do you install cold climate heat pumps? What factors determine whether you install a cold climate heat pump in a customer's home vs. a non-cold climate heat pump?
2. [If does not install] Why not?

A8. What are the primary challenges **you** face when converting a home from using gas for heating to using heat pumps for heating?

1. What are the primary challenges a **customer** will face if they are interested in converting a home from using gas for heating to using a heat pump for heating?
2. How frequently are electrical improvements needed when you install heat pumps? [Prompt: For example, panel upgrade or additional wiring]

A9. Do customers typically request air source heat pumps or do you propose them as solutions to meet their needs? Does this differ between ductless mini-splits, centrally ducted ASHPs, and dual-fuel centrally ducted ASHPs?

## *B. Baseline System Costs*

The next few questions ask about the costs associated with retrofitting existing gas heating systems with similar equipment. I understand that costs vary significantly on a project-by-project basis, but please provide your best estimate of a typical installation matching the description provided. This information will be used to help PSE understand how best to set incentive levels for future energy programs.

B1. What is the approximate cost for replacing a **gas furnace?** Assume the furnace is a minimum efficiency system with no additional features like multiple stages or modulating capacity.

B2. What is the approximate cost for replacing a **gas boiler?** Again, assume the boiler is a minimum efficiency system with no additional features.

B3. What is the approximate cost for replacing a **gas wall furnace?**

B4. What is the approximate cost for replacing a **central air conditioner?** Assume the home is approximately 1,800 square feet with two floors.
   1. Approximately how large of an air conditioner (in nameplate cooling capacity) would this system be?

B5. What is the approximate cost for installing a central air conditioner in a home with a gas furnace that did not previously have central air conditioning?
   1. In the past three years, what change, if any, have you noticed in customer interest in installing central AC for the first time? [Probe: increased, decreased, stayed the same] Why do you think this is?

## *C. Heat Pump Costs*

The next several questions ask about the costs associated with installing heat pumps to retrofit existing gas-heated homes. I will ask you for your estimate of costs for installing a variety of different heat pump systems and sizes, as well as an estimate for more specific scenarios. I understand that costs vary significantly on a project-by-project basis, but please provide your best estimate of a typical installation matching the description provided. Later on, I will ask about typical factors that can impact the cost of installing heat pumps in gas-heated homes.

C1. What is the approximate cost per ton of nameplate cooling capacity to install a **ductless mini-split heat pump** in an existing gas-heated home to fully replace the existing system? Assume this is a standard efficiency, code compliant system.
   1. Approximately how much more per ton would it cost to install an ENERGY STAR certified system?
   2. Approximately how much more per ton would it cost to install a **cold climate ductless mini-split heat pump**? [Confirm INCREMENTAL cost]

C2. What is the approximate cost per ton of nameplate cooling capacity to install a **centrally ducted air source heat pump** to fully replace an existing gas furnace? Assume that this is a standard efficiency, code compliant single-stage system.
   1. Approximately how much more per ton would it cost to install a dual-stage system? What about ENERGY STAR certified?
   2. Approximately how much more per ton would it cost to install a **cold climate centrally ducted air source heat pump?** [Confirm INCREMENTAL cost]

C3. What is the approximate cost per ton of nameplate cooling capacity to install a **centrally ducted air source heat pump** in a **dual-fuel configuration** with an **existing** gas furnace? Assume the systems are compatible and both systems are standard efficiency, code compliant systems.

C4. Approximately how much would it cost to install a **centrally ducted air source heat pump** in a **dual-fuel configuration** with a **new** gas furnace? Assume the systems are compatible and both systems are standard efficiency, code compliant systems.

C5. What are the primary factors that could drive up the cost of **ductless mini-split heat pump** installations beyond the estimate you provided previously? [Probe for potential cost adders for factors and costs specific to gas conversions, especially electrical upgrades]

1. Do you install third-party or manufacturer proprietary controls with ductless mini-split heat pumps? Why or why not?
2. [If yes] How frequently do your installations include added controls? How much do those controls typically add to the cost of an installation?

