BONNEVILLE POWER ADMINISTRATION

Industrial Adjustable Speed Drives Northwest Market Model

JULY 2022

EXECUTIVE SUMMARY

Quantifying the Industrial Pump and Fan Market

In 2020, the Bonneville Power Administration (BPA) set out to understand how the adoption of adjustable speed drives (ASDs) impacts energy consumption of standalone industrial pumps and fans in the Northwest (Washington, Oregon, Idaho, and western Montana).

This work has three goals:

1. Model how the stock of industrial standalone pumps and fans changed between 2015 and 2021.
2. Characterize the energy consumption of this equipment over that same period.
3. Calculate the Momentum Savings associated with the adoption of ASDs between 2016 and 2021.

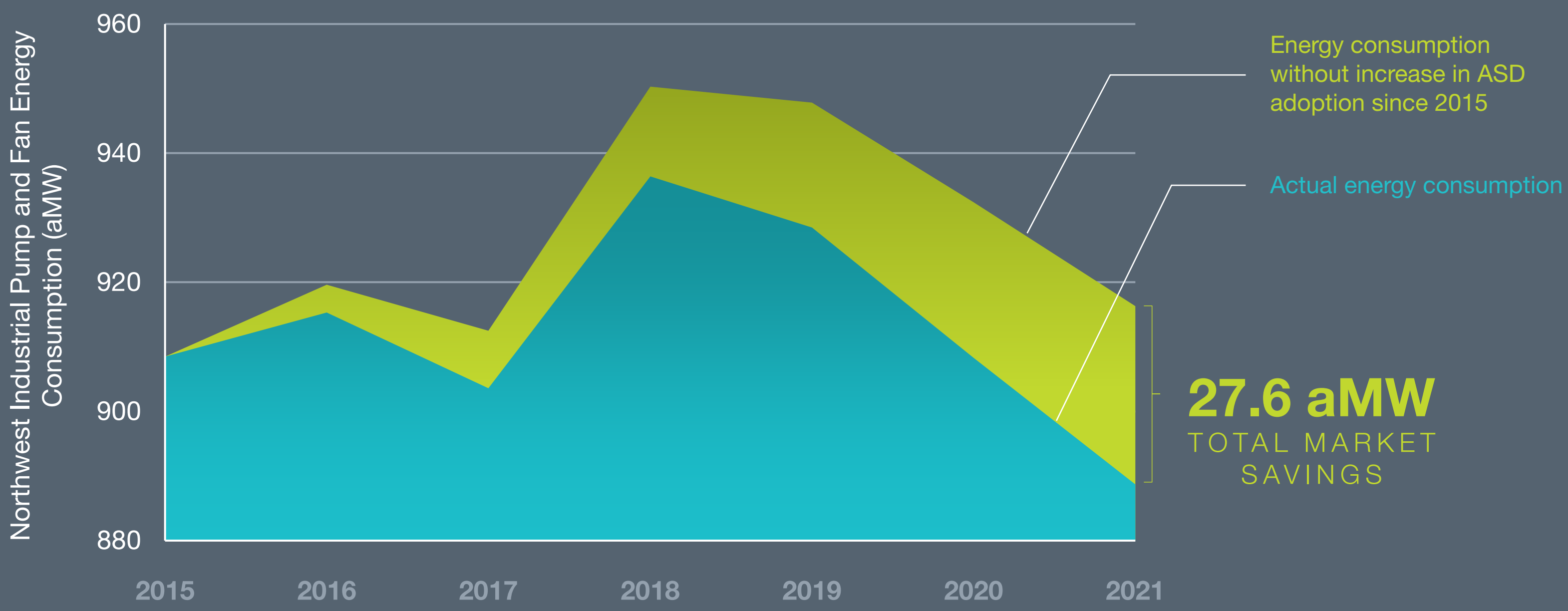
Before modeling this market, the research team interviewed over 50 market actors in the motor, ASD, and motor-driven equipment markets to understand the motor and ASD supply chain, how equipment travels to end users, and how ASD adoption has changed over the past 5–10 years. Equipped with this information, the research team collected additional primary and secondary data on the motor stock, industrial macroeconomic trends, ASD sales, equipment operations, and utility program activity.

To accomplish the three research objectives, the research team calculated the stock of motor horsepower (HP), the adoption rate of ASDs, and the energy consumption of industrial standalone pump and fan motor HP, in each year, between 2015 and 2021.

ASDs are control devices that vary the speed of a motor, creating large energy savings for motor-driven systems.

The most common types of ASDs are variable frequency drives or variable speed drives. Advanced motor technologies that are intrinsically variable speed, like synchronous reluctance motors, are also considered ASDs.

ASDs have created 27.6 aMW of savings in the Northwest since 2015



Momentum Savings are cost-effective energy savings above the Northwest Power and Conservation Council's Power Plan baseline not directly paid for by regional utility programs or part of the Northwest Energy Efficiency Alliance's (NEEA) net market effects.

REGIONAL MOMENTUM SAVINGS

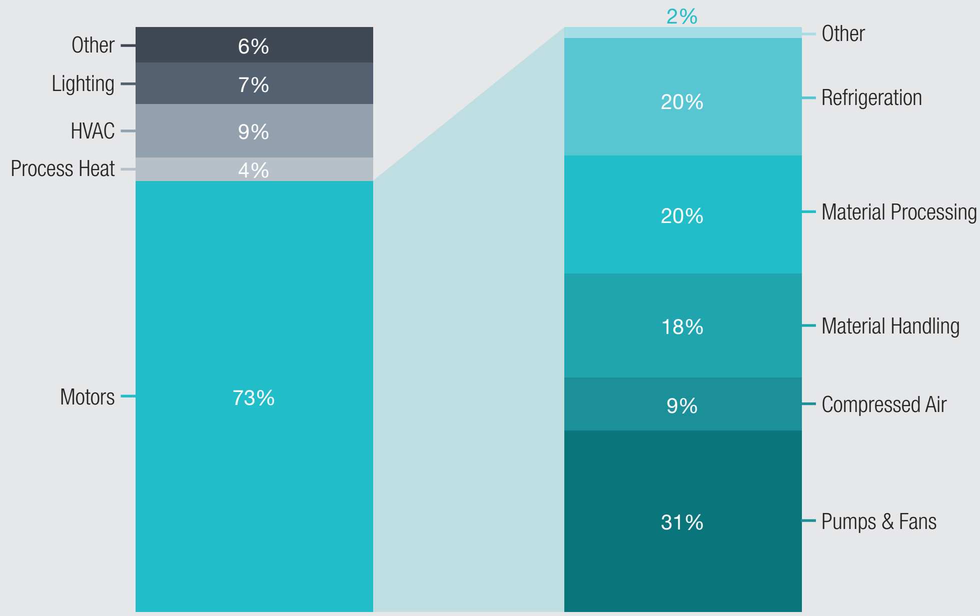
18.9 aMW

MODEL METHODOLOGY

Why the Industrial Pump and Fan Market?

From an electricity use perspective, the industrial sector is the second largest sector in the Northwest. Within the sector, pumps and fans comprise 25% of that energy consumption, representing a large end use in the region with many opportunities for energy efficiency. The energy savings potential associated with ASDs is well documented, highlighted in the 2021 Power Plan, where 19% of the annual industrial conservation potential is from ASDs. Utility programs have been driving regional ASD adoption through custom projects, and NEEA is currently working with manufacturers and distributors to increase the addition of ASDs to pumping systems.

Industrial Electricity Consumption, 2021



Source: 2021 Power Plan Industrial Tool

Leveraging the Best Available Data

The research team used both regional and national data sources to model this market. To calculate the total regional pump and fan motor HP in each year, the research team used stock information from the US Department of Energy's Motor System Market Assessment and regional data on the growth and contraction of the industrial sector from the Bureau of Economic Analysis. Using a stock turnover function, the model determines the distribution of motor HP across different installation characteristics (motor size, load type, ASD saturation), and how that distribution changes over time.

The research team used real-world operational data, specific to the Northwest, to calculate the unit energy consumption (UEC) for each specific installation configuration. Then, the research team applied the UEC estimates to the motor stock to calculate the total industrial standalone pump and fan energy consumption by year. Expert engagement and other industrial energy consumption estimates corroborated the modeled energy consumption.

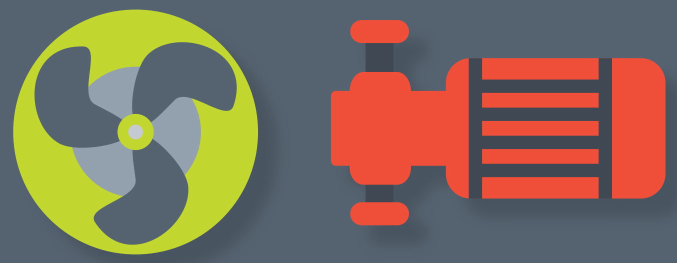
To determine the savings associated with the adoption of ASDs, the model calculates a counterfactual baseline where ASD saturation remains constant at its 2015 value. The difference in energy consumption between this baseline and the market energy consumption represents the total market savings associated with the adoption of ASDs on this equipment. Finally, the research team conducted a detailed analysis of regional custom program data to derive the total ASD program savings, which the research team subtracted from the total market savings to determine Momentum Savings.

BPA categorized the industrial sector into 11 different facility types:

- **Chemical**
- **Computer/Electronics**
- **Fabricated Metal**
- **Food**
- **Miscellaneous**
- **Paper**
- **Primary Metal**
- **Refinery**
- **Transportation Equipment**
- **Warehousing**
- **Wood Products**

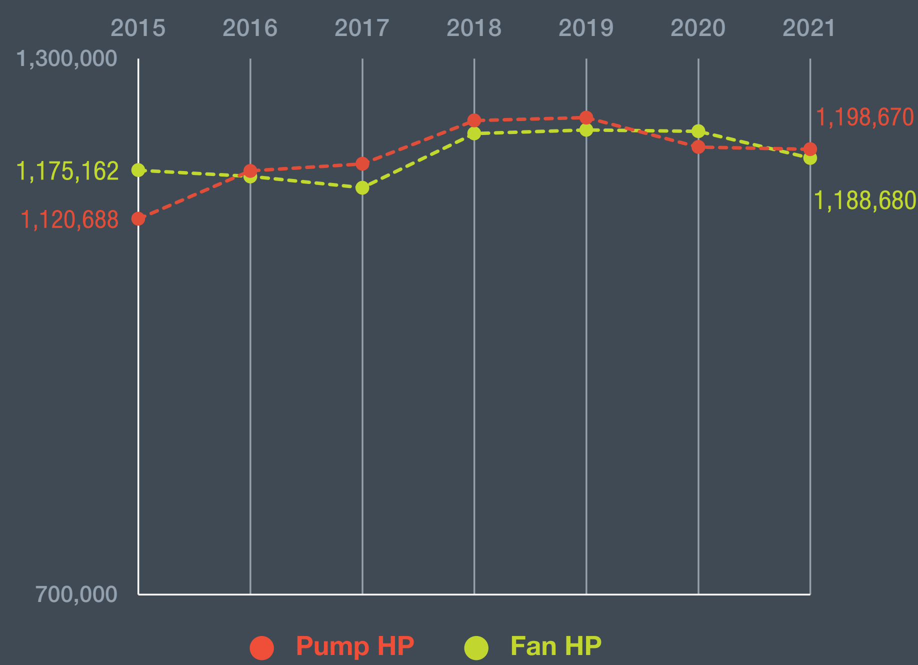
MARKET AND STOCK CHARACTERISTICS

By modeling the regional stock of industrial standalone pumps and fans, BPA can understand how the installed stock changes over time and how that change has impacted energy consumption. These energy consumption changes account for both fluctuations in demand for industrial production and the adoption of more efficient technologies, like ASDs and more efficient pumps and fans.



