Memorandum

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From: Cadeo, SBW Consulting, and Research Into Action Hot Water Team (the Research Team)

Date: January 27, 2018

Subject: Residential Hot Water Model Scope, Boundaries, Definitions, and Methods

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This memo outlines the Cadeo team's ("the research team" or "the team") proposed methodology for estimating residential hot water total consumption and Momentum Savings for the Northwest Power and Conservation Council's (the Council's) Seventh Power Plan (Seventh Plan) period (2016-2021). Residential hot water offers an interesting opportunity for Momentum Savings because it is the second largest residential end use behind space heating and has significant potential for market energy savings. BPA's goal for modeling this market is twofold:

1. Understand how total residential hot water market electric consumption is changing over the Seventh Plan period; and
2. Estimate electric Momentum Savings for the Seventh Plan period

This memo precedes model input development and offers a high-level summary of the initial methodology that the team plans to use to build the model. This document also identifies several key issues that the team will need to address during future model development phases. The research team will refine and revise this initial methodology during future phases of work.

The proposed methodology follows Bonneville Power Administration's (BPA's) four question framework, which is BPA's standard analytical framework for estimating Momentum Savings. The memo is organized into four sections that detail how the research team proposes to answer each of the four questions. Each section also describes the key data sources that the team plans to use, recommended analytical decisions, and the assumptions underpinning this methodology. This memo also presents options to model certain market segments or fill data gaps, including associated advantages and disadvantages, as applicable.

Regarding the scope of this document, this memo currently only provides a methodology for how to estimate energy savings (kWh or aMW[1]). While the hot water research team has discussed possible approaches to estimate capacity for this market during working sessions, BPA is exploring how to model capacity as part of a separate and concurrent effort that will conclude in April 2018. The hot water research team will keep abreast of this effort to ensure the hot water model design is compatible and consistent with the capacity methodology when it is completed.

[1] Average Megawatts (aMW) represent the cumulative impact of energy savings on generation. They are calculated based on the sustained kWh reduction in a given year divided by 8,760 hours to determine the average instantaneous power reduction associated with the given energy savings.

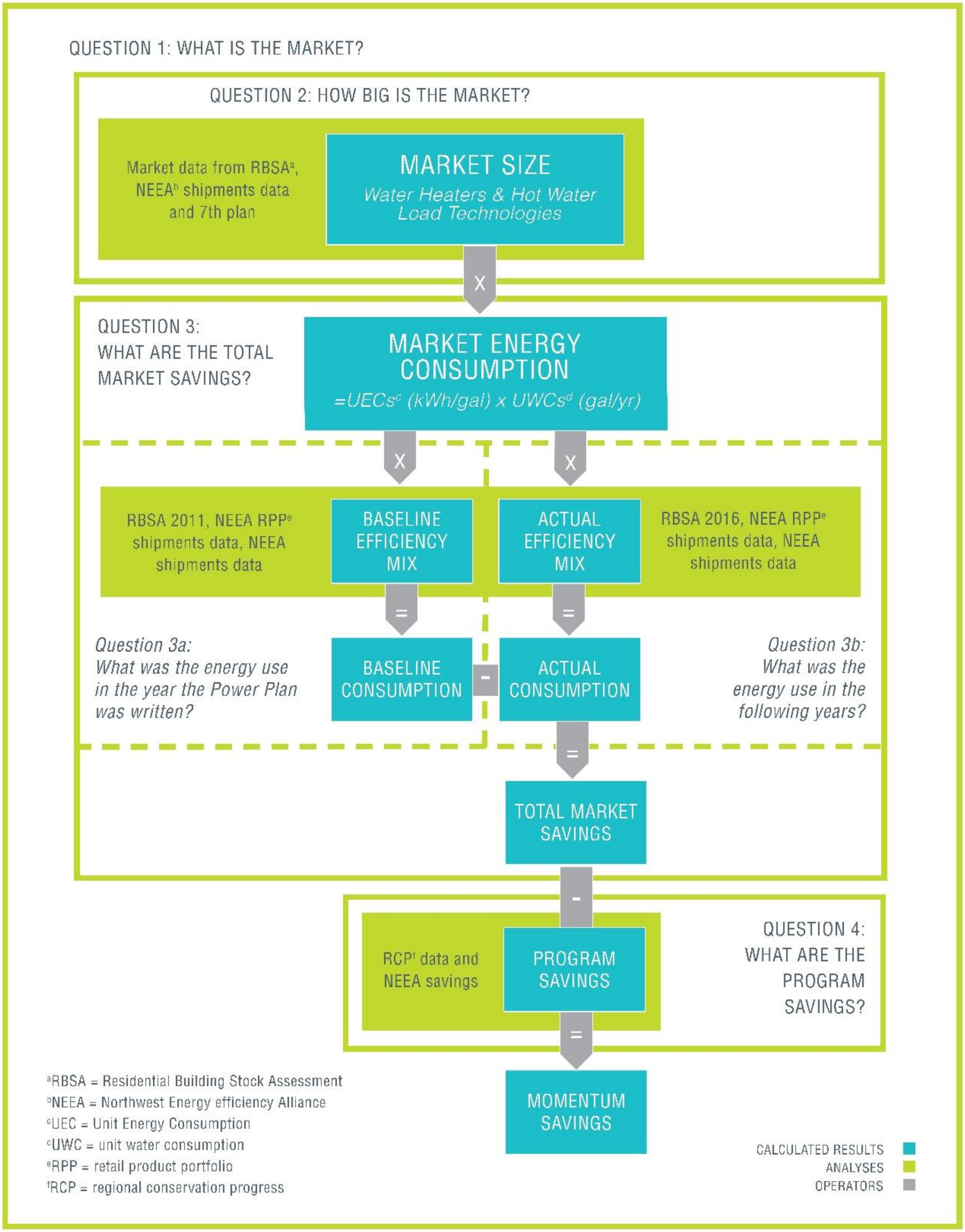
Momentum Savings Analysis Framework

The research team organized the proposed methodology based on the Four Questions, which include:

1. What is the market?
2. How big is the market?
3. What are the total market savings?
    a. What was the energy use in the year the Power Plan was written?
    b. What was the actual energy use in the following years?
4. What are the program savings?

Answers to these questions provide the information necessary to estimate Momentum Savings, which are energy savings above the Council's Seventh Plan frozen baseline that are not claimed by programs and not included in the Northwest Energy Efficiency Alliance's (NEEA) net market effects. **Error! Reference source not found.** summarizes how the Four Questions fit together, including details specific to analyzing the residential hot water market and relevant data sources. The following sections answer these questions in relation to the residential hot water market.

Figure 1: Overview of the Momentum Savings Analysis Framework for Residential Hot Water



Question 1: What is the market?

Question 1 defines the scope of the analysis. The research team proposes to define the hot water market by technology, sector, building type, and geography. Table 1 summarizes each of these dimensions, and the following sections provide further detail.

Table 1: Market Definition

Element	Description	Notes
Technology Scope	All technologies that affect hot water generation or use (i.e., water heating technologies and hot water use efficiency technologies)	Includes all Regional Technical Forum (RTF) and Seventh Plan measures
Sector and Building Type Scope	All housing types in the residential sector (single family, manufactured homes, and multifamily units with in-unit water heaters)	Includes multifamily units, but excludes common areas in multifamily buildings and multifamily units served by central water heating systems
Fuel Type Scope	Electric water heaters	Gas water heaters will only be considered to the extent that they affect the total electric water heater stock due to fuel switching
Geographic Scope	Oregon, Washington, Idaho, and Western Montana	Includes the four-state region, consistent with the Council's Power Plan
Unit of Account	Households	The model will look at the saturation of water heating efficiency and hot water load technologies by household

Technology Scope

Many technologies affect the energy used to heat and deliver water to residential homes. The research team categorizes these technologies into two groups based on how they impact energy use.

1. Technologies that impact the amount of energy required to heat and deliver a gallon of hot water (e.g., water heaters). The research team refers to these as **water heating** technologies.
2. Technologies that impact the gallons of hot water used (e.g., showerheads). The research team refers to these as **hot water use** technologies.

Table 2 lists the technologies in each category, which collectively represent the scope of the residential hot water market for this analysis.

Table 2: Categorization of Water Heating and Hot Water Use Technologies

Technology Category	Technology
Water heating	Water heaters[2]
	Pipe insulation
Hot water use	Showerheads
	Faucet aerators
	Clothes washers
	Dishwashers
	Circulators
	Thermostatic restriction valves
	Wastewater heat recovery

Each technology's relative contribution to total hot water energy consumption varies significantly, as does the data available to estimate that contribution. Therefore, to balance accuracy and granularity with the potential costs of data collection and modeling, the research team categorizes the above technologies into two groups, either primary or secondary, based on how the model will analyze them.

The research team proposes to treat water heaters, showerheads, faucet aerators, clothes washers, and dishwashers as **primary technologies**. The model will directly analyze changes in market saturation and stock efficiency mix for these technologies, as well as their impact on hot water energy consumption. The research team proposes to treat the remaining group of technologies as **secondary technologies** and will not model their market size or change directly. The impact of the secondary technologies on hot water energy consumption will, however, still be captured in the model implicitly based on their influence in the unit energy consumption (UEC) and unit water consumption (UWC) values. Question 3 details this process.

Table 3 summarizes the research team's preliminary categorization of primary and secondary technologies The Appendix includes a more detailed assessment of which technologies the research team expects to treat as primary versus secondary and a proposed approach for verifying this categorization.

[2] Includes all water heater technologies, e.g., electric resistance water heaters, solar water heaters, heat pump water heaters.

Table 3: Summary of Primary versus Secondary Technologies

Technology Category	Technology	Proposed Treatment
Water heating	Water heaters[3]	Primary
	Pipe insulation	Secondary
Hot water use	Showerheads	Primary
	Faucet aerators	Primary
	Clothes washers	Primary
	Dishwashers	Primary
	Circulators	Secondary
	Thermostatic restriction valves	Secondary
	Wastewater heat recovery	Secondary

The research team categorized technologies that are key contributors to overall hot water energy use and are expected to drive the overall market savings estimates as primary technologies. Conversely, technologies categorized as secondary technologies are not expected to significantly impact the total hot water energy consumption or resulting savings estimates over the analysis period.