C6. What are the primary factors that could drive up the cost of **centrally ducted heat pump** installations beyond the estimate you provided previously? [Probe for potential cost adders for factors and costs specific to gas conversions, especially electrical upgrades]

1. Do you install third-party or manufacturer proprietary controls with centrally ducted heat pumps? Why or why not?
2. [If yes] How frequently do your installations include added controls? How much do those controls typically add to the cost of an installation?

I am going to now provide you with more specific examples of residential homes and then ask you about your best estimate for the costs associated with a project of similar size and scope.

**Scenario 1: Gas Furnace Full Replacement**

**[Building Size]** The customer owns a 2-story, 1,800 sq. ft. single family detached [style] home that is approximately 40 years old.

**[Current System]** The current system is a standard efficiency gas furnace approximately 15 years in age. The customer does not have central air conditioning but is interested in adding cooling.

**[New System]** The customer wants to replace their furnace with a centrally ducted air source heat pump that will provide heating and cooling to the entire home.

C7. Have you worked on any projects similar in size or scope to this project?

1. Yes
2. No

C8. [IF C7=1] Based on your experience with similar projects, what system would you quote for this home and what would be the typical costs for this installation?

C9. [IF C7=2] Give your best estimate of what system you would quote for this home and at what cost if you were asked to provide a quote for this project by a potential client.

C10. Is this heat pump retrofit scenario that is a common recommendation you would make for a home like this?
   1. **[If does not recommend]** What would you recommend instead?

**Scenario 2: Gas Furnace Dual Fuel Installation**

**[Building Size]** The customer owns a 2-story, 1,800 sq. ft. single family detached [style] home that is approximately 40 years old.

**[Current System]** The current system is a relatively new standard efficiency gas furnace approximately 5 years in age. The customer does not have central air conditioning but is interested in adding cooling.

**[New System]** The customer wants to install a centrally ducted air source heat pump to provide cooling and to save money on heating costs while keeping the existing furnace in place, operating in a dual fuel capacity.

C11. Have you worked on any projects similar in size or scope to this project?
   1. Yes
   2. No

C12. [IF C11=1] based on your experience with similar projects, what system would you quote for this home and what would be the typical costs for this installation?

C13. [IF C11=2] give your best estimate of what system you would quote for this home and at what cost if you were asked to provide a quote for this project by a potential client.

C14. Is this heat pump retrofit scenario that is a common recommendation you would make for a home like this?
   1. [If does not recommend] what would you recommend instead?

**Scenario 3: Gas Boiler Full Replacement**

**[Building Size]** The customer owns a 2-story, 1,800 sq. ft. single family detached [style] home that is approximately 40 years old.

**[Current System]** The current system is a standard efficiency gas boiler approximately 15 years in age. The customer does not have central air conditioning but is interested in adding cooling.

**[New System]** The customer wants to install a ductless mini-split heat pump with one outdoor unit and four indoor units to serve as the sole source of heating and cooling to the entire home. The indoor units will be installed in the kitchen and living room on the first floor and in two bedrooms on the second floor. They will keep the existing boiler in place but do not expect to use it outside of emergencies.

C15. Have you worked on any projects similar in size or scope to this project?
   1. Yes
   2. No

C16. [IF C15=1] Based on your experience with similar projects, what system would you quote for this home and what would be the typical costs for this installation?

C17. [IF C15=2] Give your best estimate of what system you would quote for this home and at what cost if you were asked to provide a quote for this project by a potential client.

C18. Is this heat pump retrofit scenario that is a common recommendation you would make for a home like this?
   1. [If does not recommend] What would you recommend instead?

**Scenario 4: Gas Boiler Partial Displacement**

**[Building Size]** The customer owns a 2-story, 1,800 sq. ft. single family detached [style] home that is approximately 40 years old.

**[Current System]** The current system is a relatively new standard efficiency gas boiler approximately 5 years in age. The customer does not have central air conditioning but is interested in adding cooling.

**[New System]** The customer wants to install a ductless mini-split heat pump with one outdoor unit and three indoor units to provide heating and cooling to most of the home. The indoor units will be installed in the kitchen and living room on the first floor and in the primary bedroom on the second floor. They expect to keep using the existing boiler to provide heat to remaining areas and during colder periods.

C19. Have you worked on any projects similar in size or scope to this project?
   1. Yes
   2. No

C20. [IF C19=1] Based on your experience with similar projects, what system would you quote for this home and what would be the typical costs for this installation?