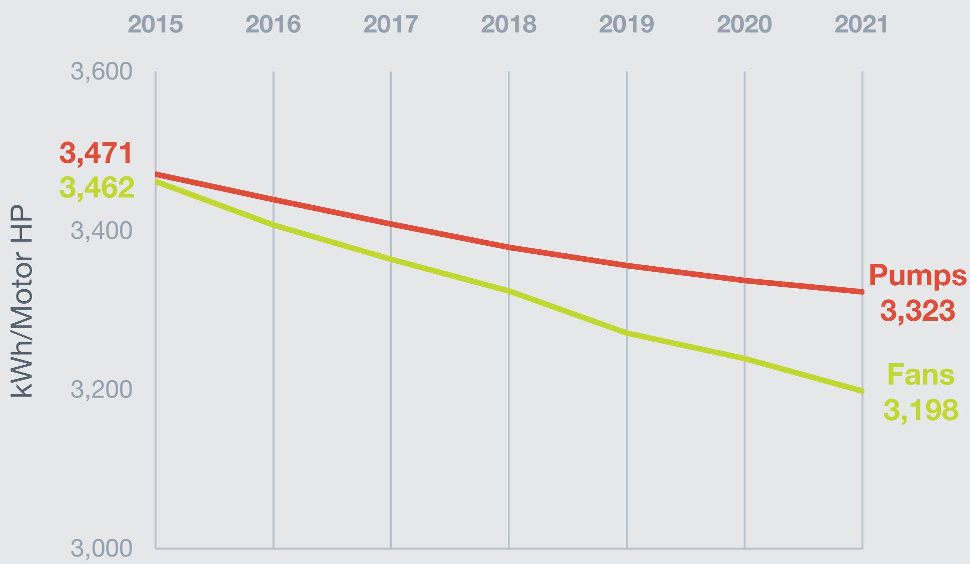
Consistent Growth in Industrial Pump and Fan Stock

From 2015 to 2021, the stock of industrial pump and fan motor HP (energy-consuming motors only) has seen an increase of 3.8%. This increase is evident in both pumps and fans and can be attributed to the growth of the region's industrial sector. The model shows a slight decrease in stock for both equipment types in 2020 and 2021, when some industrial facilities in the region reduced production during the COVID-19 pandemic. In the future, the research team will investigate the persistence of any pandemic-related impacts on the industrial sector.



Average Unit Energy Consumption Decreases Due to ASDs

While motor stock increased, total energy consumption in 2021 is less than in 2015. This is because the average per-HP energy consumption for both pumps and fans decreased every year from 2015 to 2021. Pumps saw a per-HP decrease of approximately 150 kilowatt-hours (kWh) per year and fans saw a per-HP decrease of approximately 275 kWh per year. The increased adoption of ASDs in the region is the main cause of this decrease in energy consumption.



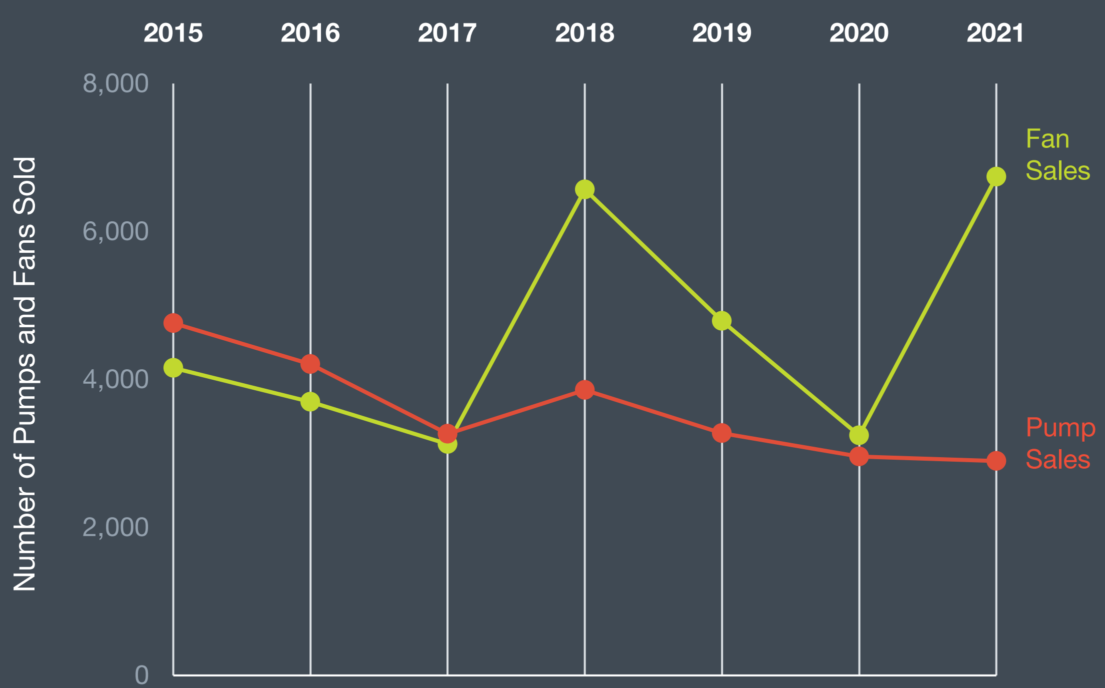
MARKET AND STOCK CHARACTERISTICS

Average Pump Size Now Bigger Than Six Years Ago

Fan motor size is consistent across the analysis period, but the average pump size has increased by 7 motor HP. This increase in average pump size is due to a change in the distribution of facility types within the region. As the analysis period progresses, facility types with larger pumps make up a larger portion of the stock on average, driving this increase in average motor size.

	PUMPS	FANS
2015	**30 HP**	**18 HP**
	+ 7 HP	– 1 HP
2021	**37 HP**	**17 HP**

Equipment Sales See Dramatic Variability Year-Over-Year

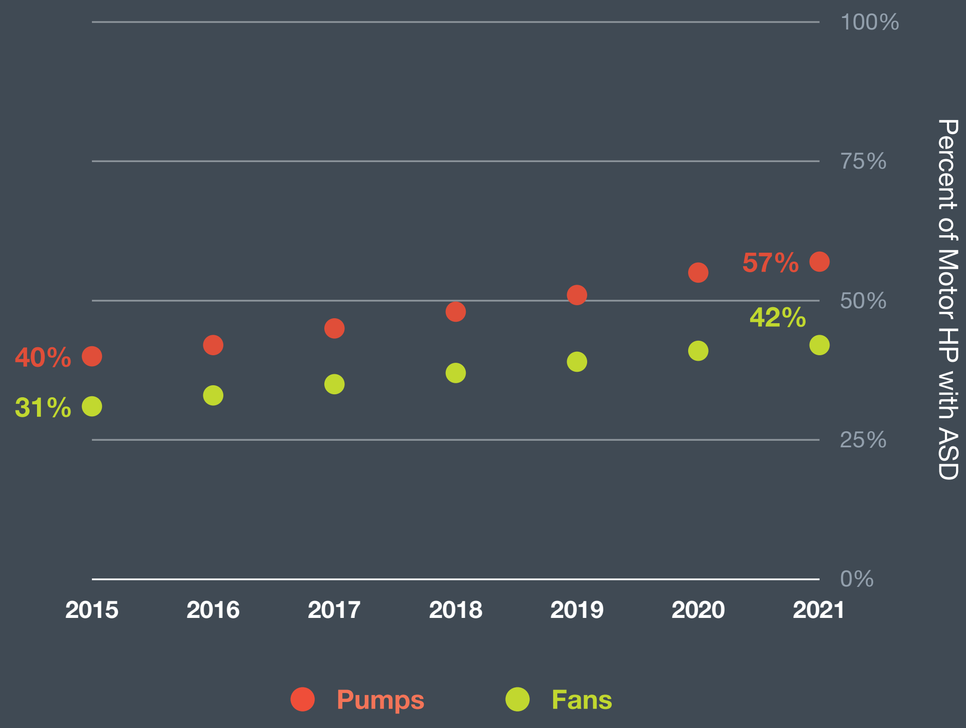


The model shows significant variability in equipment sales over the analysis period. Industry experts who reviewed the modeled equipment sales confirmed that the market is indeed variable year to year. The construction of one or two large facilities can create temporary spikes in sales, driving these trends.

The model results represent the best available estimate of regional industrial pump and fan sales, as there are no publicly available data specific to the Northwest. These estimates are much lower than estimates using secondary data sources, such as the Department of Energy's regulatory analyses and US Census Bureau information, but align with market expert experience, regional stock size, and regional energy consumption.

ASD SATURATION INCREASES SIGNIFICANTLY IN BOTH PUMPS AND FANS

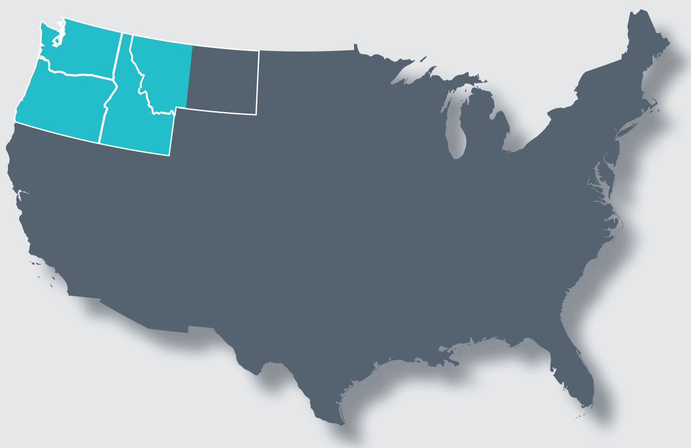
ASD saturation for both pumps and fans increased over the analysis period. The saturation of ASDs on pumps increased 17 percentage points from 40% to 57% between 2015 and 2021. On fans, ASD saturation increased from 31% to 42% over the same period. Utility program efforts, the decreasing cost of ASDs, increased comfort with the technology, and the industrial focus on connectivity could all be drivers in the increase in ASD saturation.

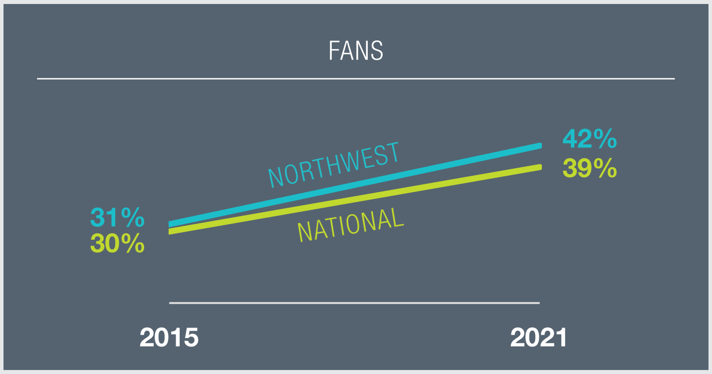


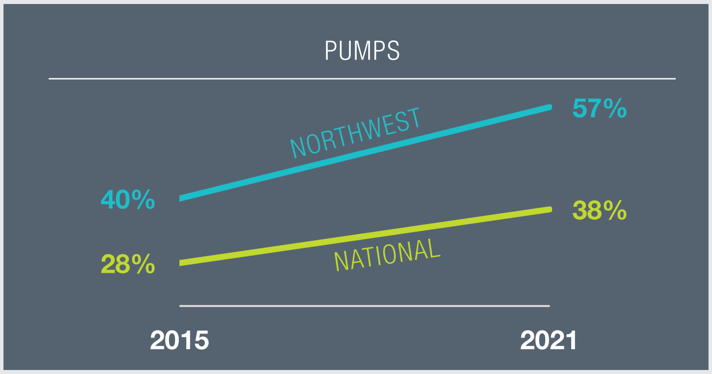
Northwest ASD Adoption Surpasses the Nation

To calculate regional ASD saturation, the model uses information on the national saturation of ASDs and proprietary data on both regional and national ASD sales.

The rate of ASD adoption has been faster in the Northwest than the nation for at least 10 years. Market actors and experts in the industry identified program activity as a main driver in this difference. The Northwest's utility programs provided early exposure to ASDs, which increased industrial facilities' comfort and knowledge of the technology and helped accelerate adoption.



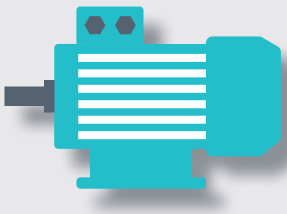




ASD INSTALLATION CHARACTERISTICS

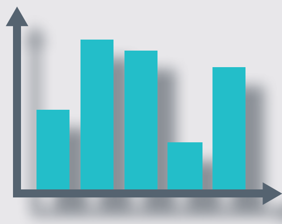
ASD installations concentrate on large motors and variable loads.