The research team applied three key metrics to identify primary technologies:

1. Relative contribution of the technology to total water use
2. Potential for market change during the analysis timeframe
3. Availability of data to accurately model any market change or resource cost associated with acquiring such data

This proposed designation of primary versus secondary technologies balances accuracy and granularity with resource cost, because it focuses modeling efforts on technologies with demonstrated potential for market impact. The research team will verify and document market penetration and change for all technologies to the extent possible, prior to finalizing secondary categorizations.[4,5]

[3] Includes all water heater technologies (e.g., electric resistance water heaters, solar water heaters, heat pump water heaters).

[4] See the appendix for more discussion of the verification approach and proposed path forward for each technology.

[5] The research team considered two other approaches to modeling changes in hot water use: (1) a bottom-up approach that requires directly modeling the hot water load contribution of all hot water end-use technologies; and (2) a top-down approach that relies on total water bills and assumptions regarding the proportion of hot versus cold water use indoors and indoor versus outdoor use. The selected approach provides a balance between granularity, accuracy, resource cost, and uncertainty based on the available data. Particularly, adding more technologies with unchanging market impact to the model will add resource cost and uncertainty to the model with potentially no analysis benefit.

Sector and Building Type Scope

The market for this analysis includes the technologies from Table 2 installed in the **residential sector**. This sector comprises the following building types: single-family homes, manufactured homes, and multifamily units with in-unit water heaters.

The proposed scope for this analysis does not include common areas in multifamily buildings, which are not a typical residential use. The market definition also excludes multifamily units in buildings served by central systems, because central hot water systems are almost exclusively gas-heated and generally non-residential technologies.[6] This market definition is consistent with the Seventh Plan, which did not estimate savings for residential central hot water systems, as well as with residential sector utility program definitions.

Fuel Type Scope

The proposed analysis focuses on changes in **electricity consumption** in the residential hot water market. As such, the market definition only considers gas water heaters insomuch as they impact the electric water heater stock due to fuel switching. Potential drivers of change in water heater fuel preferences could include customer preferences for electrification, building code requirements,[7] and beyond-code programs[8] for new homes. These factors could increase or decrease electric water heater saturation in shipments, in turn impacting overall electric saturation in the installed stock.

This trend may be most dramatic in new construction and could increase the electric water heater stock, as consumers are believed to rarely switch from electric to gas water heaters in existing homes due to increased installation cost of putting in a new gas line.[9] The research team anticipates capturing any changing fuel preferences and their impacts on the electric water heater stock in Question 2, which focuses on the size of the market.

Geographic Scope

The hot water market includes the technologies from Table 2 installed in Oregon, Washington, Idaho, and Western Montana, which is consistent with the Seventh Plan's geographic scope. The research team will exclude housing stock in Eastern Montana, consistent with the scope of the Seventh Plan.

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[6] Some multifamily buildings include both in-unit water heaters and central systems that serve the common areas and non-residential portions of the building. The model will include all multi-family units served by in-unit water heaters, regardless of whether the building also has a central water heater for other non-residential uses. In the cases where multifamily building is served by both in-unit water heaters and central systems, the research team will attempt to confirm that the central systems serve only the non-residential portions of the building.

[7] Installing a HPWH in residential homes is listed as one of the energy-efficient options in both the WA and OR state residential building code (2015 Washington State Energy Code; R406.2 and 2017 Oregon Residential Specialty Code; Table 1101.2).

[8] Such as ENERGY STAR® New Construction requirements in the Pacific Northwest, which require heat pump water heaters as part of the program specification.

[9] The research team will verify fuel switching in both directions (gas to electric and electric to gas) prior to excluding from the model.

Unit of Account

The unit of account describes the metric by which the research team quantifies the market and basis for the model. As described previous, the hot water market includes a number of water heating efficiency technologies and hot water load technologies that the model must include to accurately characterize total residential hot water total consumption. To provide a consistent basis for modeling and analysis of the various technologies included in the scope, the team proposes to use households.[10] The team will define a saturation of technologies to each household in the region, which may vary based on climate zone, building types, or other factors.[11]

Question 2: How big is the market?

The first step in estimating energy use for the residential hot water market, as defined in Question 1, is defining the market size in the baseline year (2015) and in each plan year (2016-2021). The market size, in this case, consists of the installed stock (i.e., the number of units installed in residential homes[12]) of each in-scope technology in Oregon, Washington, Idaho, and Western Montana in a given year. As Equation 1 illustrates, the installed stock of a given technology in any year is the product of the number of each type of building and the saturation of that technology. The research team will segment this equation by efficiency level, building type, and other attributes to understand growth in certain segments compared to others.

Equation 1: Market Size

$$MarketSize_N(\#\ units) = TotalHomes_N \times Saturation_N$$

Where:

N = analysis year

The research team must, therefore, develop an estimate of the total number of homes and the saturation of each technology for each year of analysis. The method for calculating the market size will vary based on the data available for each technology. The following sections discuss the size of the market with respect to both water heating and hot water use technologies.

Estimating Market Size for Water Heating Efficiency Technologies

This section presents the methodology for estimating market size for water heating technologies, which is essentially equivalent to number of residential electric water heaters installed in the region.[13] For water

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[10] Households represents distinct dwelling units. That is one home for single-family detached and manufactured homes, the appropriate number of homes for multi-family attached homes (e.g. two for duplexes, three for triplexes), and units for larger multi-family buildings.

[11] See discussion of segments in question 3.

[12] Any reference to residential homes in this document refers to all building types included in the residential scope, as described in Question 1: single-family homes, manufactured homes, and multi-family units with in-unit water heaters.

[13] This includes the saturation of electric tankless water heaters and solar water heaters (with electric backup), although based on the significance of the saturations of these technologies the research team may decide to ignore these technologies in model implementation

heaters, the research team has primary information on the installed water heater stock saturations and number of homes in 2011, from the 2011 Residential Building Stock Assessment (RBSA). To apply this information to 2015 (the baseline year) and each of the plan years (2016-2021), the research team proposes to update the installed stock estimates captured in RBSA 2011 based on how the total housing stock and/or electric water heater saturation has changed over time. The research team proposes to use two primary methods to inform changes in market size for water heaters beyond 2011: (1) a detailed stock-turnover approach based on the additions and retirements of water heaters in each year; and (2) using the updated stock characteristics as captured in the RBSA 2016 data as a calibration point to validate the results from the stock-turnover method. The following section describes each of these methods.

Stock-Turnover Model

Estimating market size based on a stock-turnover approach allows for capturing all the factors that may affect total market size during the analysis period, including growth in the housing stock (new construction), higher saturations (i.e., increasing number of water heaters per home) in subsequent years from new construction or remodels, and retirements of failed equipment not replaced by a similar technology.[14] Equation 2 shows the calculation of market size based on all these factors.

Equation 2: Annual Market Size

$$AnnualMarketSize_{N}(\#\ units) = ExistingHomes_{N-1} \times Saturation_{N-1,Ex} + NewConstruction_{N} \times Saturation_{N,NC} - Retirements_{N} + Replacements_{N}$$

Where:

N = analysis year

Ex = existing homes

NC = new construction

Retirements and replacements are expressed as the number of units.

Using Equation 2, the research team can calculate the annual market size for each year of the analysis period and capture how the stock changes from year to year. This equation relies heavily on known product flow information (shipment data) as well as data from the RBSA. Developing estimates for each of the terms shown in Equation 2 requires primary data on (1) existing installed stock; (2) new construction

for the sake of simplicity. Pipe insulation is also a water heating efficiency technology, however, the team plans to capture the impact of pipe insulation as part of estimating the unit energy consumption for water heaters and the presence or absence of pipe insulation is not necessary to estimate market size.

[14] Typically, like-for-like replacement of failed technology is assumed unless there is a compelling reason to assume consumers are switching from one technology to another. In that case, the number of replacements is equal to the number of retirements and these values do not affect total market size. However, the number of retirements and replacements are still important to track because they affect the overall efficiency mix of the stock, as discussed in more detail in question 3.

estimates and the saturation of electric water heaters in new homes; (3) water heater lifetime; and (4) annual product shipments.

Existing Installed Stock. The team will calculate the installed stock of electric water heaters as shown in Equation 1 based on the total number of residential homes/units in 2011 and the RBSA 2011 saturation information. The research team proposes to use the RBSA 2011 estimates of the total number of single-family homes, manufactured homes, and multi-family buildings in 2011 as a preliminary basis for the total number of homes/units in the residential sector. The team will research the source of the RBSA 2011 housing stock estimates in 2011 and verify their accuracy against other available data sources during model development to ensure that the best available data is used.

New Construction Growth. The research team proposes using new construction growth estimates from the Seventh Plan for each building type of the three housing types: single family, manufactured homes, and multifamily units with in-unit water heaters. Because the stock-turnover model begins in 2011, the model will require data between 2011 and 2021 to describe the housing stock over the full analysis period.[15] The research team acknowledges that the Seventh Plan housing stock estimates are projections for the years 2016-2021, and more accurate information may be available to refine these estimates. The research team will explore the basis of the Seventh Plan housing stock estimates and collect additional data to inform the housing stock values based on actual housing permit and building growth information in future model sprints. The team will also develop estimates for the saturation of electric water heaters in new construction homes based on any available data from building permits, code or above-code program information, or other sources.