C21. [IF C19=2] Give your best estimate of what system you would quote for this home and at what cost if you were asked to provide a quote for this project by a potential client.

C22. Is this heat pump retrofit scenario that is a common recommendation you would make for a home like this?
   1. [If does not recommend] What would you recommend instead?

## *Closing*

Those are all of my questions for today! Is there anything else you'd like to mention?

If I have any follow up questions, can I reach back out to you?

Thank you very much for your time. As a thank you, we would like to offer you a $150 Amazon.com gift card. Please provide us with your name and email address so we can send you your electronic gift card.

# Appendix D. Heat Pump Cost and Market Barriers Interview Guide (Builders)

**Interview Overview:** The purpose of these interviews is to collect data from builders active in Puget Sound Energy's service territory to determine the costs to install different configurations of air source heat pumps in new construction. Additionally, these interviews seek to collect information about use of cold climate heat pumps and additional barriers to electrifying heating systems from PSE gas customers.

| Research Objectives | Corresponding Question Numbers |
|---|---|
| Understand builder perspective on heat pumps in all-electric and dual-fuel homes, market trends, and customer interest | A1–A8 |
| Assess costs for primary baseline and all-electric heating and cooling equipment configurations in new construction | B1–B8 |

**Target Audience:** Builders that have developed new homes using heat pumps for space heating, cooling, and/or hot water around PSE's service territory

**Target:** Up to 5 builders

**Estimated time:** 30 minutes

## *D. Company and All-Electric Home Market Overview*

D1. In the past 12 months, about how many new homes has your company built in PSE's service territory, which includes King, Kittitas, Thurston, Pierce, and Snohomish Counties? [Follow-on: Please note that all questions we are asking about sales and costs are focused on PSE's service territory, though we realize it may be difficult to consider just these areas. Where possible, please consider PSE's territory or jobs within a 50-mile radius of Seattle]

1. Approximately how many were single-family vs. multifamily?
2. Do you typically build custom homes or build to spec?

D2. Thinking about the single-family homes you have constructed in the past 12 months, what proportion have been all-electric with no gas connection?

1. What are the primary reasons for why you make the decision to build all-electric? [Probe: Is there customer interest in all-electric? Does the cost of the gas connection come into play?]
2. How has the proportion of all-electric homes you've constructed changed in the past three years? [Probe: increased, decreased, stayed the same]

D3. Of the all-electric homes you've constructed in the past 12 months, approximately what percentage use **ductless mini-split heat pumps** for heating and cooling? Why is that? [Probe: why they are for/against installation of ductless mini-split heat pumps]

1. How often do you install ductless mini-split heat pumps in **dual-fuel** homes (that is homes with gas and electric connections)? Why is that? [Probe: what are they used for? Are they typically used for primary heating, supplementary heating, or just cooling?]

D4. Of the all-electric homes you've constructed in the past 12 months, approximately what percentage use **centrally ducted or unitary air source heat pumps** for heating and cooling? Why is that? [Probe: why they are for/against installation of centrally ducted or unitary air source heat pumps]

1. How often do you install centrally ducted air source heat pumps in **dual-fuel** homes? Why is that? [Probe: what are they used for? Are they typically used for primary heating, supplementary heating, or just cooling?]

D5. Of the all-electric homes you've constructed in the past 12 months, approximately what percentage use **electric resistance baseboards or furnaces** for heating? Why is that?

1. How often do these homes also have cooling? Why is that?
2. [If yes] What type of cooling system is most common in these instances?

D6. What circumstances make you most likely to choose a heat pump for a new home?

1. Does this differ whether the home is all-electric or dual-fuel?
2. What makes you more likely to choose a ductless or centrally ducted air source heat pump for a new home?

D7. What are the primary reasons why you choose to use heat pump vs. gas heating systems for new homes?

1. For new homes with gas connections where you also install a heat pump but no gas furnace, what is the primary reason for using a heat pump in place of a gas heating system?

D8. Of the all-electric homes you've constructed in the past 12 months, approximately what percentage use **heat pump water heaters** for domestic hot water? Why is that?