LARGE MOTORS



The average motor size for an ASD-equipped pump or fan is much larger than that same equipment without an ASD. On average, ASD-equipped fans are 23% larger than non-ASD-equipped fans. ASD-equipped pumps are 16% larger than non-ASD-equipped pumps.

VARIABLE LOADS

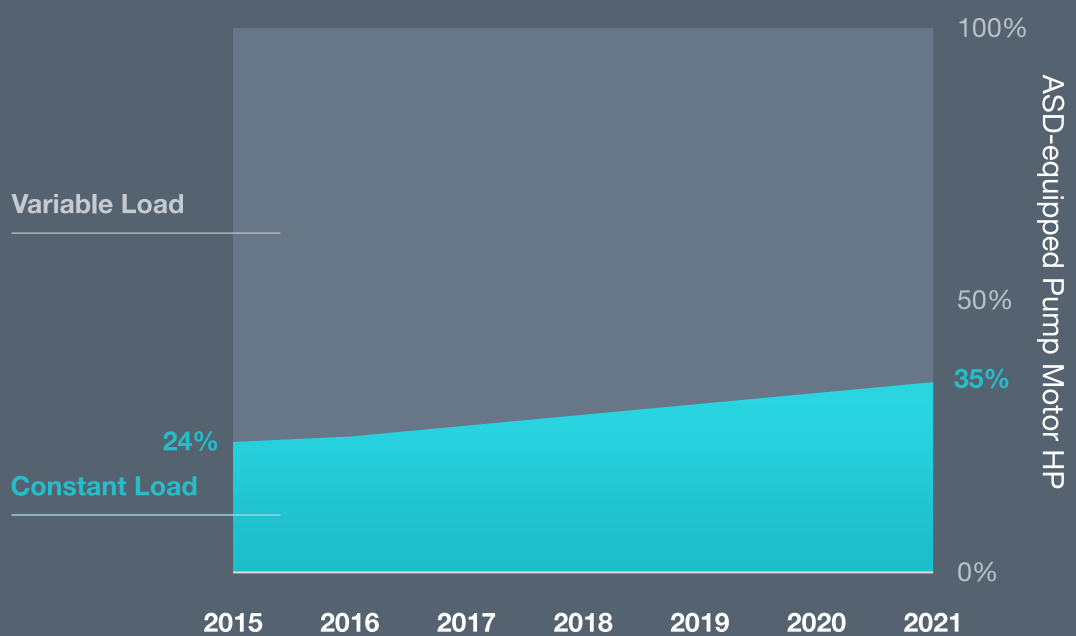


For both pumps and fans, variable load systems—systems that operate at more than one load point—are much more likely to have ASDs than constant load systems, which operate most of the time at one load point. For fans and pumps, 93% and 65% of ASD-equipped motor HP is variable, respectively.

This higher ASD saturation is tied to the energy savings created by these characteristics. More variability in the system load increases the impact an ASD has in efficiently meeting lower load points; larger motors see a larger total savings per piece of equipment. In both scenarios, the high energy savings help decrease the payback period associated with installing an ASD, which makes cost-justification easier.

ASDs Installations on Constant Load Pumps are Increasing

While most ASDs are installed on pumps with variable load systems, there are more and more constant load pumps with ASDs. The percent of ASD-equipped pump motor HP serving constant load systems increased from 24% in 2015 to 35% in 2021. The ASD saturation on pumps has reached a level where the biggest energy savings opportunities are already equipped with ASDs, and installations now occur on pumps that were previously overlooked (like constant load systems).

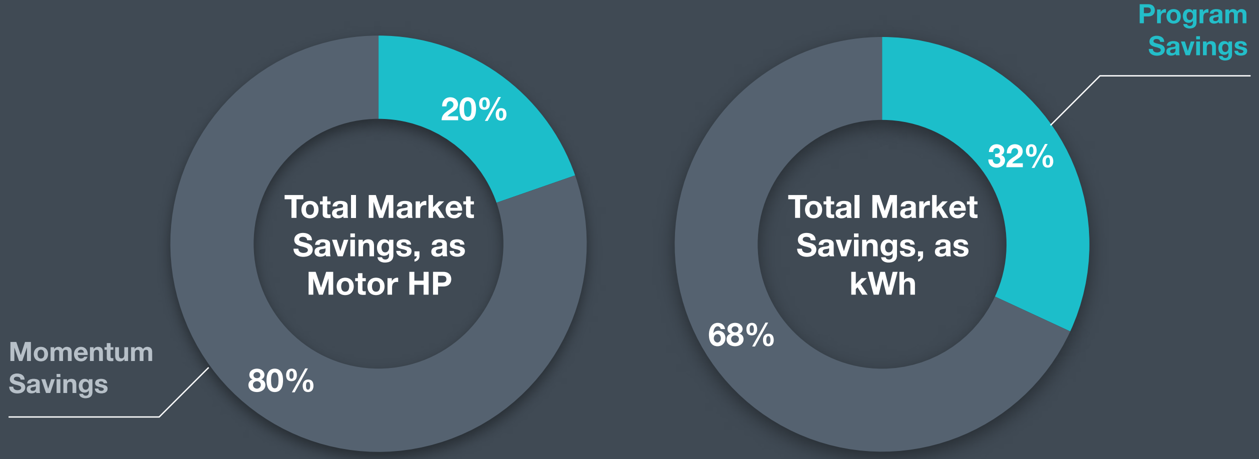


CUSTOM PROGRAMS DRIVE ASD ADOPTION

Programs Target Highest Savings Opportunities

Northwest utilities typically incentivize energy efficiency using deemed measure or custom projects. For industrial applications, utilities have predominantly incentivized ASDs through custom projects.

The research team's detailed analysis of regional program activity shows that pumps and fans receiving ASD program incentives are more concentrated in variable load and large-sized systems than the overall stock. This means that while programs incentivized 20% of the ASD-equipped motor HP added since 2015, the savings those programs generated accounted for 32% of the electricity savings due to ASDs over the same period.



Facility Types with Program Investment Have Highest ASD Saturation

Northwest ASD program activity is concentrated in 5 of the 11 modeled facility types. These facility types have some of the highest ASD saturations in the region, indicating that programs have effectively influenced ASD adoption in these facility types.

91% of program-incented fan motor HP is found in these 4 facility types.

98% of program-incented pump motor HP is found in these 4 facility types.

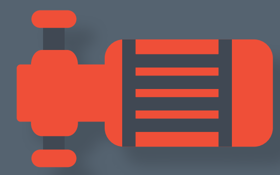
THE FUTURE OF ASD INSTALLATIONS

Model results show that a large portion of the Northwest stock remains without ASDs. 57% of fan motor HP and 43% of pump motor HP are not equipped with ASDs. The energy savings opportunity for each load type is different; variable load systems see higher per-HP savings because of load matching, whereas constant load systems see lower per-HP savings from equipment right-sizing. ASD installations have concentrated in variable load systems in the past, meaning most of the remaining motor HP without ASDs exist in constant load systems.

FANS

683,000 Motor HP without ASDs

CONSTANT	VARIABLE
63%	37%



PUMPS

513,000 Motor HP without ASDs

CONSTANT	VARIABLE
71%	29%

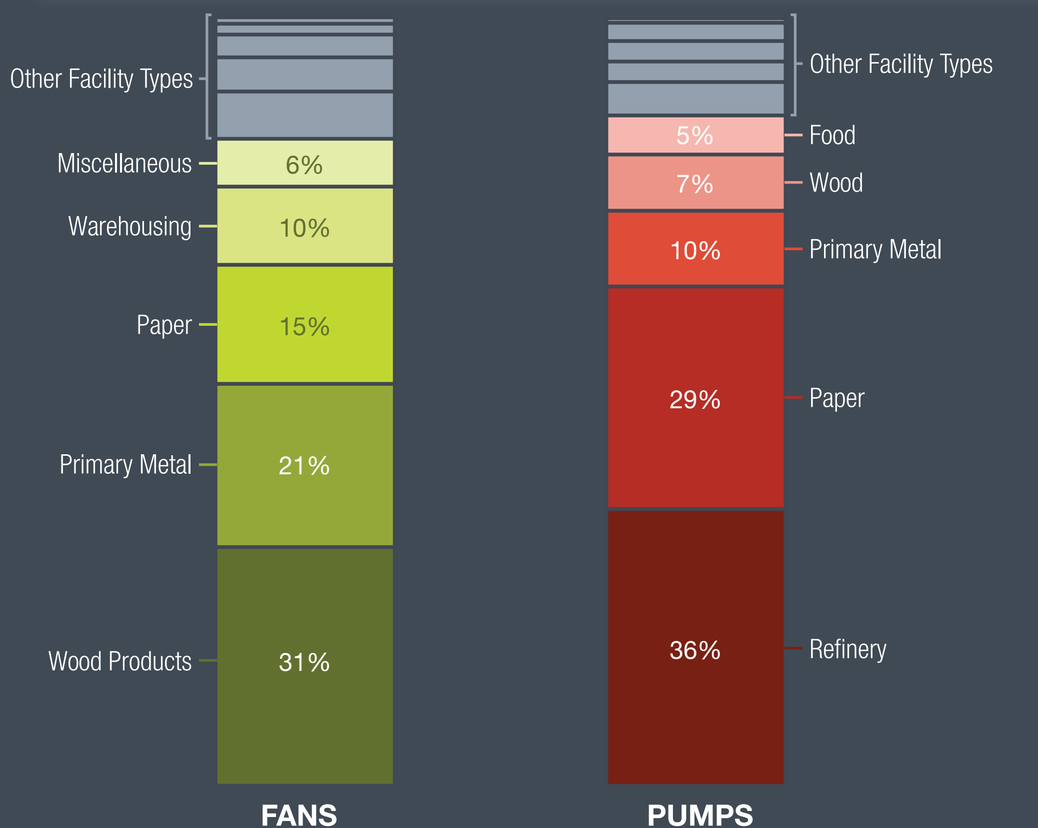
80% of Remaining Potential Reside in 5 Facility Types

For fans, 83% of the remaining potential falls into the wood, primary metal, paper, warehousing, and miscellaneous facility types. Of those five, programs are actively engaged in the wood and miscellaneous facility types; they comprise 25% of the regional ASD program activity for industrial fans.

Similar for pumps, the remaining potential is concentrated in five facility types: refinery, paper, primary metal, wood, and food. Programs are already actively working with the paper and food industries, with 70% of the regional ASD program activity for industrial pumps fall into those two facility types.

Across both pumps and fans, primary metal, warehousing, and refinery are facility types where incentives could make a big impact in the future.

Distribution of non-ASD-equipped motor HP, by facility type



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Bonneville Power Administration
Industrial Adjustable Speed Drives
Northwest Market Model Methodology

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Acknowledgements

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Introduction

As a public energy provider in the Pacific Northwest (the region), Bonneville Power Administration (BPA) aims to continually improve the regional body of knowledge about energy consumption and savings. This helps BPA and other regional organizations better track, understand, and account for energy consumption and energy efficiency activities in the region. These efforts serve to facilitate regional power planning, support program efforts, and help the region understand the impact new technologies have on the market. To achieve this improved insight, BPA develops quantitative models that characterize the energy consumption of different regional markets. These "market models" calculate the size of a market year-over-year and estimate the change in energy consumption over time. They also account for the program savings (through regional utility incentive programs or market transformation initiatives) and quantify Momentum Savings, defined as cost-effective energy savings resulting from newly installed energy efficiency measures, which are above the Northwest Power and Conservation Council (the Council) baseline and not included in program savings.[1]

This memo outlines the methodology BPA used to model the energy consumption of standalone industrial pumps and fans in the region. The model also calculates Momentum Savings from the addition of adjustable speed drives (ASD) to these systems during the Council's Seventh Power Plan (Seventh Plan) Action Plan Period.[2] BPA's goals for modeling this market include:

1. Understand how the energy consumption of standalone industrial pumps and fans is changing in the region from 2015 through 2021.
2. Estimate Momentum Savings associated with the installation of ASDs on standalone industrial pumps and fans from 2016 through 2021.
3. Gather valuable data to inform a better regional understanding of standalone industrial pumps and fans.