Water Heater Retirements and Replacements. Once the research team identifies the number of existing water heaters installed in the stock in 2011 and estimates the number of homes built from 2011 through 2021, the team will then estimate how the existing stock is changing due to water heater retirements and replacements over the same time period. To estimate the number of water heaters retiring in any given year, the team will rely on two key inputs:

1. **Characterization of equipment age of installed stock.** The number of water heaters in the stock that will fail in each year depends on the age distribution of water heaters in the stock. Accordingly, the research team proposes to develop an age distribution of the installed stock in the initial year of the stock turnover model (2011) based on the manufactured year captured in the 2011 RBSA information. The team will then forecast this age distribution to the baseline year (2015) and then for each of the plan years (2016-2021). The team will calibrate this to equipment vintage saturations observed in the 2016 RBSA.
2. **Estimate of the rate of existing stock turnover each year.** Water heater lifetime estimates determine the pace at which existing stock turns over each year. The research team will research data on lifetime estimates for the model. Primary data sources include the U. S. Department of Energy's (DOE) 2010 water heater rulemaking and the RTF heat pump water heater (HPWH) analysis workbook.

[15] While the Seventh Power Plan period consists of the years 2016 through 2021, the Seventh Power Plan contains estimates of new construction spanning back to 1985.

To estimate the number of water heaters being added to the stock as replacements for failed water heaters in any given year, the team will rely on annual shipments data. Shipments estimates in the stock turnover model comprise both replacement stock and new construction shipments. NEEA recently acquired annual water heater shipment information from major manufacturers for 2013-2016.[16] The research team proposes to compare these data to stock turnover shipment estimates to gain insight into water heaters attributable to fuel switching (gas to electric), as well as to corroborate overall stock turnover estimates.

RBSA Calibration

The upcoming RBSA 2016 will also provide critical primary data to characterize the installed stock. After the team has developed the stock-turnover approach to estimate market size for water heaters, they will then use the RBSA 2016 data as a calibration point to validate the detailed stock-turnover model. To do this, the research team will compare the stock turnover results to the RBSA 2016 saturation characteristics to confirm they agree within the bounds of uncertainty of both estimates.

Estimating Market Size for Hot Water Use Technologies

This section reviews the potential technologies that affect hot water use and proposes a method to estimate the market size for each technology. As shown in Table 3, the research team identified seven hot water use technologies, four of which will be modeled explicitly as primary technologies: showerheads, faucet aerators, clothes washers, and dishwashers.[17] Again, estimates of the market size are only necessary for primary technologies. Secondary technologies will be included in the model implicitly in the estimate of hot water baseload,[18] and the team will not model their market size or change directly.

Equation 1 also applies to hot water use technologies, where the total number of residential homes and a given technology's saturation in the installed housing stock determine its total market size in any given year. The total number of residential homes, including single-family homes, manufactured homes, and multifamily units with in-unit water heaters, is the same for water heating technologies and hot water use technologies. The team will therefore apply the same estimate of total residential housing stock developed for water heating technologies to all hot water use technologies. However, the method for estimating market saturation in each year will vary by hot water use technology based on available data and how much the stock is anticipated to change in the baseline.

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[16] The research team will continue to work with NEEA to collect annual shipments information throughout the analysis period (through 2021).

[17] The three hot water use technologies--circulator pumps, thermostatic restriction valves (TSRVs), and wastewater heat exchangers--are secondary technologies.

[18] The hot water baseload includes secondary hot water load technologies implicitly because it represents the saturation of all non-primary technologies and their contribution to overall hot water load as measured in 2011. By definition, secondary technologies do not change significantly over the analysis period (between 2011 and 2021), so the measured saturation and hot water load contribution in 2011 is assumed to be representative of the average contribution to hot water load during that time period. For more discussion of this concept and the derivation of the hot water baseload, see the discussion of "Annual Energy Consumption for Hot Water Load Technologies" in question 3 on pages 18-23.

Clothes Washers. The research team anticipates building a full stock-turnover model for clothes washers, like the approach described above for water heaters. The team will use detailed shipments data from NEEA's Retail Product Portfolio (RPP), estimates of equipment lifetime, and information on new construction growth to estimate the market size in each year of the analysis period. Additionally, BPA's existing clothes washer DOE standard model developed by Cadeo and Navigant in 2015 will provide many necessary inputs. As with water heaters, the research team will similarly use 2011 and 2016 RBSA data as calibration points to validate the stock turnover model results.

Showerheads, Faucet Aerators, and Dishwashers. The research team is not aware of reliable, current shipment or other market flow information for the remaining primary hot water use technologies. The 2011 and yet-to-be-released 2016 RBSA results are the only known available stock saturation data sources for the majority of hot water use technologies.[19] As such, developing a stock turnover model would require a significant number of assumptions that could not be validated by shipments or market flow data from another primary source. Researchers therefore propose to develop a simple stock-to-stock comparison to estimate annual market size for these technologies.

The simplest approach to estimating stock saturation for these technologies involves using the RBSA 2011 and RBSA 2016 results to establish a linear trend from 2011 to 2016 for the saturation of each technology. The number of installed units in a given year (i.e., the market size) can then be calculated by multiplying the assumed saturation in that year by the number of homes, based on the Seventh Plan residential housing stock estimates.[20] This approach is simple and robust, because it relies on measured data; however, it lacks granularity on market trends between measurement points and does not reveal why such trends might be occurring (e.g., increased new construction driving increased stock efficiency). In addition, it is not reliable to project such a trend to future years, so insights on market changes during the complete analysis period would depend on a future RBSA, presumably conducted in 2021.

One way to gain better insights into the saturation trends between analysis points could be to use additional existing data to develop rough estimates of the most significant market flow inputs. These market flow inputs could describe how and why the stock is changing (e.g., new construction additions, replacement behavior and rates, etc.). Existing data could include new construction growth and saturations, information on lifetime and replacements, and other sources of market flow data. Though it is not as robust as using shipments data, such information could provide greater clarity on how and why the stock is changing over time and improve the validity of market savings estimates between stock assessments and in future years, until an additional RBSA measurement point is available. However, the market data necessary to inform such an analysis may be limited and unreliable, and may introduce additional uncertainty to the model. If the markets of interest are changing slowly, such that 5-year measurement intervals are appropriate, the additional complexity inherent in a stock-turnover-style approach may not be worth it.

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[19] It is important to note that RBSA 2011 and RBSA 2016 do not collect information regarding TSRVs, wastewater heat exchangers, or circulator pumps for the market as defined in Table 3. Question 3 explains the approach for capturing the impact of those technologies on hot water.

[20] As noted above, the research team will validate and refine the housing stock estimates based on the best available data for all past years as the model is developed.

Recommended Path Forward. The research team will move forward with collecting data and developing a shipments-driven stock turnover model to estimate market size for clothes washers. For all hot water use technologies that lack shipments data (i.e., showerheads, faucet aerators, and dishwashers), the research team will initially develop a simple linear stock-to-stock comparison model based on RBSA 2011 and RBSA 2016 (when published) to characterize the market size and changes in market size over the analysis period. Based on that preliminary assessment, the research team will evaluate the need for more complex modeling options and additional data inputs. If rapid market changes warrant more comprehensive market flow data, the research team will provide BPA with recommendations for how to collect data that better inform the stock change assumptions.

Table 4 summarizes the proposed approaches for estimating market size for each primary hot water use technology.

Table 4: Summary of Proposed Approaches for Estimating Market Size for Each Primary Hot Water Use Technology

Technology	Initial Market Size Approach	Data Sources
Showerheads	Simple stock comparison	RBSA 2011 and 2016
Faucet Aerators	Simple stock comparison	RBSA 2011 and 2016
Clothes Washers	Shipments-driven stock turnover	NEEA RPP shipments data, calibrated based on RBSA 2011 and 2016
Dishwashers	Simple stock comparison	RBSA 2011 and 2016

Question 3: What are the total market savings?

Total market savings represent the difference between baseline energy consumption and actual energy consumption in aMW. The baseline is informed by the installed stock and efficiency mix in the year the Power Plan was written (2015). The research team will develop the actual energy consumption using the installed stock and efficiency mix in each year of the analysis period (2016-2021).

The first step in estimating total market savings is developing a method to estimate energy consumption for the residential water heater market (as defined in Questions 1 and 2) in a given year. The research team will then apply this method to both the baseline and actual scenarios to estimate energy consumption in the baseline and actual cases, respectively, for each year of the analysis period. To arrive at total market savings, the team will then compare the baseline energy consumption to the actual case energy consumption for each year of the analysis period.

Calculating Annual Energy Consumption

Energy consumption refers to the annual energy usage of the total market, as defined by Questions 1 and 2 (i.e., the energy consumed by all residential water heaters in the Northwest, as it is affected by regional hot water use).

Two primary factors drive energy consumption in the residential hot water market: (1) the “efficiency” of the water heating equipment in producing and delivering hot water; and (2) the amount of hot water used.

- **Water heating efficiency.** This represents the amount of energy needed to heat a gallon of hot water to the desired temperature. The research team notes that this is not efficiency in the purest sense of the term, but rather a normalized consumption value; it describes the input energy (in kWh) over the useful output (in gallons of hot water).[21] Regardless, the research team uses the term **water heating efficiency** to describe this normalized consumption value, largely because the primary driver of water heating efficiency is the efficiency of the water heater. The presence or absence of pipe insulation on the exposed pipes near the water heater also impacts the efficiency of a water heater, especially the standby losses. As such, the research team considers pipe insulation to be a driver of water heating efficiency.[22]
- **Hot water use.** This is the amount of hot water (gallons) consumers require. A number of factors affect hot water use:
    - The number of household members
    - The efficiency and presence of water-consuming appliances, such as clothes washers and dishwashers
    - The efficiency and presence of water-dispensing devices, such as faucet aerators and showerheads
    - Inlet supply water temperature[23]

The amount of hot water used will vary over time for a given household, based on the efficiency of the associated hot water use technologies (controlling for occupancy).

It is thus important that the resulting model accurately characterizes changes in hot water use and water heating efficiency independently and capture their interaction. This means the model must account for potential changes in hot water use technologies and the resulting change in regional hot water use. In addition, the model must accurately account for the change in water heating efficiency accurately in order to characterize total water heating electric consumption and the impact of any changes in hot water use.

Equation 3 demonstrates the general proposed methodology, which separately calculates: (1) the energy associated with providing a gallon of water (kWh/gal) at a specific temperature and (2) the total hot water consumption (gallons of hot water).It then multiplies these two quantities together to arrive at total annual energy consumption in a given year. Note that the product of these two values (i.e., water heating efficiency and hot water load) represents the annual energy consumption in one household, since the

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[21] Efficiency is defined as the ratio of useful output over energy input and is presented as a percent.