1. How often do you install heat pump water heaters in **dual-fuel** homes? Why is that?

D9. Of the all-electric homes you've constructed in the past 12 months, approximately what percentage use **induction stoves**? Why is that?

1. How often do you install induction stoves in **dual-fuel** homes? Why is that?

D10. Are you familiar with cold climate air source heat pumps? [Prompt: The Northeast Energy Efficiency Partnerships certifies air source heat pumps as "cold climate" if they include a variable-speed compressor, have an HSPF of 9 or higher, and are able to maintain a COP of at least 1.75 at 5°F]

1. How frequently do you install cold climate heat pumps in your new homes? What factors determine whether you install a cold climate heat pump in a new home vs. a non-cold climate heat pump?
2. [If does not install] Why not?

D11. In the past three years, how has homebuyer interest in all-electric vs. dual-fuel homes changed? [Probe: Increased, decreased, stayed the same] Why do you think that is?

1. For homebuyers who are skeptical of all-electric homes, what are their primary concerns about buying an all-electric home?
2. Has the 2018 Washington State Energy Code impacted whether you choose to use electric heating and cooling or build all-electric homes?
3. [If original response to A11 is increased or decreased] Are there other key drivers for why your organization has been building [more/fewer] all-electric homes in the past three years? What impacts your decision-making process on whether to build all-electric or dual-fuel?

D12. Regardless of whether you are installing a heat pump or a gas system in a new home, do you typically install code-minimum equipment or do you install more efficient equipment, such as ENERGY STAR-certified appliances? Why is that? [Probe: Is code compliance a key driver for your decision to install higher efficiency equipment?]

## *E. Baseline and All-Electric Home Costs*

The next few questions ask about new dual-fuel single-family homes and the costs for the HVAC systems. We understand that new homes can often vary in size, layout, and customer interests but we ask that you consider a typical single-family home with both gas and electric utility connections.

E1. Characterize a typical single-family home you have built in the past 12 months with both gas and electric utility connections. Be specific. [Probe: Square footage, size/layout, cost per square foot]

E2. Describe the HVAC system that you would include in a typical dual-fuel home. [Probe: Give an example, e.g. Gas furnace with central AC, on-demand gas water heater]

1. Do you typically install ENERGY STAR or other high efficiency equipment? Why is that?
2. Can you give examples of typical costs for each of the components you mentioned?
   (1) Heating system
   (2) Cooling system [if heating system is not heat pump]
   (3) Water heating system

E3. Approximately how much does it typically cost to provide a gas connection to the new home?

The next several questions ask about new **all-electric** single-family homes and the costs for all-electric HVAC systems.

E4. How would a typical all-electric single-family home be similar/different to what you described previously as a typical dual-fuel home? [Prompt with what respondent had previously provided] [Probe for specific elements: size of home, heating/cooling equipment, location]

E5. Describe the HVAC system that you would include in a typical all-electric home. [Probe: Give an example, e.g. ductless mini-split heat pumps, heat pump water heater]

1. Do you typically install ENERGY STAR or other high efficiency equipment? Why is that?
2. Can you give examples of typical costs for each of the components you mentioned?
    (1) Heating system
    (2) Cooling system [if heating system is not heat pump]
    (3) Water heating system

E6. [If B5 is a ductless mini-split heat pump] If you were to build a home with a centrally ducted air source heat pump instead of a ductless mini-split heat pump, approximately how much more or less would it cost? [Confirm INCREMENTAL cost]

E7. [If B5 is a centrally ducted mini-split heat pump] If you were to build a home with a ductless mini-split heat pump instead of a centrally ducted air source heat pump, approximately how much more or less would it cost? [Confirm INCREMENTAL cost]

E8. If you were to instead install a heat pump water heater for domestic hot water instead of a storage water heater, how much would it cost? [Confirm INCREMENTAL cost]

E9. With all other aspects of the home being equal, do you consider all-electric homes more or less expensive to build than dual-fuel homes? Why is that? [Probe for specific cost elements]

## *Closing*

Those are all of my questions for today! Is there anything else you'd like to mention?

If I have any follow up questions, can I reach back out to you?

Thank you very much for your time. As a thank you, we would like to offer you a $150 Amazon.com gift card. Please provide us with your name and email address so we can send you your electronic gift card.