Background

Industrial motor-driven systems represent a segment of energy consumption and potential energy savings that is a focus in the region. Motor-driven systems represent a significant energy end use nationally,[3,4] and the Pacific Northwest is no different; motor-driven systems make up approximately 70% of the region's industrial load.[5] In response to motor-driven systems' large energy consumption, organizations in the region are promoting energy efficiency associated with these systems. The Regional

[1] "Methods for Calculating Momentum Savings", August 2016, https://www.bpa.gov/-/media/Aep/energy-efficiency/momentum-savings/methods-for-calculating-momentum-savings.pdf, accessed 5/24/2022

[2] The Seventh Plan defines the Action Plan Period as 2016-2021. These savings are measured against a baseline year (2015). https://www.nwcouncil.org/sites/default/files/7thplanfinal_allchapters_1.pdf, accessed 5/25/2022

[3] "Energy Efficiency Policy Opportunities for Electric Motor-Driven Systems", https://www.iea.org/reports/energy-efficiency-policy-opportunities-for-electric-motor-driven-systems, accessed 2/6/2022

[4] "Annual Energy Outlook 2021", https://www.eia.gov/outlooks/aeo/, accessed 2/6/2022

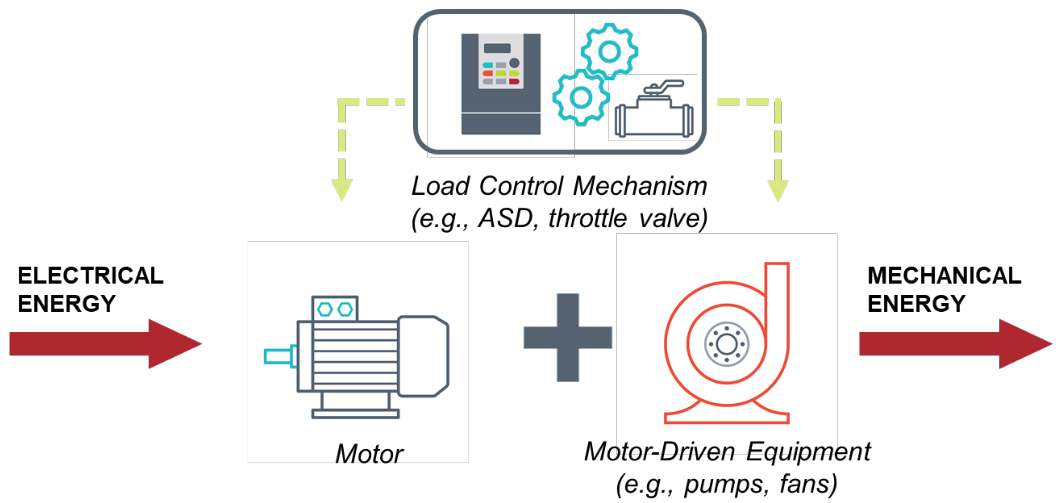
[5] "Industrial_tool_7thPlan v09.xlxm", https://nwcouncil.app.box.com/v/7thplanconservationdatafiles/file/54717875397, accessed 2/6/2022

Technical Forum[6] (RTF) has developed four measures in the past five years focused on motor-driven systems, and the Northwest Energy Efficiency Alliance (NEEA) has an initiative focused on increasing the efficiency of motor-driven systems.[7] After identifying a large regional value in understanding this market, BPA began conducting research on the motor-driven system market in 2020.[8]

This memo presents a summary of the methodology used to model energy consumption and Momentum Savings from 2016 through 2021. It also presents high-level results from the model and an investigation into the uncertainty associated with these values. The model starts in 2014, which allows calculated results to inform 2015 (the baseline year of the Seventh Power Plan) through 2021 (which covers the Seventh Plan Action Plan Period).

Before presenting the methodology and model results, this section outlines concepts and terms that are necessary to understand the scope and approach of the model - specifically, the definition of motor-driven system. There are three main components of a motor-driven system: (1) the motor, (2) the motor-driven equipment, and (3) the load control mechanism. Figure 1 shows a diagram of these components.

Figure 1: Motor-Driven System Diagram



Motor: The motor is the main energy consuming component of the system. Motors serve to convert electrical energy to mechanical energy. A motor transfers this mechanical energy, usually in the form of shaft rotation, to the motor-driven equipment.

Motor-driven equipment: The motor-driven equipment refers to the equipment that meets the end user's needs. For example, if someone wants to move air, they would use a motor to drive a fan (the motor-driven equipment), which would rotate and create airflow (referred to as the "equipment load"). Motor-driven equipment is considered "standalone" when not embedded in a larger piece of equipment or unit. For example, a fan serving a packaged refrigeration unit would be considered embedded, as the

[6] The Regional Technical Forum is a technical advisory committee to the Northwest Power and Conservation Council. The RTF serves to develop standards which verify and evaluate energy efficiency savings. Through their work, the RTF establishes deemed unit energy savings (UES) values for different energy efficiency measures in the Northwest. More information on the RTF can be found at https://rtf.nwcouncil.org/

[7] For more information of the relevant RTF motor-driven system measures and NEEA's ASD-related initiatives, see Question 3 in this document.

[8] BPA conducted interviews with 53 market actors in 2021 to characterize the market of motor driven equipment and ASDs in the Pacific Northwest. Results of those interviews can be found at https://www.bpa.gov/-/media/Aep/energy-efficiency/momentum-savings/2021-bpa-asd-market-actor-interview-findings.pdf accessed 5/25/2022

energy would not ever be measured separate from other system components. Conversely, while a boiler feedwater pump is intrinsic to a boiler system, that pump's energy consumption would be measured separate from the rest of the system, making it a standalone pump. This methodology only models standalone equipment (and not embedded equipment) because utilities and energy efficiency programs often attribute the energy savings associated with embedded equipment to energy savings from the larger unit (e.g., the addition of a variable speed fan to a commercial packaged boiler is attributed to an increase in efficiency of the boiler, not the embedded fan).

Control Strategy: There are many forms of motor and load control, all enabling the motor and motor-driven equipment to meet the system's equipment load requirements. These strategies can vary from mechanical devices installed in the system, such as balancing valves and dampers, to electronic controls that vary the speed of the motor. The most common form of electronic controls are ASDs. This memo uses the term ASD to describe any electronic controls that allow a motor to rotate at different speeds, controlling the motor and motor-driven equipment via changes in the rotational speed of the motor. The majority of ASDs are variable frequency drives (VFD) and variable speed drives (VSD), but the term also includes less common technologies such as switch reluctance motors and electronically commutated motors (ECM). ASDs do not include mechanical control strategies like belt and sheave systems, gear boxes, or eddy-current drives (which operate by varying the rotational speed of the motor-driven equipment, not the motor). Using ASDs to meet varying demands in equipment load changes the relationship between the system's electric power draw and the flow rate of the load, or the power-load relationship.[9] Using an ASD is often more efficient than employing other mechanical strategies for controlling equipment load.

Multiple factors impact the energy consumption of a motor-driven system. These include (1) the efficiencies associated with each component, as well as transmission efficiencies between the motor and motor-driven equipment, (2) the power-load relationship associated with the system's load control mechanism, and (3) the characteristics of the load the motor-driven system is serving. This model accounts for each of these impacts to fully characterize the energy consumption of industrial standalone pumps and fans. Changes to any of these three factors can impact the energy consumption of a system, and there are energy efficiency programs active in the region that address all three. However, ASDs, which impact the power-load relationship of a system, are a technology with potential to significantly change the energy consumption of motor-driven systems. Thus, the ASD market model accounts for changes in the other factors over the analysis period but only characterizes energy savings from the adoption of ASDs.

Four Question Framework

Every market presents unique challenges in modeling energy consumption and Momentum Savings. BPA developed the Four Question Framework as a way of standardizing the approach to modeling different markets while facilitating the flexibility to treat each market differently.[10] The Four Questions, described in greater detail in the following chapter, are:

[9] For more information on the specific ways the speed control of a motor-driven system impacts energy consumption, refer to the UEC Methodology section of this document.

[10] "Methods for Calculating Momentum Savings", August 2016, https://www.bpa.gov/-/media/Aep/energy-efficiency/momentum-savings/methods-for-calculating-momentum-savings.pdf, accessed 5/24/2022

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 energy use in the following years?
4. What are the program savings?

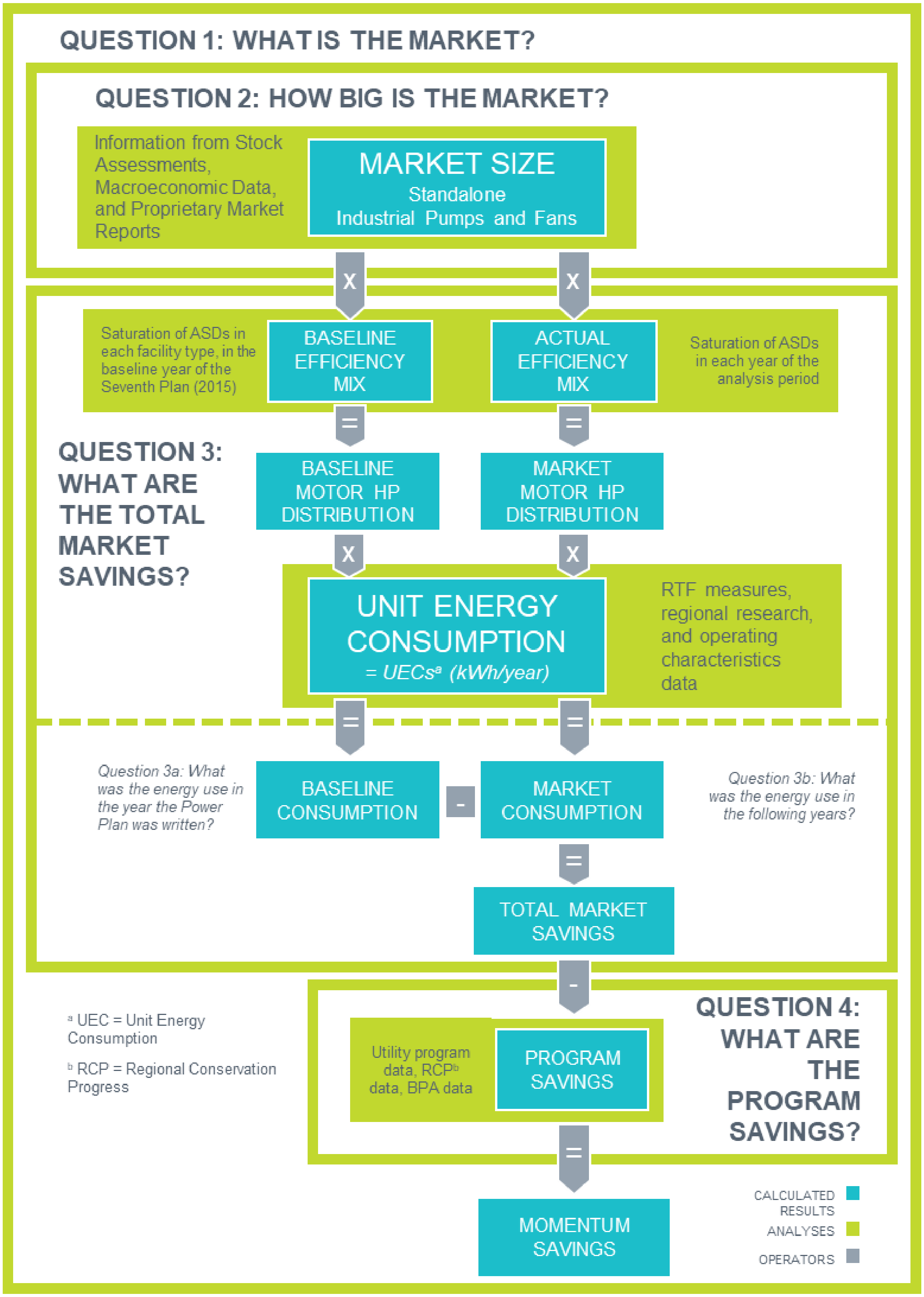
The following methodology describes the process by which the research team addressed each of the Four Questions, resulting in a market model that calculated energy consumption for standalone motor-driven systems and Momentum Savings associated with the adoption of ASDs.