[22] The research team realizes that pipe insulation can also be added throughout the distribution system, not just on the exposed pipes immediately adjacent to the water heater. Whole-house pipe insulation and other issues related hot water distribution and delivery, such as plumbing layout, pipe sizes, and pipe location (i.e., conditioned or unconditioned space) are issues that primarily affect the volume of hot water used, rather than the efficiency of heating it. For example, less insulated pipes or longer pipe runs will lead to higher hot water draws due to faster cooling of water in the pipes and a larger volume of structural waste. As such, the research team proposes to consider these issues in the development of the hot water load; specifically, in the technology-specific UWCs and baseload.

[23] Inlet supply water temperature affects both the water heating efficiency, because it affects how much the water must be heated to reach a desired outlet temperature, as well as hot water use, because it affects how much hot water you need to mix with cold water to reach the desired mixed water temperature at the fixture.

water heating efficiency and hot water load may vary from house to house based on a number of factors. Total annual market energy consumption is the sum of annual energy consumption for each house in the region, as shown in equation 3.

Equation 3: Annual Energy Consumption

$$\text{Annual Energy Consumption}_N(\text{kWh/yr}) = \sum_h \left(\text{Water Heating Efficiency}_{h,N}(\text{kWh/gal}) \times \text{Hot Water Use}_{h,N}(\text{gal/yr})\right)$$

Where:

h = all households in the stock

N = analysis year

The subsequent sections discuss how the research team will calculate water heating efficiency and hot water use in the baseline and actual case in each year of the analysis period (2015-2021).

Unit Energy Consumption for Water Heating Efficiency Technologies

Water heating efficiency describes the energy needed to heat a gallon of hot water to the desired temperature in a given household. This value is characterized in units of kWh per gallon.

Water heating efficiency in any given year is described by a normalized unit energy consumption value (UEC), which varies based on a number of factors, including climate zone, building type, installation location, volume, the presence of pipe insulation, and efficiency level. As shown in Equation 4, each of these unique cases (i.e., unique combination of climate zone, building type, installation location, etc.) is referred to as a "segment" of the installed housing stock. The research team will define separate UEC values for each segment of the installed stock to account for energy consumption variations between segments. Each of these segments is described in more detail below.

Equation 4: Unit Energy Consumption Variation

$$\text{Water Heating Efficiency}_s\ (\text{kWh/gal}) = \text{StockSaturation}_{c,b,i,v,p,e} \times \text{UEC}_{c,b,i,v,p,e}$$

Where:

s = segment of the installed stock (i.e., household with unique combination of climate zone, building type, installation location, water heater volume, pipe insulation, and efficiency level)

c = climate zone, designated in the Seventh Plan as three heating zones and three cooling zones for nine total climate zones

b = building type (i.e., single family, manufactured home, or multifamily unit)

i = installation location (i.e., conditioned or unconditioned space)

v = water heater volume

p = adjacent pipe insulation (i.e., pipes are insulated or they are not)

e = efficiency level of the water heater

Climate Zone. The energy consumption and efficiency of water heaters is affected by the temperature surrounding the water heater, especially for HPWHs, and the required temperature rise for the supply water to the temperature set-point of the water heater. The outdoor air temperature influences the temperature surrounding the water heater for water heaters in unconditioned spaces (e.g., garages and basements). The inlet supply water temperature and the outdoor air temperature both vary by climate zone. The research team plans to use the climate zones designated in the Seventh Plan, which relied on three heating zones and three cooling zones.

Building Type. Building type does not directly affect water heating efficiency; however, the number of water heaters in each installation location, the typical tank volume, and other factors may vary based on building type. For example, smaller water heaters may be more common in multi-family units. The research team plans to account for these variances by differentiating the installed stock of water heaters based on building type and defining unique climate zone, installation location, and water heater volume distributions based on the building type.

Installation Location. The installation location affects the UEC of the water heater because it affects the surrounding air temperature and the impact of the water heater on HVAC energy consumption.[24] While the installation location can be very specific (e.g., garage or basement) the research team proposes to simplify the analysis by classifying location as either conditioned or unconditioned, since this is the primary driver for differences in energy consumption.

Water Heater Volume. Water heater volume affects the efficiency of the water heater in a number of ways[25] and can range from zero gallons for tankless water heaters (uncommon) to approximately 85 gallons for residential water heaters. Water heater volumes, however, are typically 40 to 80 gallons in size, so the research team will disaggregate water heaters into two general volume segments, consistent with DOE's treatment of storage water heaters in the federal standards:[26]

- ≤55 gallons
- >55 gallons

These volume bins are consistent with the treatment in the HPWH RTF measure analysis and NEEA's shipments data.

Pipe Insulation. Pipe insulation affects how much energy it takes to produce and deliver hot water. The research team anticipates modeling UECs separately for cases with and without pipe insulation for each water heater segment, as applicable.

Efficiency Level. The UEC of the water heater obviously varies by efficiency level. The biggest contributor to water heater efficiency is whether or not the water heater uses electric resistance elements or a heat pump to heat the water. There are multiple efficiency levels available for both electric resistance and heat pump technologies. Water heater efficiency is typically described in terms of a Unified Energy Factor (UEF) based on the Federal test method[27] and NEEA defines efficiency tiers for HPWH in their Advanced Water

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[24] See the HVAC Interaction Factor section on page 22 for discussion on how this residential hot water model will address HVAC interaction.

[25] Tank volume affects both standby energy losses and the recovery efficiency of HPWH as described in more detail in the UEC section, below.

[26] 10 CFR 430. 32(e)

[27] 10 CFR 430.23€

Heater specification. The research team will evaluate the appropriate number of efficiency levels for the model during future model development efforts.

The research team will rely on the latest data and information available from the RTF HPWH measure analysis, the DOE residential water heater rulemakings, and other relevant sources to develop the UECs for water heating efficiency.

Specifically, the team will develop water heater UECs for each segment based on the Simplified Energy Enthalpy Model (SEEM)[28] output for each segment, as presented in the forthcoming RTF HPWH workbook.[29] SEEM's HPWH model includes recent HPWH models and space conditioning interactions and has been validated by field research (HPWH Model Validation Field Study).[30] SEEM provides an output in terms of kWh/yr, based on a statistically representative draw pattern and average hot water draw volume, developed using the same HPWH Model Validation Field Study.[*Id.*]

The research team will modify the SEEM output to develop UEC cases with and without pipe insulation, based on the demonstrated efficiency improvement in the BPA-Qualified Measure memo.[31] This approach allows for the most accurate accounting of efficiency improvements from pipe insulation, since the efficacy of pipe insulation is based on the efficiency of the water heater itself; that is, the presence of a heat trap reduces standby losses and heat transfer from the water to the adjacent piping. The granularity of the approach also enables greater precision and reduces ambiguity when determining the impact of pipe insulation and any changes to the market penetration of pipe insulation over time.

Another approach would be to embed the weighted average impact of pipe insulation in water heater efficiency UEC for each water heater segment. However, while it is more straightforward, such an approach would be more difficult to update and compare to estimates of program savings associated with pipe insulation. Therefore, the research team does not recommend the embedded approach.

As described previously, the total energy consumption is influenced by both water heating efficiency and hot water use. In addition, some portions of water heater efficiency change significantly as a function of hot water use (i.e., the efficiency of the heating element or recovery efficiency), while some do not (i.e., standby efficiency[32]). To capture this dependency, the research team proposes to develop a linear

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[28] The SEEM program is a building simulation model designed to assess small scale residential building energy use in the Pacific Northwest. The program consists of an hourly thermal simulation and an hourly moisture (humidity) simulation that interacts with duct specifications, equipment, and weather parameters to calculate the annual heating and cooling energy requirements of the home. See https://rtf.nwcouncil.org/simplified-energy-enthalpy-model-seem

[29] Forthcoming. The HPWH measure workbook is currently being revised and is anticipated to be presented at the January 2018 RTF meeting.

[30] Ecotope, Inc., "Heat Pump Water Heater Model Validation Study," Rep. Northwest Energy Efficiency Alliance (NEEA). March 2, 2015. Available at: https://neea.org/docs/default-source/reports/heat-pump-water-heater-saving-validation-study.pdf?sfvrsn=8

[31] SBW Consulting, Inc., "Measure Analysis Summary: Residential Water Pipe Insulation," Rep. Bonneville Power Administration, July 12, 2013.

[32] The research team acknowledges that while standby efficiency (i.e., the amount of insulation on the water heater) does not vary as a function of hot water use, the actual energy associated with standby losses may vary as a function of hot water use due higher use being associated with a lower average tank temperature. The team will explore the significance of this relationship and potentially develop a method for addressing it in the model, if warranted, during future model development stages.

equation for each water heating efficiency level. The equation will model the energy consumption as a function of hot water use, based on the recovery efficiency and standby losses of the water heater, as shown in Equation 5. The team will develop the linear equation coefficients based on the methodology and analysis that DOE used to model water heaters in the 2010 rulemaking, which provides a method for translating energy factor (EF) or uniform energy factor (UEF) to recovery efficiency and standby losses.[33]

Equation 5: Unit Energy Consumption Calculation

$$UnitEnergyConsumption_{c,b,i,v,p,e} = RecoveryEfficiency_{c,b,i,v,p,e} \times HotWaterUse_{c,b} + StandbyLoss_{c,b,i,v,p,e}$$

Where:

c = climate zone, designated in the Seventh Plan as three heating zones and three cooling zones for nine total climate zones

b = building type, i.e., single family, manufactured home, or multifamily unit

i = installation location, i.e., conditioned or unconditioned space

v = water heater volume

p = pipe insulation, i.e., pipes are insulated or they are not

e = efficiency level of the water heater

For electric resistance water heaters, recovery efficiency does not vary based on hot water use, so it is possible to use a single equation to describe the relationship between annual energy consumption and water heater use. The research team will normalize the total energy consumption value in Equation 5 based on hot water use to create the UEC values (in kWh/gal) for electric resistance water heaters.