To develop the most robust model possible, the team solicited input and feedback from experts to refine the modeling approach and review results. Over the course of model development, the research team engaged an Expert Panel consisted of ten industry, market analysis, and technology experts to provide independent feedback and input on the modeling approach. Based on the Expert Panel's collective feedback, the team refined model inputs and key assumptions, which increased the confidence in the model results.[11] The team also vetted model results with six market actors with experience selling and installing ASDs[12] using an iterative and anonymized process to ensure feedback from the market actors are independent and unbiased. Overall, the market actors deemed the model results reasonable according to their knowledge and experience of the regional ASD market. The team has noted feedback from the Expert Panel and the market actors throughout this memo.

Figure 2 summarizes the high-level approach this memo takes to answering the Four Questions, including details specific to motor-driven systems and relevant data sources. The following chapters present the Methodology used to calculate energy consumption and Momentum Savings, the Model Results, and a Sensitivity Analysis characterizing the impact uncertainty in model inputs has on model results.

[11] All Expert Panel feedback and the team's responses to feedback can be found at https://www.bpa.gov/energy-and-services/efficiency/market-research-and-momentum-savings/adjustable-speed-drives-market-research.
[12] This group of regional market actors was made up of two individuals from engineering service firms, two manufacturer representatives from national motor manufacturers, and two ASD distributors.

Figure 2: Overview of the Momentum Savings Four Question Framework for ASDs



[a] UEC = Unit Energy Consumption

[b] RCP = Regional Conservation Progress

Methodology

This chapter describes the methodology used to model the industrial standalone pump and fan market. The research team separated this chapter into four sections, with each section addressing one of the Four Questions presented in the Four Question Framework chapter. Each section describes the method for addressing each question, key data sources used, and any assumptions underpinning this methodology.

While the Methodology chapter addresses the robustness and uncertainty of data sources, this memo also includes a Sensitivity Analysis chapter at the end, which investigates the impact of the main sources of uncertainty on model results.

Question 1: What is the market?

Question 1 defines the scope of the market model using six elements: analysis period, geography, sector, technology, fuel type, and unit of account. This question “draws the box” around the portion of the market that the research team is including in the model. Table 1 provides an overview of the market definition, with following sections describing additional detail on each element.

Table 1: ASD Market Model Scope

Element	Description	Notes
Analysis period	2015–2021	Corresponds with the Seventh Plan baseline year (2015) and Action Plan Period (2016–2021).
Geographic scope	Oregon, Washington, Idaho, and Western Montana	This model only includes the western portion of Montana, calculated as 57% of the state, consistent with BPA’s other market models and the Council’s Power Plans.
Technology scope	Standalone motors driving pumps and fans	The model characterizes energy consumption and Momentum Savings for standalone pumps and fans in all industrial segments identified in the Seventh Plan.
Fuel type scope	Electricity	This model focuses on electric motors only.
Sector scope	Industrial	The model covers the entire industrial sector, as defined in the Seventh Plan using 19 three-digit NAICS codes.
Unit of account	Number of motor horsepower (HP)	The model accounts for energy consumption on a kWh/motor HP basis.

Analysis Period

The analysis period refers to the timeframe over which this model characterizes energy consumption, **2015–2021**. The base year of this model is 2014, enabling the model to calculate energy consumption for the analysis period and Momentum Savings for 2016–2021, which corresponds with the Council's Seventh Plan Action Plan Period.

Geographic Scope

The geographic scope identifies the portion of the country for which this model calculates savings. Different regional entities define the scope of the "Northwest" or "Pacific Northwest" slightly differently, and this element ensures clarity on the geographic coverage of the model.

This model accounts for energy consumption in **Oregon, Washington, Idaho, and Western Montana**, which is consistent with all of BPA's market models and the Council's Power Plans.[13] While the model calculates energy consumption for the entire region, there is not information to support disaggregating energy consumption or Momentum Savings to the state level. As such, model outputs do not include state-specific results.

Technology Scope

This market model characterizes energy consumption of **standalone pumps and fans** greater than 1 motor HP installed in the industrial sector.[14] The research team identified four other standalone motor-driven equipment types (air compressors, circulators, material processing equipment, and material handling equipment), but did not include these in the technology scope of this model. The model characterizes the energy consumption of the pumps or fans, the motor itself, as well as the control strategy applied to the motor. However, when calculating Momentum Savings, the model only accounts from the impact from the addition of an ASD.

Fuel Type Scope

Fuel type scope refers to the energy sources the model intends to account for (e.g., electricity, natural gas, propane). All motors addressed in this model are electric motors, therefore the fuel type scope of this model is **electricity**.

Sector Scope

Regional entities generally consider there to be four customer sectors: (1) Commercial, (2) Industrial,[15] (3) Agricultural, and (4) Residential. This market model focuses on the **industrial sector**, characterizing energy consumption in all industries identified in the Seventh Plan.

The Seventh Plan included 19 different industries in the industrial sector, identified using three-digit NAICS codes. The market model uses the same three-digit NAICS codes to define the industrial sector,

[13] Northwest Power Act, Northwest Power and Conservation Council, https://www.nwcouncil.org/reports/poweract/3_definitions, accessed 2/6/2022

[14] Standalone fans include condenser fans in cooling towers and large cooling systems.

[15] The Seventh Plan does not include Water and Wastewater applications in the "Industrial" sector.

categorizing them into 11 facility types.[16] The model excludes aluminum smelting from the Facility Type "Primary Metal", as this industry is historically a Direct Service Industry (DSI) and is not covered by the Seventh Plan.

Table 2 presents the Seventh Plan industries and the corresponding NAICS codes and model facility type.

Table 2: Seventh Plan Industries, NAICS Codes, and Model Facility Types

Seventh Plan Industry	NAICS Code	Model Facility Type
Mechanical Pulp	322	Paper
Kraft Pulp		
Paper		
Foundries	331*	Primary Metal
Frozen Food	311	Food
Other Food		
Sugar		
Wood - Lumber	321	Wood
Wood - Panel		
Wood - Other		
Hi Tech - Chip Fab	334	Computer/Electronics
Metal Fab	332	Fabricated Metal
Transportation Equip.	336	Transportation Equipment
Refinery	324	Refinery
Cold Storage	493	Warehousing
Fruit Storage		
Chemical	325	Chemical
Hi Tech - Silicon		
Misc Manf	339	Miscellaneous
	315	
	313	
	337	
	323	
	326	
	316	
	327	
	335	

*Excludes NAICS 33131 – Alumina and Aluminum Production and Processing

[16] The research team confirmed with Council staff that the industrial sector defined in the Seventh Plan is inclusive of all energy consumption within the 19 3-digit NAICS codes.

Unit of Account

The unit of account describes the metric by which the model quantifies the market. To provide a consistent basis for modeling energy consumption across different motor-driven equipment, the model uses **number of motor HP** as the unit of account. For this model, motor HP refers to nameplate motor HP, or the motor's rated shaft output power.

Both operating characteristics (such as operating hours and load profile) and the size of the system (commonly identified by motor HP) dictate the energy consumption of a motor-driven system. Using number of motor HP as the unit of account allows the model to calculate energy consumption independent of size and allows for comparisons across equipment sizes.

Question 2: How big is the market?

To estimate the region's industrial standalone pump and fan energy consumption, the model must determine the market size. For this model, market size refers to the stock of installed motor HP serving industrial pumps and fans in the region, in each year of the analysis period. The team used seven dimensions to define the industrial pump and fan motor stock in the Pacific Northwest. These dimensions, presented in Table 3, represent the installation characteristics identified as significantly impacting the energy consumption of a motor HP, as well as the year of analysis. Each combination of these dimensions (called "cells") represents a segment of the stock with unique and discrete energy consumption characteristics. Calculating the number of motor HP in the context of these cells allows the team to effectively calculate the energy consumed by each cell.

Table 3: ASD Market Model Dimensions

Dimension	Values	Description
Vintage	Year motor HP was installed	Newly installed motors and motor-driven equipment must comply with federal energy conservation standards (ECS) and energy code requirements, which are more efficient than equipment sold prior to the standard.
Equipment Type	Standalone pumps and fans	Different equipment types have different operating characteristics, like load profile and operating hours.
Facility Type	11 different industries	The U.S. Department of Energy's (DOE) Motor System Market Assessment (MSMA)[17] indicated the saturation of control strategy varies based on the industry.
Motor Size	Installed nominal motor HP range, grouped into 9 bins	Characterizing motor size allows the model to translate from total motor HP to the number of motor-driven equipment in the region. The team identified distinct operating characteristics across 9 different motor size bins.
Load Type	Constant load, variable load	The amount of time equipment spends at various loading points affects the average power draw of the equipment.
Control Strategy	No ASD, ASD	The ability to vary the speed of a motor changes the power-load relationship associated with the system. "No ASD" accounts for all non-ASD load control mechanisms.

[17] United States Industrial Electric Motor Systems Market Opportunity Assessment, December 2002, https://www.energy.gov/sites/prod/files/2014/04/f15/mtrmkt.pdf, accessed 2/6/2022

The calculation of market size (presented in this section) accounts for vintage, equipment type, and facility type. The distribution of motor HP across the remaining three dimensions (motor size, load type, and control strategy) depends on the control strategy serving the motor HP, discussed in detail in Question 3 of this document.

While the market includes all motor HP installed on standalone pumps and fans in the region, some portion of the installed motor HP may not be operating during some time periods (e.g., a pump or fan installed on a production line that does not operate due to a decrease in demand). This motor HP remains installed in the region but does not consume energy when it is not operating. However, it may operate in a future year. While the operating motor HP are the only units that consume energy, the reintroduction of sidelined motor HP impacts both the number of new motor HP sold into the region and the vintage mix of the in-service motor HP in a given year. The model accounts for this dynamic by establishing two categories for the installed motor HP:

> **In-Service Motor HP** represents the installed motor HP that is operating and consuming energy in each year. The model calculates energy consumption for in-service motor HP.
>
> **Out-of-Service Motor HP** represents the installed motor HP that is not operating in a given year but may resume operation in a future year. This includes temporarily shut down production lines that remain in the facility.

The model accounts for changes to the total installed motor HP, as well as changes in in-service and out-of-service motor HP via a stock model that relies primarily on regional gross output information and national data on in-service motor HP in each year. These two variables inform the number and characteristics of in-service motor HP in the region in each year. Changes in out-of-service motor HP in each year and how many out-of-service motor HP are reintroduced in each year (as compared to new sales) are informed by the number of facilities in the region in each year. The model then accounts for motor HP leaving the stock permanently based on equipment-specific retirement rate information.

The following sections present the high-level modeling approach, as well as the specific methods and data sources the team used to calculate the in-service motor HP, retirement rates, and size of the out-of-service segment of the market.

High-Level Modeling Approach

Equation 1 illustrates how the model calculates installed motor HP in each year of the analysis period:

Equation 1: Annual Installed Motor HP

$$\text{InstalledMotorHP}_{t,f,e} = \left(\text{Rate}_{\text{ISHP}_{f,e}} \times \text{Gross Output}_{t,f}\right) + \text{OOSHP}_{t,f,e} - \text{Retirements}_{t,f,e} + \text{New Sales}_{t,f,e}$$

where

InstalledMotorHP	=	Total installed motor HP *(motor HP)*
$Rate_{ISHP}$	=	In-service motor HP Rate *(motor HP/million 2012\$)*
Gross Output	=	Annual regional gross output *(million 2012\$)*
OOSHP	=	Out-of-service motor HP *(motor HP)*
Retirements	=	Annual retirements *(motor HP)*
New Sales	=	Annual sales *(motor HP)*

t = Year
f = Facility type *(e.g., Transportation, Chemical)*
e = Equipment type *(pump or fan)*

The model employs the following process to calculate motor HP installed in each facility type in each year of the analysis period:

1. **Calculate the number of in-service motor HP in each year of the analysis period.** The model calculates a national in-service motor HP/gross output rate for each equipment and facility type in 2018, using national in-service motor HP and national gross output information. The team assumes these national rates are applicable to the region and to every year in the analysis period, and multiplies these rates by annual regional gross output to determine the number of regional in-service motor HP in each year of the analysis period. This allows the model to both scale the national information to the Pacific Northwest and account for region-specific fluctuations in industrial production by facility type. The In-Service Motor HP section describes these data sources in more detail.

   For each year from 2014 on, assess if the in-service motor HP increases or decreases from the previous year. If the in-service motor HP increases, the model first reintroduces out-of-service motor HP as in-service in that year. The model sets a limiter, in terms of percent of out-of-service motor HP, which constrains the amount of out-of-service motor HP that can be reintroduced in each year. Out-of-service motor HP are reintroduced with the same distribution of dimensions as the out-of-service motor HP in the previous year. The Out-of-Service Motor HP Constraints section provides more details on the data informing the size of the out-of-service motor HP market. Once the model reintroduces out-of-service motor HP up to the limiter, it adds new motor HP to the stock until the stock reaches the in-service motor HP in that year. The new motor HP sales introduced has the same distribution of dimensions as the stock. If the in-service motor HP decreases in a given year, the model moves the requisite in-service motor HP to out-of-service. The motor HP moved to out-of-service have the same distribution of dimensions as the stock.

2. **Determine the number of motor HP retired.** The number of retired motor HP in a given year is determined by multiplying the number of in-service motor HP by the retirement rate. Motor HP is retired proportional to the distribution of stock. The Equipment Retirement Rates section describes the data the team uses to inform the retirement rate for each equipment type.

3. **Add new sales of motor HP to the stock.** The model replaces retired in-service motor HP with new sales of motor HP. The dimensions of these new sales are the same as the retired equipment, except the vintage is equivalent to the current year. This step, combined with any new sales from Step 2, determines the number of new motor HP sold into the region in each year, an output of the model.

4. **Determine the ASDs in existing stock.** To characterize control strategy, the model uses ASD saturation information to determine the number of motor HP with and without ASDs for each facility type and equipment type in each year. The model applies the ASD saturation to both existing and new motor HP, allowing the model to account for the fact that ASD installations occur independent of equipment installations and can occur on newly installed or previously existing equipment

5. **Repeat steps 2-5 for all years of the analysis period.**

In-Service Motor HP

The ASD market model uses information on national in-service motor HP and national and regional macroeconomic information to scale the market to the region and models year-over-year changes in in-service motor HP. The Stock Characterization Model Input Workbook provides details and data associated with the calculation of in-service motor HP.[18]

Macroeconomic Trends

Through discussion with the Expert Panel, the team determined that in-service motor HP correlates with an industry's production levels. As production increases, the number of in-service motor HP increases, and the converse is the same. Therefore, the team decided to use year-over-year changes to production to estimate year-over-year changes to in-service motor HP. However, direct information on industry production is not available. The research team investigated three macroeconomic trends as potentially representative of changes in production year-over-year:

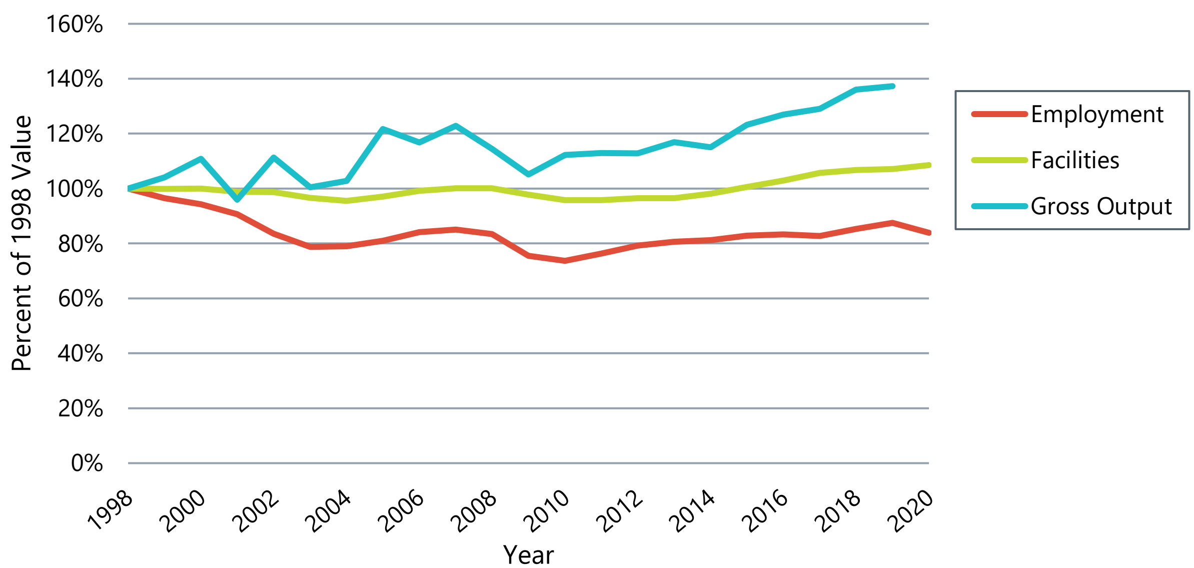
- **Number of Facilities:** The U.S. Bureau of Labor Statistics (BLS) collects quarterly information on the number of operating facilities (physical locations),[19] available at a national and state level and by six-digit NAICS codes.
- **Employment:** BLS also tracks the quarterly number of workers for which an establishment pays unemployment insurance at the national, state, and six-digit NAICS level,[20] which can translate into employment trends in each industry. This data does not capture companies that only have one employee (self-employed individuals), but the team assumes the data collected by BLS is representative of employment in the industrial sector as this sector is unlikely to include companies with only one employee.
- **Gross Output:** The U.S. Bureau of Economic Analysis (BEA) tracks the annual gross output of each industry. Gross output measures the economic growth for a given industry, including intermediate inputs (raw and semi-finished materials used to construct a final product).[21] Gross output differs from Gross Domestic Product (GDP) in that GDP only values the labor and capital required to produce a final product but does not value any of the intermediate steps or inputs. This data is only available at the national level so BEA recommends applying the percentage of national industry-specific GDP made up by each state to the national gross output to calculate the gross output in each state. This assumes the geographic distribution of GDP is the same as the geographic distribution of gross output.

As shown in Figure 3, changes to number of facilities lags changes to employment, which lags changes in gross output. This suggests companies increase or decrease employment quicker than they build or shut down facilities (i.e., companies lay off people before they close down a plant). Additionally, it shows that

[18] The workbook can be found at https://www.bpa.gov/energy-and-services/efficiency/market-research-and-momentum-savings/adjustable-speed-drives-market-research.
[19] Quarterly Census of Employment and Wages, US Bureau of Labor and Statistics, available at https://www.bls.gov/cew/downloadable-data-files.htm, accessed 2/6/2022
[20] Quarterly Census of Employment and Wages, US Bureau of Labor and Statistics, available at https://www.bls.gov/cew/downloadable-data-files.htm, accessed 2/6/2022
[21] Bureau of Economic Analysis, GDP by industry, Chain-Type Real Gross Output by Industry. Available at: https://apps.bea.gov/iTable/iTable.cfm?reqid=150 &step=2&isuri=1&categories=gdpxind, accessed 2/6/2022

gross output is the most sensitive indicator of market change. Decreases in demand will first decrease production, before causing layoffs or facility closings. The research team, with input from the Expert Panel and economists at the BEA, identified gross output as the macroeconomic trend that most closely represents changes in production. Therefore, the team used national and regional industrial gross output data from the BEA to inform how in-service motor HP changes every year. As part of an Expert Panel engagement, Council staff also indicated that while the Seventh Plan uses employment to project industrial load growth, they have since transitioned to using gross output in the 2021 Power Plan.

Figure 3: Regional Industrial Macroeconomic Trends from 1998 to 2020



Source: Cadeo analysis of BLS and BEA data.

The team developed this model before final gross output information was published for 2021. Because of this, the team used the quarterly gross output information for the first two quarters of 2021 (which was available) and the quarterly trend in gross output from 2020 to extrapolate the gross output in the second two quarters in 2021.

Using macroeconomic information allows the model to account for year over year fluctuations in the industrial sector. This allowed the model to account for any impact of the COVID-19 Pandemic in the same way it accounts for any other non-routine event. There were certain industries in the region where gross output decreased in 2020 and 2021 (Refinery, Transportation), potentially attributable to COVID-19, and others where gross output increased (Warehousing, Wood Products).

National In-Service Motor HP

The research team identified two sources of information on national in-service motor HP: the 1998 MSMA and the 2018 MSMA, both published by DOE's Advanced Manufacturing Office. The 1998 MSMA presents a detailed profile of the national stock of motor-driven equipment in industrial facilities in 1998.[22] This report included information on the distribution of installed and in-service motor HP by facility type, equipment type, motor size, and control strategy (including the presence of ASDs). The 2018

[22] United States Industrial Electric Motor Systems Market Opportunity Assessment, December 2002, https://www.energy.gov/sites/prod/files/2014/04/f15/mtrmkt.pdf, accessed 2/6/2022

MSMA updated the information from 1998, expanded the scope to include the commercial sector, and published an online database of detailed results in addition to the report.[23]

The 2018 MSMA represents the best available data on national in-service motor HP collected during the analysis period, and includes detailed information on the statistical significance and uncertainty surrounding the data. As such, the team elected to use 2018 MSMA information directly to calculate the national relationship between in-service motor HP and gross output (shown in Table 4).

In finalizing this model input, the team adopted an iterative calibration process that entailed: 1) running the model with the developed model inputs, 2) performing a high-level reasonableness check on the results, 3) identifying any unreasonable or unrealistic model result and the specific model input causing this result, and 4) adjusting the model input. A similar calibration process is done for all major model inputs across all of BPA's market models to ensure quality control and quality assurance.

Since the in-service motor HP/gross output model input shown in Table 4 ultimately impacts the model's energy consumption output, the team compared the modeled facility-level energy consumption to three external data sources (the Seventh Plan, the 2018 MSMA, and data published by the Energy Information Administration) to assess the model results' reasonableness. The Model Results chapter holds more information on these data sources. In this comparison, the team noted five facility types with unrealistically low or high modeled energy consumption and adjusted the in-service motor HP/gross output rates to either the upper bound or the lower bound of the 90% confidence interval from the 2018 MSMA, ensuring the resulting modeled energy consumption is within a reasonable range. Table 4 presents the final calibrated in-service motor HP/gross output rates used as inputs in the model.

Table 4: National In-Service HP per Gross Output Rates, by equipment type and facility type

Model Facility Type	In-Service Motor HP/Gross Output (motor HP/million $2012)	
	Fans	Pumps
Paper	22,089	32,885
Primary Metal	24,522	14,646
Food	2,231	4,833
Wood*	19,600	5,143
Computer/Electronics*	2,070	2,134
Fabricated Metal	3,968	834
Transportation Equipment*	2,246	2,978
Refinery	1,863	8,200
Warehousing	20,219	1,600
Chemical*	10,943	15,855
Miscellaneous*	15,655	5,897

Source: Cadeo analysis of 2018 MSMA and BEA data.
** Denotes values that have been adjusted as part of the model calibration process. Please refer to the Stock Characterization Model Input Workbook for more information.*

[23] *2018 Motor System Market Assessment Online Database and Full Report*, https://motors.lbl.gov/inventory/, accessed 2/6/2022

To calculate regional in-service motor HP in each year of the analysis period, the model multiplied the national in-service motor HP/gross output rates in Table 4 by annual regional gross output from the BEA.

Market Size Uncertainty

To understand the uncertainty associated with market size, the research team calculated upper and lower bounds for national in-service motor HP/gross output rates. The team used sector-level relative precision data from the 2018 MSMA, +/- 11% at a 90% confidence interval, to inform reasonable bounds by which the in-service motor HP may fluctuate. These bounds are multiplied by the in-service motor HP/gross output rates in Table 4 to generate upper and lower bounds for the in-service motor HP/gross output rates for the sensitivity analysis. Results of the sensitivity analysis are documented in the Sensitivity Analysis chapter at the end of this memo.

Out-of-Service Motor HP Constraints

Identifying a portion of the installed motor HP as "out-of-service" allows the model to account for complexities in how different facility types purchase and retire equipment, as well as how not all installed motor HP is "in-service" in each year. Accounting for out-of-service motor HP also allows the model to calculate new motor HP sold to the region every year. As outlined in Step 2 of the High-Level Modeling Approach, when the market grows (when in-service motor HP increases from the previous year), the model moves motor HP from out-of-service to in-service up to a limit. Once that limiter is reached, new sales are introduced into the region.