For HPWHs, however, water heater recovery efficiency varies based on hot water use, due to the variable use of back-up electric resistance elements in many hybrid HPWHs.[34] The research team will develop unique linear equation coefficients for different draw volume bins to accurately represent the varying efficiency of HPWHs based on hot water use. Table 5 presents hypothetical hot water use volume bins to illustrate the proposed method associated with Equation 5. The recovery efficiency will be different for each hot water volume use bin, but the standby losses will be the same. The research team will develop the precise number and range of the hot water use volume bins during future modeling efforts.

[33] DOE, "Energy Conservation Program: Energy Conservation Standards for Residential Water Heaters, Direct Heating Equipment, and Pool Heaters – Final Rule." 75 FR 20112. April 16, 2010. Available at: https://www.regulations.gov/document?D=EERE-2006-STD-0129-0005.

[34] Ecotope, 2015. Heat Pump Water Heater Model Validation Study. Northwest Energy Efficiency Alliance (NEEA). Portland, OR. Available at: https://neea.org/docs/default-source/reports/heat-pump-water-heater-saving-validation-study.pdf?sfvrsn=8

Table 5: HPWH UEC Hot Water Use Volume Bins (Hypothetical)

Efficiency Level Bins	Hot Water Use Volume Bins
HPWH Tier 1 & 2	<20 gallons/day
HPWH Tier 3 & 4	20 to 40 gallons/day
	>40 gallons/day

The research team plans to compare the total water heating energy consumption for each water heater segment that results from this methodology to measurements of water heater energy use from the 2011 RBSA Metering Report, HPWH Model Validation Field Study, and any other available measurements of water heater energy consumption[35] to validate the total energy use in a given year.

Unit Water Consumption for Hot Water Use Technologies

The magnitude of hot water use, in gallons per year, drives the energy consumption of residential water heaters. The water heater technology only determines how efficiently the load is served. The research team must therefore quantify the gallons of hot water used in each household to determine the water heating energy consumption in that household and of the total market. Similar to water heating efficiency, the hot water use for each technology in a given year is the product of the saturation of hot water use technologies in the housing stock by segment, multiplied by the unit water consumption (UWC) for each segment. The total hot water use is the sum of the hot water use of each technology in a given segment (or unique household), as Equation 6 illustrates.

Equation 6: Hot Water Use

$$\text{HotWaterUse}_s \text{ (gal/yr)} = \sum_t \left(\text{StockSaturation}_{t,c,b,e} \times \text{UWC}_{t,c,b,e}\right)$$

Where:

- *s* = segment of the installed stock (i.e., household with unique combination of climate zone, building type, installation location, water heater volume, pipe insulation, and efficiency level)
- *c* = climate zone, designated in the Seventh Plan as three heating zones and three cooling zones for nine total climate zones
- *t* = hot water use technology, e.g., showerheads
- *b* = building type, e.g., single family or manufactured
- *e* = efficiency level

The team does not anticipate needing as many segments and associated UWC values as the water heating efficiency analysis required (e.g., climate zone, storage volume, installation location, etc.). For hot water

[35] Other smaller field studies or the upcoming NEEA End-Use Load Research (http://neea.org/get-involved/end-use-load-research) may provide additional sources of data for validation.

use, the team only anticipates requiring segments based on the climate zone, building type, and efficiency level for each technology. The team will, however, analyze any basis for differing water consumption among hot water use technology segments in future model development efforts and will develop unique UWCs for any justifiable segments.[36]

Climate Zone. The inlet supply water temperature impacts the total amount of hot water needed to generate a given mixed water temperature, which in turn impacts the total hot water use in a given household. For example, less 120 ^{o}F water is necessary to mix with 65 ^{o}F water to generate a mixed water temperature of 105 ^{o}F than would be required if the inlet supply water was 50 ^{o}F. As described previously, the inlet supply water temperature varies by climate zone. The research team plans to use the climate zones designated in the Seventh Plan, which relied on three heating zones and three cooling zones.

Building Type. As was the case for water heating efficiency, building type does not *directly* affect hot water use; however, the saturation of technologies or efficiency mix may vary based on building type. The research team plans to account for these variances by differentiating the installed stock of households based on building type and defining unique climate zone, installation location, and efficiency level distributions based on the building type.

Efficiency Level. UWC represents the gallons of hot water associated with each technology and segment, which the water heater must heat to a specified temperature.[37] The UWC of the water heater varies by efficiency level for a given technology. For example, showerheads with a flow rate of 2.5 gallons per minute (gpm) may have a higher UWC value than 2.0 gpm showerheads.

Calculating the UWC for each hot water use technology is, however, challenging due to data gaps for most secondary technologies (i.e., circulators, thermostatic restriction valves and wastewater heat recovery). It is also unnecessary because, by definition, water usage associated with secondary technologies is not likely to change significantly over the analysis timeframe.[38] Instead, the research team proposes to use two components to represent hot water use: (1) the stock and UWC of primary technologies by segment; and (2) the baseload hot water use, which represents the water consumption associated with secondary technologies. Equation 7 illustrates this calculation.

Equation 7: Calculating Hot Water Use for Primary and Secondary Technologies

$$\text{HotWaterUse}_s\ (\text{gal/yr}) = \sum_t \left(\text{StockSaturation}_{t,c,b,e} \times \text{UWC}_{t,c,b,e}\right) + \text{Baseload}_{c,b}(\text{gal/yr})$$

Where:

- *s* = segment of the installed stock (i.e., household with unique combination of climate zone, building type, installation location, water heater volume, pipe insulation, and efficiency level)
- *c* = climate zone, designated in the Seventh Plan as three heating zones and three cooling zones for nine total climate zones

[36] Unique UWC (or UEC) values are justified for any segment for which water (or energy) use varies from other segments.

[37] Note that regional differences in the temperature differential required to reach a given water heater set point based on variation in inlet water temperature is captured in the UEC calculation for each climate zone.

[38] See Question 1 for a discussion on the categorization of primary versus secondary technologies.

t = primary hot water use technology

b = building type (e.g., single family or manufactured home)

e = efficiency level

The equation sums the hot water contribution of each primary technology to determine the total hot water consumption associated with these primary technologies, which will likely vary in each year of the analysis period. The baseload represents the contribution of secondary technologies to overall residential hot water use. In addition, there are some attributes of hot water distribution and use (e.g., plumbing leaks, bath tubs, whole-house piping, and plumbing layout) that are not well characterized, are not addressed by utility programs, and are not expected to significantly impact total residential hot water use over the analysis timeframe. The research team also proposes to capture the impact of these "secondary" technologies in the baseload.

The following sections describe how the team proposes to develop the UWCs and the baseload.

UWCs. The research team will develop UWC values to quantify the hot water use (gal/yr) for each primary hot water use technology and segment (i.e., efficiency level and building type). For example, the team will develop estimates of hot water use for showerheads by building type (i.e., single family, manufactured homes, and multifamily) for efficiency levels (flow rates) of >2.5 gallons per minute (GPM), 2.0 to 2.5 GPM, and 1.5 to 2.0 GPM. The research team will determine the specific number of efficiency levels for each technology in subsequent model development efforts.

The method for calculating the UWC will vary by technology. The research team will develop UWC values based on the assumptions and analysis contained in the Seventh Plan analysis and RTF workbooks for each primary hot water use technology, as applicable, as well as other available evaluations, research data, or savings estimates. The team will not use the RTF savings estimates directly, as the RTF values typically represent energy savings associated with a given technology (as opposed to water consumption) and may include assumptions and weightings associated with HVAC interaction and average water heater savings different than those used in the water heating efficiency and HVAC interaction analysis components of this model.[39] Instead, the team will assess and incorporate the same fundamental assumptions to develop engineering estimates of the typical **water use** associated with a given technology and efficiency level that are consistent with the RTF analysis and methodology. Table 6 summarizes key variables, assumptions, and data sources for each primary technology.

[39] See discussion of water heating efficiency and HVAC interaction model components on pages 15-19 and 24-25, respectively.

Table 6: UWC Key Variables, Assumptions, and Data Sources for Primary Hot Water Use Technologies

Technology	Efficiency Level	Key Variables & Assumptions	Primary data sources
Showerheads	Flow rate (GPM)	Actual/rated flow Primary and secondary status Percent hot water Shower duration Number of showers (per year, per person) Occupancy	RTF workbook Residential End Uses of Water (REUWS) 2016[40] California Energy Commission showerhead analysis Other evaluations
Faucet Aerators	Flow rate (GPM)	Actual/rated flow Fixture location Percent hot water Event duration Events (per year, per person)	Seventh Plan Energy Trust of Oregon Blessing Memo Cadmus Michigan Evaluation Other evaluations
Clothes washers	IWF	Clothing washed per year (pounds per year) IMEF adjustment based on field research[41]	RTF workbook NEEA Clothes Washers research (cite)
Dishwashers	Water factor (WF)	Cycles per year, average mode selection	RTF Dishwashers Workbook DOE 2016 Dishwashers rulemaking

The research team will verify the reasonableness of the UWC values determined for each technology and segment by comparing the calculated hot water use from each technology based on the UWC to actual measured load in 2011, as recorded in the 2011 HPWH Model Validation Field Study.

The HPWH Model Validation Field Study accompanied the RBSA 2011 metering effort, and measured hot water use in 99 residential single-family homes throughout the Northwest with a mix of electric water heaters (both electric resistance and heat pump). NEEA selected the homes in the study based on their

[40] Aquacraft, Inc. Water Engineering and Management, "Residential End Uses of Water, Version 2." Rep. Water Research Foundation, April 2016.

[41] NEEA has done extensive research regarding real-world clothes washer energy use and has developed adjustments to the rated Integrated Modified Energy Factor (IMEF) and Integrated Water Factor (IWF) values to better reflect field consumption and usage characteristics (cite).

representativeness of single-family homes in the Northwest. These selections also represented a range of climate zones, occupancies, and home vintages.