The model requires two inputs to calculate out-of-service motor HP: an initial out-of-service motor HP for 2014 (the model base year) and an out-of-service limiter applied to all subsequent years. The initial 2014 out-of-service motor stock is modeled based on the 2014 capacity utilization from the Federal Reserve, which is the national percent of an industry's production capacity that is in use.[24] Table 5 presents the 2014 out-of-service motor HP as a percentage of total installed motor HP.

In each subsequent year, the model limits the percentage of out-of-service motor HP that can be reintroduced into service. This accounts for the assumption that facilities on aggregate will not reintroduce all out-of-service motor HP before installing new motor HP. As part of the calibration process, the team compared the number of installed motor HP to the number of facilities in the region (collected by BLS) and increased/decreased the limiting value so the directionality of the total installed stock's year-over-year changes aligned at the facility type level with the changes in number of facilities in the region. Table 6 presents the return-to-service limiter, as a percentage of out-of-service motor HP that can be returned to service in each year.

Table 5: Out-of-Service HP as Percent of Installed HP in 2014

Facility Type	Paper	Primary Metal	Food	Wood	Comp. - Elec	Fab. Metal	Trans.	Refin.	Ware.	Chem.	Misc Manf
Initial Value	84%	73%	77%	72%	72%	80%	82%	82%	77%	72%	76%

[24] *Industrial Production and Capacity Utilization, https://www.federalreserve.gov/releases/g17/current/, accessed 2/6/2022*

Table 6: Return-to-Service Limiter

Facility Type	Paper	Primary Metal	Food	Wood	Comp. - Elec	Fab. Metal	Trans.	Refin.	Ware.	Chem.	Misc Manf
Limiter	5%	15%	5%	15%	15%	5%	15%	40%	15%	15%	5%

Equipment Retirement Rates

Equipment retirements represent the number of in-service units that retire each year. The model uses the reciprocal of equipment lifetime, shown in Equation 2, to calculate equipment retirement rates.

Equation 2: Equipment Retirement Rate

$$\text{Retirement Rate} = \frac{1}{\text{Equipment Lifetime}_e}$$

where

Retirement Rate	=	The rate at which equipment leaves service in any given year *(% of stock)*
Equipment Lifetime	=	Lifetime of the equipment *(years)*
e	=	Motor-driven equipment *(pump or fan)*

This model relies on equipment lifetime information developed by DOE. Over the course of the regulatory process, DOE develops lifetime analyses to inform rulemakings on different equipment. DOE completed this analysis for pumps[25] and fans[26], and the research team leveraged that work to determine equipment lifetime. The model assumes the lifetime of a pump at 12 years and the lifetime of a fan at 22 years.

Equipment Sales

As mentioned previously, the model calculates and outputs the number of motor HP sold into the region every year serving industrial pumps and fans. The model tracks two types of equipment sales: natural replacements and newly installed equipment. Natural replacement sales are motor HP replacing retired motor HP due to end of useful life and is determined by multiplying the stock of in-service motor HP in a given year by the retirement rate for that equipment. Newly installed equipment are the motors that are installed in the region due to growth in the industrial sector. These installations are impacted by the year-over-year growth in in-service motor HP in each industry and the out-of-service limiter established for that facility type.

[25] DOE's Final Rule Technical Support Document for Pumps, Section 8.3.2.5: https://www.regulations.gov/document?D=EERE-2011-BT-STD-0031-0056, accessed 2/6/2022
[26] DOE's Notice of Data Availability 3 Life Cycle Cost Assessment, Tab "Lifetime"; https://www.regulations.gov/document?D=EERE-2013-BT-STD-0006-0190, accessed 2/6/2022

Question 3: What are the total market savings?

While Question 2 addresses modeling how the stock of industrial pump and fan motor HP in the region is changing over time, Question 3 uses this information to model regional energy consumption of those pumps and fans and, in turn, total market savings from the addition of ASDs. Total market savings represent the difference between the energy consumption that occurred over the analysis period and baseline energy consumption. The market scenario energy consumption accounts for the increase in ASD saturation over the analysis period; that is, models the energy consumption as the market existed. The baseline energy consumption represents the energy consumption of pumps and fans, assuming the ASD saturation does not change throughout the analysis period. Question 3 of the Four Question Framework has two sub-questions that address these two scenarios:

> **Question 3a.** What was the energy use in the year the Power Plan was written?
>
> **Question 3b.** What was the energy use in the following years?

Question 3b determines the actual energy consumed by all in-scope motor-driven systems in each year of the analysis. Addressing this sub-question fulfills this methodology's goal of characterizing how the regional energy consumption of motor-driven systems is changing. Question 3a establishes the baseline energy consumption upon which all market savings due to the adoption of ASDs are based. The difference between the value calculated in each year for **Question 3a** and **Question 3b** represents the total market savings, or total energy saved due to the adoption of ASDs.

The model calculates the total energy consumption in any given year in either the baseline or the market scenario as the sum product of the distribution of motor HP across all model cells in the market in either the baseline or market scenario multiplied by the unit energy consumption (UEC) associated with each model cell, as shown in Equation 3.

Equation 3. Regional Energy Consumption

$$\text{Total Annual Energy Consumption}_{t,s} = \sum_{c} \left(\text{Market Size}_{cv,t} \text{x UEC}_{cv,t} \right)$$

where

Total Annual Energy Consumption	=	Modeled energy consumption *(kWh/year)*
UEC	=	Normalized energy consumption for a single motor HP in a given cell *(kWh/motor HP/year)*
Market Size	=	Number of motor HP in a given cell *(motor HP)*
t	=	Analysis year
s	=	Scenario *(market or baseline)*
c	=	Model cell

This section of the methodology presents the method used to calculate the UEC of each model cell, as well as the motor HP distribution in both the market and baseline scenarios.

UEC Methodology

The first step in calculating the actual and baseline energy consumption is determining the UEC value (in kWh/motor HP/yr) for each model cell. The distribution of motor HP across model cells will vary based on the scenario (market or baseline), but the UEC for a specific cell will not change between scenarios or over time. For example, if a cell has a UEC of 1,000 kWh/motor HP/yr and there are 10 motor HP in this cell in the baseline scenario, then the cell represents 10,000 kWh/yr of energy consumption. The same cell may only hold 5 motor HP in the market scenario, but that 5 motor HP is multiplied by the same 1,000 kWh/motor HP UEC and consumes 5,000 kWh/yr in the market scenario.

The research team reviewed several approaches for characterizing industrial standalone pump and fan energy consumption in the region and used this information to develop a single UEC equation that covers the entire model scope. The following sections present the UEC equation as well as the inputs used in the equation.

UEC Equation

The research team began the process of modeling energy consumption for each model cell by reviewing previously generated equations for calculating pump and fan energy consumption in the region. The RTF established three unit energy savings (UES) measure sets for equipment covered in the scope of this model: Efficient Pumps[27], Commercial & Industrial Fans[28], and Variable Speed Drives.[29] The first two measure sets calculate energy savings associated with an increase in equipment efficiency, while the third measure set calculates energy savings associated with the addition of ASDs to a pump or fan. All three measure sets use information from DOE's commercial and industrial pumps[30] and fans[31] rulemaking analyses (as applicable), as well as field research on regional pump operation completed by NEEA in 2019.[32]

The team identified two main differences between the market model and the RTF UES measure sets that limited the applicability of the RTF's energy consumption equations to the model:

Differences in scope: The scopes of the RTF UES measure sets are narrower than the ASD market model scope. The RTF measures align with equipment that DOE regulates (for pumps) or considered regulating (for fans) and for which specific rating metrics have been developed to characterize equipment efficiency – the pump efficiency index (PEI) for pumps and fan efficiency index (FEI) for fans. These metrics define efficiency relative to a minimum efficiency standard set forth in their respective rating procedures and are undefinable for equipment outside the scope of those metrics. The ASD market model covers equipment outside the scope of these rating methodologies (both in size and equipment class) so using the RTF's UES measure set equations would lead to model cells with undefined equipment efficiencies.

Differences in model granularity: The RTF UES measure sets couple load type with control strategy, using the presence of a drive to identify an average load profile. The goal of this market model is to

[27] *Efficient Pumps UES Measure*, https://rtf.nwcouncil.org/measure/efficient-pumps, accessed 2/6/2022
[28] *Commercial & Industrial Fans UES Measure*, https://rtf.nwcouncil.org/measure/commercial-industrial-fans, accessed 2/6/2022
[29] *Variable Speed Drives UES Measure*, https://rtf.nwcouncil.org/measure/variable-speed-drives, accessed 2/6/2022
[30] *Rulemaking Docket: Energy Efficiency Standard for Pumps*, https://www.regulations.gov/docket?D=EERE-2011-BT-STD-0031, accessed 2/6/2022
[31] *Rulemaking Docket: Energy Conservation Standard for Commercial and Industrial Fans and Blowers*, https://www.regulations.gov/docket?D=EERE-2013-BT-STD-0006, accessed 2/6/2022
[32] *Extended Motor Products Savings Validation Research on Clean Water Pumps and Circulators*, https://neea.org/resources/extended-motor-products-savings-validation-research-on-clean-water-pumps-and-circulators, accessed 2/6/2022

calculate savings from the adoption of ASDs on both constant load and variable load systems, which necessitates decoupling the control strategy and load type. In addition, the RTF UES measure sets calculate current practice baseline savings, and do not need to account for differences in installation year. To characterize changes in energy consumption over time, the model must account for changes in average motor and equipment efficiency over time, which necessitates the inclusion of "vintage" as a model dimension.

To account for out-of-scope equipment and capture model dimensions not considered in the RTF measures, the team developed a model-specific UEC equation shown in Equation 4, and vetted the equation with the Expert Panel.[33] The model uses this equation to calculate the energy consumption of all in-scope industrial standalone pumps and fans.

Equation 4: Unit Energy Consumption

$$UEC = FullLoadPowerDraw_{e,v,m} \times LoadingFactor_{e,g,c} \times OpHrs_{e,f,m} \times OpFactor_{e,c}$$

where

UEC	=	Annual unit energy consumption per motor HP *(kWh/HP/year)*
FullLoadPowerDraw	=	Power draw of the equipment at full load (operating at its design point) *(kW)*
LoadingFactor	=	The relationship between the load profile of a given unit and the power load relationship associated with the control strategy. This factor accounts for the difference in part load energy consumption due to load type and control strategy (*unitless)*
OpHrs	=	Average annual operating hours of the equipment *(hours/year)*
OpFactor	=	Operating factor that adjusts for real-world operating conditions (*unitless)*
m	=	Motor size bins *(e.g., 1-5 HP, 6-10 HP)*
e	=	Equipment type *(pump or fan)*
v	=	Equipment vintage *(e.g., 2016, 2017)*
f	=	Facility type *(e.g., Transportation, Chemical)*
g	=	Load type *(constant load or variable load)*
c	=	Control strategy *(ASD control or non-ASD control)*

UEC Variables

The UEC equation has four components: full load power draw, loading factor, operating hours, and operating factor. The load factor converts the full load power draw to average power draw, which is adjusted by the operating factor to account for real-world operating characteristics. The operating hours then converts average power draw to average annual energy consumption.

This section describes how the research team determined values for each component. The UEC Model Input Workbook contains more details on the possible values and analysis performed for each variable.[34]

[33] A draft version of the UEC equation included a "Resizing Factor", which accounted for motor downsizing due to improvements in equipment efficiency. The Expert Panel noted that motors are rarely, if ever, downsized due to an increase in equipment efficiency so the team removed the resizing factor from the UEC equation.

[34] The workbook can be found at https://www.bpa.gov/energy-and-services/efficiency/market-research-and-momentum-savings/adjustable-speed-drives-market-research.

Full Load Power Draw

Full load power draw represents the power draw, per motor HP, of the equipment at full load. This component of the UEC equation, shown by Equation 5, is impacted by motor oversizing, motor efficiency, drive efficiency, and the equipment efficiency adjustment term.