To validate the UWC values, the research team will estimate the contribution to total hot water use from each technology in 2011 by using the UWC values developed during the engineering analysis, as well as the saturation and efficiency mix of technologies in the 2011 HPWH Model Validation Field Study homes and compare this to the total measured load from the HPWH Model Validation Field Study. This will allow the research team to determine the percentage of measured load associated with each primary hot water use technology (e.g., showerheads, faucet aerators, clothes washers, and dishwashers). The research team can compare this calculated relative contribution from each primary technology to the relative contribution from the literature (e.g., REUWS 2016) to confirm the reasonableness of the UWC assumptions. The research team realizes this is not a robust calibration approach; it is, however, the best validation approach available based on the data. More rigorous validation would require disaggregated monitoring of hot water uses to compare to the engineering estimates, which has not been done at a large scale for this region. To the extent that limited, technology-specific hot water usage measurements are available, the research team will use them to develop and validate UWC estimates, as applicable.

Determination of the Hot Water Baseload. The determination of hot water use in any given year also comprises hot water baseload that represents all the technologies and building characteristics not explicitly modeled as primary technologies (i.e., secondary technologies). The research team assumes this baseload hot water use is not changing significantly over the analysis period on a per capita basis. While developing the baseload during the model building phase, the research team will evaluate any additional variables, beyond occupancy, that may impact the baseload over time and, if possible, account for them in the model.

An assumption of constant per capita baseload consumption means that the hot water use associated with all secondary technologies is not changing significantly over the analysis period. As discussed above, the team will evaluate the list of technologies categorized as secondary technologies by comparing the RBSA 2011 and RBSA 2016 reported efficiency mixes for each technology and verifying the extent and impact of any observed market change. For example, a dramatic increase in wastewater heat recovery installations could indicate it should be a primary technology and should be modeled directly, instead of included in the baseload.

To determine baseload hot water use, the research team will rely on the measurement of average regional hot water use (gal/yr) observed in the HPWH Model Validation Field Study. The team will determine the baseload by subtracting the calculated hot water use for each primary technology in 2011 from the measured 2011 hot water use. The team will determine the calculated hot water use from each technology based on the saturation and efficiency mix of technologies in 2011,[42] multiplied by the UWC for each technology and efficiency level. The team will determine the hot water baseload for single family homes first, because the HPWH Model Validation Field Study data represents that building type.

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[42] The assumed efficiency mix when determining the baseload will be designed to match the HPWH Model Validation Field Study homes as closely as possible.

Equation 8: Baseload Hot Water Consumption

$$\text{Baseload}_{2011}(\text{gal/yr}) = \text{MeasuredTotalHotWaterLoad}_{2011}(\text{gal/yr}) - \sum_{t,c,b,e}\left(\text{StockSaturation}_{2011,t,c,b,e} \times \text{UWC}_{t,c,b,e}\right)$$

Where:

t = primary hot water use technology

b = building type, i.e., single family

c = climate zone

e = efficiency level

The team will attempt to validate the reasonableness of the baseload results based on the REUWS 2016 and any other available data.

The research team will then normalize the baseload for single-family homes in terms of occupancy, based on the single-family occupancy observed in the HPWH Model Validation Field Study. Based on the analysis, this relationship may be a ratio or a linear equation; the team will determine the exact form of the occupancy relationship during future modeling efforts. Based on the relationship between baseload and occupancy, the team can then translate the single-family baseload to other building types based on the difference in occupancy among the building types. The team will attempt to verify the baseload estimates for manufactured housing and multifamily building types using any available measured hot water use data from those building types.

HVAC Interaction Factor

Though it is not a direct component of residential hot water energy consumption, it is important to note that several of the technologies the model addresses have secondary impacts on space heating and cooling energy consumption. Notably, HPWHs installed in conditioned spaces use heated air to heat water, which increases space conditioning load in the heating season and decreases air conditioning load in the cooling season. Table 7 summarizes the source of the interaction and impact (i.e., the ratio of change in HVAC energy consumption over the change in water heater energy consumption, in percent) for all technologies. Note that only water heating efficiency measures interact with HVAC in a measurable way;[43] hot water use measures are shaded in the table and will not be modeled directly.

[43] The research team realizes that reductions in hot water load may result in slightly reduced hot water losses, some of which enter conditioned space and serve to heat the conditioned space. Therefore, hot water end-use technologies (i.e., showerheads and faucet aerators) may also have a small impact on HVAC loads. However, we anticipate that this impact will be insignificant given the inherent model uncertainty and do not anticipate modeling these directly. The research team will analyze this impact in developing the hot water end-use UWCs and consider developing analogous HVAC UECs if warranted.

Table 7: Summary of HVAC Interaction

Technology	Source of Interaction	Magnitude of Interaction (ΔHVAC kWh/ΔWH kWh x 100%)
Water Heaters (HPWH)	HPWH in conditioned space use heated air to heat water	Approximately 11 to 32% (depends on HVAC type)[1]
Pipe Insulation	Reduced pipe losses in conditioned space	19%[2]
Circulator Pumps	Reduced hot water recirculation reduces domestic hot water losses for pipes in conditioned space	Approximately 16 to 18%[3]

[1] RTF HPWH Workbook, v3.4
[2] BPA Pipe Insulation Qualified Measure memo; RTF value from efficient tanks measure - RTF Efficient Tanks Workbook, v3.0
[3] RTF Circulator Pump Workbook, v1.2

While, HVAC is not within the scope of the residential hot water energy consumption model, this secondary interaction is embedded in the estimates of regional utility program reported savings. Therefore, it is important to characterize HVAC interaction to compare program savings estimates for the model to those reported in the Regional Conservation Potential (RCP) data annually. In addition, the impact of these water heating measures on total residential load, inclusive of this HVAC component, is also a potentially important aspect to consider for regional load forecasting. Therefore, the research team proposes to develop an estimate of HVAC impact associated with any modeled market savings in residential hot water use.

The program savings analyses for each measure characterize the interaction of hot water measures with HVAC, as well as the direct water heater energy savings. Specifically, the RTF analysis supporting the HPWH measure and the BPA Qualified Measure analysis for pipe insulation provide the necessary detail and assumptions to effectively estimate the HVAC interaction for each measure and disaggregate water heating and HVAC components of the savings estimates. Based on these data, the research team will estimate an HVAC UEC, in terms of kWh/gal, to accompany each unique water heating UEC.

The research team will employ the same analysis approach described above for determining total water heating efficiency to determine the total HVAC interaction in any given model year. That is, the team will multiply the HVAC UECs by the total water heater stock, by segment, to determine the HVAC impact as a function of hot water use in a given year. The team will multiply the resulting value by the hot water use in that year to determine the total HVAC impact in a given year.

The research team also considered a simpler approach that applies HVAC interaction factors (percentages) to the total energy consumption results. However, due to the dependency of HVAC interaction on water heater efficiency level, building type, HVAC system type, installation location, and hot water use, it is necessary to embed the HVAC interaction calculations in the model on a per-segment basis to accurately account for the impact of water heaters and residential HVAC load.

Calculating Total Market Savings

The difference between the baseline energy consumption and the actual energy consumption determines total market savings in each year of the analysis period. Therefore, to estimate total market savings in any given year, the research team must answer the following two questions:

- Question 3a: What was the energy use in the year the Power Plan was written?
- Question 3b: What was the actual energy use in the subsequent years?

To determine the energy consumption in the baseline and actual cases in each year, the team will multiply the efficiency mix in the stock by a UEC value (for water heating technologies) or a UWC value (for hot water use technologies) that is unique to each technology, efficiency level, and segment.[44] The water heating efficiency and hot water load will then be multiplied together for each segment and then summed over all households and segments to determine the total annual energy consumption in a given year. Equations 9a and 9b illustrate how to calculate energy use in any given year in the baseline and actual cases, respectively.

Error! Reference source not found. Where:

h = household in the installed stock

s = segment of the installed stock (i.e., household with unique combination of climate zone, building type, installation location, water heater volume, pipe insulation, and efficiency level)

c = climate zone, designated in the Seventh Plan as three heating zones and three cooling zones for nine total climate zones

b = building type (e.g., single family or manufactured home)

i = installation location (i.e., conditioned or unconditioned space)

v = water heater volume

p = adjacent pipe insulation (i.e., pipes are insulated or they are not)

EfficiencyMix = saturation in the installed stock of different efficiency levels in the baseline or actual case (previously shown as $StockSaturation_e$)

t = primary hot water use technology

e = efficiency level

The stock of each technology in both Equations 9a and 9b is defined in Question 2, the market size. The UEC, UWC, and Baseload values are described previously in Question 3, "Calculating Annual Energy Consumption."

The driver of total market savings—and the only variable the team will not hold constant between the base case and actual case—is the efficiency mix of equipment in the installed stock. In other words, the

UEC and UWC values and the stock, both in terms of number of units and segments (besides efficiency), will be the same in both the baseline and actual cases; only the efficiency mixes in the stock will vary.

This method of holding everything constant except the efficiency mix allows for the most straightforward and accurate comparison of the market to a fixed baseline efficiency mix. In this method, the baseline represents business-as-usual efficiency practices, but reflects the same market size growth observed in the actual case.

In the baseline year (2015), the market savings are zero because the baseline and actual case efficiency mixes are the same. In future years (2016-2021), the baseline efficiency mix remains equivalent to the efficiency mix of equipment assumed in the Seventh Plan baseline, while the actual efficiency mix changes to reflect the observed efficiency mix in the stock in each year. The specific method for determining the baseline and actual efficiency mix will vary based on the modeling approach and the data available for each technology. The subsequent sections discuss the derivation of the baseline efficiency mix for water heating efficiency and hot water use, then the derivation of the actual efficiency mix.

Baseline Efficiency Mix

As described above, the efficiency mix is the only variable that changes between the baseline and actual cases. The baseline efficiency mix represents business-as-usual efficiency practices and is equivalent to efficiency mix of equipment in the year the Power Plan was written for all technologies. However, based on the available data, modeling approach, and assumptions in the Seventh Plan baseline, the method for determining the baseline efficiency mix will vary for each technology.

Water Heating Efficiency. The baseline efficiency mix for water heating efficiency includes the baseline efficiency mix for both water heaters and pipe insulation. For water heaters, the Seventh Plan baseline for water heaters assumes that the current practice efficiency mix of **shipments** in 2015 is constant over the entire analysis period (2015-2021). The efficiency mix of the baseline stock, however, gets more efficient over time because the efficiency distribution of shipments in the baseline is more efficient than the existing stock. Therefore, the natural replacement of older water heaters with current market practice shipments will increase the efficiency of the stock in the baseline case. As in Question 2, the team will employ the same stock turnover model used to define the market size to develop the efficiency mix, based on data from RBSA 2011, RBSA 2016, and NEEA shipments data in 2015. The RBSA 2011 will define efficiency of existing units in 2011 and the NEEA data will describe the efficiency of units added to the stock each year. RBSA 2016 will provide an observation of the efficiency of the total stock in 2016 and will be used to calibrate the shipments model in that year. In other words, RBSA 2016 will be used to validate the trends resulting from the shipments data.

The Seventh Plan does not address pipe insulation; thus, no baseline assumptions exist. Therefore, for pipe insulation, the research team will overlay pipe insulation saturation information on the water heater stock efficiency mix based on the observed saturation captured in RBSA 2016. The research team anticipates holding the saturation of pipe insulation constant in the baseline case efficiency mixes based on the saturation of pipe insulation observed in RBSA 2016. The research team assumes the RBSA 2016 saturation information for pipe insulation is generally representative of the analysis period. The saturation may, however, require adjustment based on the significance of reported program savings. As such, the team may backcast and forecast data based on new construction and replacement rates (assuming new construction and replacement water heaters receive insulation with the new water heater installation).

Hot Water Load. For hot water load technologies, similar to water heater efficiency, the baseline efficiency mix is intended to represent business-as-usual efficiency practices, and it should be equivalent to the baseline from the Seventh Plan.

For clothes washers, consistent with the Seventh Plan, the research team plans to use a frozen **shipments efficiency mix** in the baseline based on the regional shipments data available from the NEEA RPP program in 2015. This will result in a changing stock efficiency over time in the baseline case, based on the average lifetime and replacement cycles of the equipment.

Information on the efficiency mix of current practice shipments in the baseline (i.e., 2015) is largely unavailable for other primary hot water use technologies (i.e., showerheads, faucet aerators, and dishwashers). Therefore, the team cannot assume a constant baseline shipments efficiency mix. These technologies rely on a simple stock comparison to estimate market size in Question 2. Similarly, the team proposes to use the **stock efficiency mix** in 2015, determined through RBSA 2011 and RBSA 2016 observations, as the baseline efficiency for these hot water use technologies. The research team proposes to initially assume that the baseline stock efficiency will be constant over the analysis period (i.e., the stock efficiency mix in 2021 is equal to the stock efficiency mix in 2015).

The research team realizes that this may slightly overstate baseline energy consumption—and subsequently market savings—because it does not account for the natural replacement of older equipment with current market practice efficiency technology. However, this is consistent with the Seventh Plan, which assumes a static stock efficiency in the baseline case for showerheads and faucet aerators. It is likely a reasonable approach based on the long lifetimes of showerheads and faucet aerators compared to the length of the analysis period (i.e., it is uncommon for natural replacement to occur).

For dishwashers, however, it may not be appropriate to assume the baseline stock efficiency will hold constant, and it may be important to develop an estimate of the baseline shipments efficiency mix to better inform the baseline stock. As the response to Question 2 described, there is potential to add more detail and complexity to the stock comparison model that would allow the research team to estimate current practice market changes in the baseline case based on additional secondary data sources and/or additional primary data collection. The team will determine if this is necessary during future model development efforts based on an initial assessment of market change from RBSA 2011 and 2016, as well as a sensitivity analysis of an assumed static stock efficiency compared to a static shipments efficiency. For example, assuming a static stock efficiency for dishwashers may overestimate the baseline efficiency distribution and energy use overtime. However, the contribution of dishwashers to total water use is small; thus, even if the market efficiency is changing significantly, these changes may not significantly impact the overall energy consumption or market savings. Therefore, it may not be necessary to update the model to develop estimates of the efficiency mix of shipments in the baseline case.

Actual Efficiency Mix

The actual efficiency mix represents the stock efficiency of each technology as it occurred and was observed.

Water Heating Efficiency. For water heaters, the research team will develop the actual efficiency mix in plan years 2016-2021 based on the efficiency mix of water heater **shipments** in each year, as HPWH manufacturers reported to NEEA. As there is limited data available on pipe insulation, the research team anticipates holding the saturation of pipe insulation constant in the baseline and actual case efficiency mixes based on the saturation of pipe insulation observed in RBSA 2016. The research team will perform a sensitivity analysis to determine whether this assumption significantly affects the model results and whether more data collection is warranted. **Hot Water Use.** The research team anticipates developing estimates of stock change for most hot water use technologies based on RBSA 2011 and RBSA 2016 data alone and without manipulation. The team will develop the actual efficiency mix in plan years 2016-2021 for hot water use technologies without shipments data (i.e., showerheads, faucet aerators, and dishwashers) based on the RBSA 2011 and RBSA 2016 observations of stock efficiency distribution, interpolated and extrapolated to each year of the analysis period. If additional inputs emerge to further inform or refine the stock change model for some of these technologies (e.g., dishwashers), the research team will reevaluate the method for estimating the actual case efficiency mix as well.

For hot water use technologies with shipments data (i.e., clothes washers), the team will develop the actual efficiency mix in plan years 2016-2021 by updating the baseline stock efficiency mix in 2015 based on the actual efficiency mix of shipments of clothes washers in that year, as reported in the NEEA RPP data. The research team will confirm the validity of the shipments data and resultant stock efficiency mix assumptions based on the RBSA 2016 saturations.

Cumulative Savings

The research team will compute the total market savings in each year of the plan years (2016-2021) as the difference between the baseline and actual cases, as Equation 9 illustrates.

Equation 9: Cumulative Savings

$$\text{TotalMarketSavings} = (\text{BaselineStockConsumption} - \text{ActualStockConsumption}) \times \text{BusbarFactor}$$

The busbar factor in Equation 9 converts energy savings at the customer's meter to the generation source. The research team will receive guidance from BPA regarding the appropriate busbar adjustment.

It is important to note that direct comparisons of stock energy consumption in any given year, as Equation 9 illustrates, yield **cumulative** energy savings (i.e., savings that include efficiency improvements in prior years). In contrast, Momentum Savings are **first-year** savings, so adjustments will be necessary to ensure that the model does not overestimate Momentum Savings based on accrued savings in prior years. To determine first year savings, the research team proposes to deduct the prior year's cumulative savings from the cumulative savings for the current year, as shown in Equation 10. This is consistent with the 2016 residential lighting team Momentum Savings analysis.

Equation 10: First-Year Savings

$$\text{FirstYearSavings}_N = \text{CumulativeSavings}_N - \text{CumulativeSavings}_{N-1}$$

Where:

N = analysis year

Question 4: What are the program savings?

The final step in the Momentum Savings Analysis Framework corresponds to Question 4: What are the program savings? The actual energy consumption in the response to Question 3's estimate relied, in part, on data that includes high-efficiency units, such as HPWHs, some of which receive program incentives or are associated with NEEA's claimed savings. Therefore, the last step in the Momentum Savings analysis is to subtract all reported regional residential water heating program savings from the total market savings calculated in Question 3. After subtracting these program savings, any remaining savings are Momentum Savings.

Calculating regional program savings is complex because different program-funders may use different baselines from which they calculate their program savings. To end up with an accurate representation of regional program savings, the research team must perform analysis to true-up program savings against a single consistent baseline—the Seventh Power Plan baseline. This will avoid double counting of Momentum Savings and program savings.

Note that the team plans to further analyze and develop a more detailed approach for estimating regional program savings during the model development process. This memo provides an initial high-level overview of the team's general plan.

Program Savings Data Sources

The research team has identified several relevant sources for residential program activity.

Utility Program Activity

For the purposes of this analysis, utility program activity includes any hot water incentives provided by utility-funded programs in the Northwest, including those from BPA's public customer utilities, and private investor-owned utilities.

The research team plans to gather regional utility program activity by relying primarily on the Council's annual **Regional Conservation Progress (RCP) survey and report.** The RCP survey and report is a broad snapshot of regional program activity which assesses progress toward Seventh Plan goals. Council staff survey the region's utilities (including BPA and NEEA) each summer and publish results annually, typically in late fall. The most recent study includes program activity for 2010 through 2016. Technologies currently reported in the RCP data that are relevant to the residential hot water market include water heaters, clothes washers, and showerheads. This publicly-available data does not include efficiency assumptions or total units.

Although BPA reports its customer utility program data to the Council via the annual RCP survey, the research team may also rely on data from **BPA's IS2.0 database** for more detail about BPA customer utility program activity. This database is a central repository of detailed program savings information that is reported to BPA by its customer utilities.[45] The research team has an initial extract for reported program activity from IS2.0 related to the technologies in the scope of this Momentum Savings analysis for fiscal years 2011 through 2017.[46] This extract includes thermostatic shut-off valves, clothes washers, HPWHs, pipe insulation, and showerheads. BPA will provide updated data extracts from IS2.0 to the research team as requested to support the analysis.

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[45] Past evaluations of BPA's reporting system found that not all program activities are reported to BPA, and that sometimes there can be a long delay between when a utility completes a rebate and when the utility reports it to BPA.

[46] 2017 is currently partial year information.

NEEA Initiatives

NEEA has active initiatives for HPWHs and clothes washers. The research team will account for savings from these initiatives in the analysis of regional program savings.

NEEA estimates net market effects that result from its support for HPWH adoption in the Northwest. The **Alliance Cost-Effectiveness (ACE) model** relies on a stock turnover approach and efficiency shares to arrive at estimated savings. The per-unit savings rely on RTF analyses.

NEEA also provides and tracks midstream incentives for clothes washers through its **Retail Product Portfolio (RPP)**. It collects model characteristics and efficiency tiers for units sold and tracked through RPP. In addition, NEEA acquires total regional shipments and, by combining the collected information, calculates UECs and regional savings. The UECs rely on DOE technical documents, adjusted for regional-specific information.

Methodology

Leveraging the above-mentioned data sources, the research team will calculate regional program savings by modeling savings using the same method the team is using for Question 3 to calculate Total Market Savings. In this case, the team will calculate a "program scenario" that consists of and accounts for all the savings associated with program-incented units, and then compare the total market energy consumption in that year against the baseline year to calculate program savings.

Here are two simple examples:

- If program activity is a single HPWH, the total consumption is the HPWH UEC (kWh/gal), multiplied by baseline hot water use (gallons/year).
- If program activity is a single showerhead, total consumption is adjusted baseline hot water use (accounting for reduced showerhead GPM), multiplied by the baseline water heating UEC (kWh/gal).

The primary challenge with accounting for program savings is balancing data gaps with regional representation. NEEA's analysis and BPA's program data provide detailed information regarding the number of units and savings assumed, but represent only a portion of total regional program activity. The RCP provides all (or nearly all) regional program activity, but it does not include unit- or efficiency-level assumptions.

Given the available data, the research team proposes to rely on the RCP to understand regional program activity and to leverage NEEA and BPA information to derive two essential estimates:

- Units incented
- Associated efficiency

For example, the team could use BPA-reported showerheads to derive a weighted-average unit energy savings (UES) for showerheads that, in conjunction with the RCP-reported total savings, could derive a regional program unit count. Similarly, the weighted-average efficiency associated with the program units would be used to construct a "program case" hot water usage value. Before using this approach, however, the research team will investigate the availability of unit information for RCP-reported savings by asking

Council staff if such information is available, or possibly reviewing utility regulatory filings or (as a last resort) requesting detailed information directly from reporting entities.[47] Acquiring unit-level data would provide a higher level of certainty and eliminate gap-filling analysis.

Once the team has developed estimates of regional program savings, the final step is to subtract all reported regional residential water heating program savings from the total market savings calculated in Question 3. After subtracting these program savings, any remaining savings are Momentum Savings.

Sources of Uncertainty

There are several key areas of risk and uncertainty in the model. The research team will approach these risks cautiously and with an open mind to clearly assess the advantages and disadvantages associated with developing a more complex model and additional data inputs to address limitations versus overall model accuracy. The section below summarizes several key areas of uncertainty and opportunities for improvement in model inputs. The team will propose a plan for performing sensitivity analysis once the preliminary model is complete to understand which key assumptions introduce the most uncertainty and drive model results.

Market Data Gaps. The largest possible source of uncertainty in the model stems from the lack of information regarding market flow data (i.e., shipments) to inform changes in stock overtime in both the baseline and actual case scenarios for some technologies. Specifically, the research team currently does not have robust sources of shipments information for showerheads, faucet aerators, dishwashers, or pipe insulation. For each of these technologies, the research team proposes to conduct a preliminary assessment based on RBSA 2011 and RBSA 2016 data to assess the stock change in that five-year period. A sensitivity analysis will determine the impact of improved or more granular efficiency mix estimates in the baseline or actual stock. We will also research potential sources of additional data to inform such updated assessments.

Based on the results of this analysis, the research team will work with BPA to determine the appropriate path for each technology based on the cost and feasibility of collecting additional data, and the impact of the additional data on the accuracy and validity of the model results.

There are several options, ranging from a simple stock comparison based on RBSA data to a full stock turnover model based on comprehensive shipments information. The proposed approach will support prudent and informed decisions about the appropriate level of effort for each technology in Table 8. Note, these potential options would be considered in addition to an assessment of the total stock change based on RBSA 2011 and RBSA 2016. In addition, the presented options are not mutually exclusive; several options could be pursued simultaneously, if warranted.

[47] Any direct inquiries would be handled or directed by BPA. The research team will not contact reporting entities without express direction to do so by BPA.

Table 8: Modeling and Research Options

Technology	Option to Fill Data Gap	Level of Effort
Showerheads and Faucet aerators	Develop an estimate of new construction additions to stock and model as compliant with current code in baseline and actual case.	Low
	Interview retailers about sales and efficiency mix.	High*
Dishwashers	Develop an estimate of new construction additions to stock and model as compliant with current code in baseline and actual case.	Low
	Develop an estimate of regional shipments based on assumed lifetime, national shipments data from the Association of Home Appliance Manufacturers (AHAM), and model information from DOE's Certification Compliance Management System database. [48]	Med
	Collect regional shipments information for dishwashers from regional distributors and retailers.	High*
Pipe insulation	Develop an estimate of new construction additions to stock and model as compliant with current code in baseline and actual case moving forward.	Low
	Review code change between 2011 and 2016 and assume 2011 saturation/efficiency mix to assess 2011 to 2016 market change to inform stock efficiency distribution/saturation.	Low-Med
	Model all (or a portion of) new water heater installs (from the water heater stock turnover model) as receiving new pipe insulation in baseline and efficient case.	Low
	Interview builders, home performance contractors, and plumbers to understand trends in the installation of pipe insulation on new and existing water heaters outside of programs.	High*

* = Primary data collection required.

Validation approach. In addition to market efficiency mix gaps, the accuracy and validity of the model depends on primary data, to the extent possible. However, the degree to which this calibration step (i.e., comparison of model results to measured data) provides a reliable comparison and calibration point for the model depends on how representative and robust the measured data are. Table 9 summarizes the existing model calibration points and limitations.

Table 9: Summary of Model Calibration Points and Limitations

Model Input	Calibration Point(s)	Limitations
Water Heating	RBSA 2011 Metering	The RBSA 2011 Metering report only reports load shapes and

[48] See https://www.regulations.doe.gov/ccms

Model Input	Calibration Point(s)	Limitations
UEC Values	Report	average consumption values for electric resistance and heat pump water heaters, not specific efficiency levels.
	Other research studies in the region reporting water heater energy consumption	Smaller-scale research efforts may not be representative of the average Northwest population in terms of housing characteristics, hot water use profile, or occupancy.
Hot Water Use UWC Values	2011 NEEA HPWH Model Validation Field Study	NEEA only measured total hot water use, so it is not possible to verify the end-uses individually (only as a percentage of total load).
	REUWS 1999[49] and/or REUWS 2016[50]	Only aggregated information is publicly available. The full dataset is available for purchase, but only one of the participating utilities is from the Northwest (Tacoma), so it is unclear if the underlying data would be representative of the region.

[49] Aquacraft, Inc. Water Engineering and Management, "Residential End Uses of Water." Rep. AWWA Research Foundation and American Water Works Association, 1999.

[50] Aquacraft, Inc. Water Engineering and Management, "Residential End Uses of Water, Version 2." Rep. Water Research Foundation, April 2016.

Appendix: Detailed Review of Data Sources

The following table describes the data availability and preliminary analysis recommendation for all hot water load technologies identified by the research team. The research team based this table on a comprehensive review of available data sources for these technologies, including RTF workbooks, the Seventh Plan, utility program documents, regional research (e.g., RBSA and NEEA HPWH Model Validation Research), and other national resources. Detailed reviews of these data are included in a separate document. This table summarizes the relevant information necessary for model development, namely:

- Is there sufficient data available to model the technology?; and
- Should the technology be treated as primary or secondary, based on the criteria established in Question 1?

For technologies the research team has proposed to treat as secondary, the table outlines a verification approach the team will follow to verify and justify secondary classification.

Technology	Data Sufficiency/Issues	Preliminary Recommendation for Treatment
Water Heating Efficiency Technologies		
Water Heaters	All necessary data available; some manipulation required	**Primary:** Treat as primary because essential to correctly estimate energy consumption; for now, the majority of savings will be program savings.
Pipe Insulation	Potential unknown; limited data for baseline; no data on shipments efficiency or market efficiency post RBSA 2016	**Primary:** Treat as primary due to potential impact on Momentum Savings and to provide complete picture of water heating efficiency. Consider approach for data gaps.
Solar Water Heaters	Minimal market case information	**Secondary:** Verify limited market penetration and market shift from 2011 based on RBSA 2016. If small, treat as secondary.
Hot Water Use Technologies		
Showerheads	No data on shipments efficiency or market efficiency post RBSA 2016; need to revisit UES basis	**Primary:** Estimate market shift from RBSA 2011 to RBSA 2016 and develop approach for filling data gaps. Confirm primary treatment and determine path forward based on RBSA stock change assessment.

Technology	Data Sufficiency/Issues	Preliminary Recommendation for Treatment
Faucet Aerators	No data on shipments efficiency or market efficiency post RBSA 2016; need to revisit UES basis (RTF measure underdevelopment)	**Primary:** Estimate market shift from RBSA 2011 to RBSA 2016 and develop approach for filling data gaps. Determine treatment and path forward based on RBSA stock change assessment.
Clothes Washers	All necessary data available; some manipulation required	**Primary:** Develop estimate for total impact on consumption over analysis period based on RBSA 2011 and 2016 observed market shift. If large, treat as primary due to potential for market shift, although Momentum Savings are likely to be limited.
Dishwashers	Little hot water savings, but need to verify; no data on shipments efficiency or market efficiency post RBSA 2016	**Primary:** Estimate market shift from RBSA 2011 to RBSA 2016 and develop approach for filling data gaps. Determine treatment and path forward based on RBSA stock change assessment.
Circulators	Limited data and momentum savings at this time; potential for future impact	**Secondary:** Verify assumed low penetration of recirculation pumps in in-scope building types. If so, exclude.
TSRV	Baseline efficiency and stock questionable; no data on market efficiency post RBSA 2016	**Secondary:** Verify limited market penetration and market shift from 2011 based on RBSA 2016. If small, treat as secondary.
Wastewater Heat Recovery	No source of market efficiency information; no programs	**Secondary:** Verify assumed low penetration of recirculation pumps in in-scope building types. If so, treat as secondary.