Equation 5: Full Load Power Draw

$$FullLoadPowerDraw = \frac{0.746}{OF_{e,m} \times \eta_{motor_{e,v,m}} \times \eta_{asd_{m,g,c}} \times Eff_{equip_{e,v,m}}}$$

where

0.746 = HP to kW conversion factor
OF = Oversize factor *(unitless)*
η_{motor} = Motor efficiency *(%)*
η_{asd} = ASD electricity conversion efficiency *(%)*
Eff_{equip} = Equipment efficiency relative to installed stock equipment efficiency *(unitless)*
e = Equipment type *(Pump or Fan)*
m = Motor size bins *(e.g., 1-5 HP, 6-10 HP)*
v = Equipment Vintage *(e.g., 2016, 2017)*
g = Load type *(constant load or variable load)*
c = Control strategy *(ASD control or non-ASD control)*

Full load power draw serves as a starting point for understanding motor-driven system energy consumption and acts as an upper bound for a system's power draw. The sections below describe each of the variables used to calculate full load power draw.

Oversize Factor (OF)

The motor oversize factor accounts for the tendency of designers/installers to oversize motors beyond the equipment's demand. Oversizing occurs for two reasons: 1) motors are sold in nominal sizes and often the equipment demand falls between two nominal motor sizes, and 2) oversizing ensures the system can accommodate fluctuations in system demand.

The market model uses oversize factors from the RTF measure sets. For pumps, the oversize factors were determined through NEEA's Pump Research[35] and used in the RTF measures for Efficient Pumps. This research indicated that motor oversizing (as a percentage of the motor size) decreases as motor size increases. For fans, the model assumes motor oversizing is constant across the range of motor sizes, which aligns with DOE's fan energy consumption calculation methodology and the RTF measures for Commercial and Industrial Fans.

Motor Efficiency (η_{motor})

The motor efficiency term accounts for electric losses as the motor converts electric energy to mechanical energy. The model uses an average motor efficiency, calculated for full load operation, which varies

[35] *Extended Motor Products Savings Validation Research on Clean Water Pumps and Circulators*, https://neea.org/resources/extended-motor-products-savings-validation-research-on-clean-water-pumps-and-circulators, accessed 2/6/2022

based on motor size bin and motor vintage. As motors size increases, motor efficiency increases,[36] which necessitates different motor efficiency values based on motor size. To account for differences in vintage, the model calculates average installed stock motor efficiency in the model's base year (2014). In each subsequent year, the average efficiency value represents the market average motor efficiency, or the average efficiency of motors sold in that year.

The model assumes motor efficiency is constant unless impacted by an energy conservation standard (ECS) (DOE established an ECS for electric motors, with compliance required starting in 2016). The research team considered modeling changes in average motor efficiency due to market forces, but DOE's Electric Motor ECS supporting documentation[37] suggested that market-driven changes in motor efficiency distribution have a negligible effect on average motor efficiency values.

Drive Efficiency (η_{asd})

Drive efficiency accounts for electrical efficiency losses that occur within the ASD. This variable only accounts for electrical losses; the power load relationship curves account for the mechanical losses from non-electric control devices (discussed in more detail in the Loading Factor section). The model assumes drive efficiency varies based on motor size and load type, based on information from DOE's Advanced Manufacturing Office,[38] and calculates an average ASD efficiency differentiated by equipment type, motor size bin, and load type.

Equipment Efficiency Adjustment Factor (Eff_{equip})

The equipment efficiency adjustment factor is the ratio of average equipment efficiency of equipment sold in a given year, as compared to the average installed equipment efficiency of model's base year, 2014. In other words, it accounts for the reduction in energy consumption due to improvements in equipment efficiency over time since newer, more efficient equipment will require less power to drive the same load.

Equipment efficiency adjustment factors are differentiated based on equipment type, motor size bin, and equipment vintage. The model uses data from DOE's Compliance Certification Database[39] and regulatory analyses to inform this factor. The model assumes there is no change in average equipment efficiency in the absence of a federal standard requiring changes in equipment efficiency. Therefore, the efficiency adjustment factor for pumps prior to the implementation of DOE's Commercial and Industrial Pumps ECS in 2020 is equal to one. Industrial fans remain unregulated, so the fan efficiency adjustment factors are equal to one across all model dimensions. The research team considered modeling changes in average equipment efficiency due to market forces, but the team did not identify enough information to justify accounting for market transformation.[40]

[36] *Rulemaking Docket: Energy Conservation Standard for Electric Motors*, https://www.regulations.gov/docket/EERE-2010-BT-STD-0027, accessed 2/6/2022

[37] *Rulemaking Docket: Energy Conservation Standard for Electric Motors*, https://www.regulations.gov/docket/EERE-2010-BT-STD-0027, accessed 2/6/2022

[38] DOE Advanced Manufacturing Office, Motor Systems Tip Sheet #11, Adjustable Speed Drive Part Load Efficiency, https://www.energy.gov/sites/prod/files/2014/04/f15/motor_tip_sheet11.pdf, accessed 2/6/2022

[39] DOE Compliance Certification Database, https://www.regulations.doe.gov/certification-data/#q=Product_Group_s%3A*, accessed 2/6/2022

[40] NEEA is currently working on a market transformation initiative focused on increasing pump and fan efficiency, but their work to date is almost exclusively concentrated in the commercial sector.

Loading Factor

The loading factor represents the average part load power draw of the equipment, given as a percentage of full load power draw. For example, a loading factor of 0.62 indicates that, on average, the equipment operates at 62% of its full load power draw. The loading factor accounts for the varying operating points of a piece of equipment and the efficiency with which the equipment's control strategy meets the load. Two components determine the loading factor: the load profile and the power-load relationship (PLR) curve.

> **Load Profile:** The load profile defines the percentage of time spent at each load point. The model considers four design flow load points in defining load profile: 25%, 50%, 75%, and 100%.

> **PLR Curve:** The PLR curve defines the percent of full load power required to meet each of the load points. The model considers the same four design flow load points: 25%, 50%, 75%, and 100%.

Equation 6 shows how the research team calculated the loading factor for a motor-driven system. The following sections present the information used to determine the load profile and PLR curves for the model.

Equation 6: Loading Factor Calculation

$$\text{LoadingFactor}_{e,g,c} = \sum_{i=1}^{4} \omega_i \times P_i$$

where

$LoadingFactor$ = Loading Factor (*unitless)*
ω_i = The load profile, defining the percentage of time spent at load point i
P_i = The PLR curve, defining the percentage of full load power required to meet load point i
i = A given design flow load point (25%, 50%, 75%, 100%)
e = Equipment type *(Pump or Fan)*
g = Load type *(constant load or variable load)*
c = Control strategy *(ASD control or non-ASD control)*

Load Profiles

Load profiles account for the percentage of time a system spends at various load points over the course of a year. The model's load profiles represent average load profiles for all equipment of the same equipment type and load type. The model establishes load profiles for each equipment type and the following two load types:

> **Constant Load:** Equipment that operates at a single load point for 90% or more of their operating hours.

> **Variable Load:** Equipment that spends more than 10% of their operating hours at more than one load point.

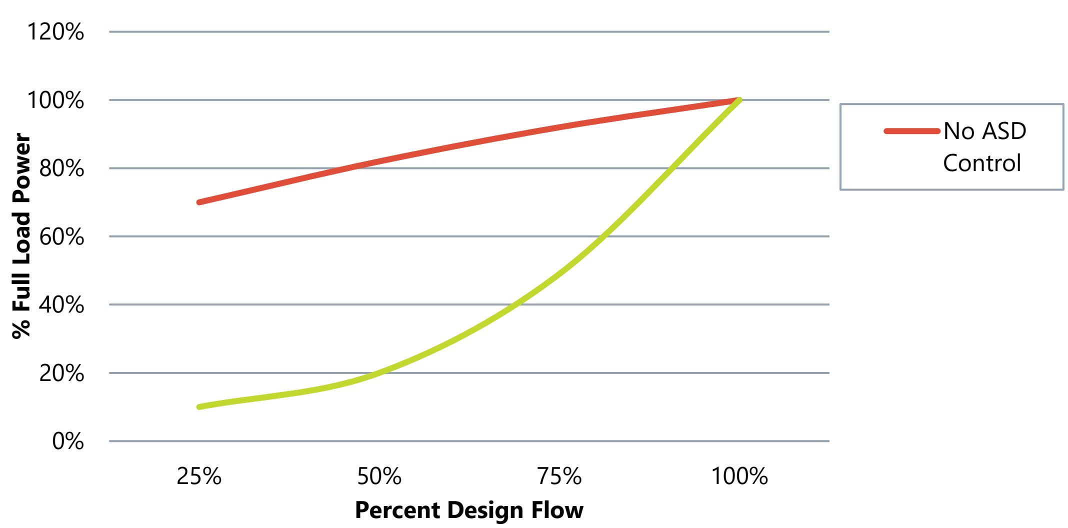
DOE's Commercial and Industrial Pumps ECS supporting documentation and NEEA's Pumps Research are the two best resources on pump load profile that account for load variability. The research team used this information to calculate a weighted average load profile for each load type. The weights applied to the load profiles from each data source were refined by the Expert Panel. DOE's Commercial and Industrial Fans rulemaking analysis is the only resource available that provides information on fan load profile and load variability. Through collaboration with the Expert Panel, the team applied DOE's fan load profiles directly.

PLR Curves

As a system's load increases, the power required to meet that load changes. PLR curves represent the relationship between the power draw of the motor-driven system and the load the system is serving. Different control strategies have different PLR curves, resulting in each having a different impact on energy consumption. PLR curves are dependent on the equipment type (pump or fan), control strategy (non-ASD control or ASD control), and load type (constant load or variable load). The PLR curves used in the model are based on curves from either "Flow Control", a Westinghouse publication cited in multiple resources[41] or EnergyPlus modeling documentation from Lawrence Berkeley National Labs (LBNL).[42]

ASD control PLR curves represent the power-load relationship for an ASD. There is no variation between the constant load and variable load ASD control PLR curves. Non-ASD control PLR curves represent a weighted average of all control strategies that are not ASDs; both uncontrolled systems (no control or bypass flow control[43]) and systems with mechanical control fall into this category. This results in two PLR curves for pumps (Figure 4) and three PLR curves for fans, as the fans' non-ASD control PLR curves are load-type dependent.

Figure 4: Model Pump PLR Curves



Source: Cadeo analysis of available power-load relationship curves

[41] Ernest Orlando Lawrence Berkeley National Laboratory (LBNL). (2013, April 1). EnergyPlus Engineering Reference: The Reference to EnergyPlus Calculations.
[42] Westinghouse (no date). Bulletin B-851, F/86/Rev-CMS 8121. Flow Control.
[43] No control and bypass flow control have the same PLR curve.

As shown in Equation 6, the product of the PLR curves and load profiles produce the Loading Factor. The model includes four Loading Factors for each Equipment Type, corresponding to the four combinations of load type (constant, variable) and control strategy (ASD control, Non-ASD control) that are possible.

Operating Factor

The UEC equation uses the operating factor to align the modeled power draw with metered data. Operating factor, shown in Equation 7, is the ratio of metered power draw to the power draw predicted by the UEC equation. An operating factor of one indicates that the UEC equation is consistent with real-world average power draw, whereas deviation above or below indicates that the model underestimates or overestimates the power draw, respectively. Incorporating the operating factor allows the modeled UECs to characterize actual energy consumption more accurately.

Equation 7: Operating Factor

$$\text{OpFactor}_{e,c} = \frac{\text{AvgPower}_{\text{metered}}}{\text{AvgPower}_{\text{modeled}}}$$

$AvgPower_{metered}$ = Average power draw per HP based on metered data *(kW/HP)*

$AvgPower_{modeled}$ = Average power draw per HP modeled as the product of the Full Load Power Draw and Loading Factor terms in the UEC equation *(kW/HP)*

e = Equipment type *(Pump or Fan)*

c = Control strategy *(ASD control or non-ASD control)*

The research team developed a database of metered operating data using supporting documents from BPA's industrial custom projects completed from 2015 through 2021. This database contained both metered energy consumption, as well as operating hours, equipment type, control strategy, and load type. This allowed the research team to calculate average power from the metered information, and analyze the operating factor based on equipment type, control strategy, and load type.

The available data included operating information for 17 constant load systems and 145 variable load systems. The research team, with input from the Expert Panel, concluded that the metered average power value for constant load systems was not robust enough due to the small sample size. As a result, the model uses an operating factor of one for all constant load systems. For variable load systems, there was enough metered data to generate statistically meaningful operating factors for variable load systems disaggregated by equipment type (but not by control strategy). Therefore, the model uses a separate operating factor for variable load pumps and variable load fans to reduce the uncertainty associated with modeled UEC variables.

Operating Hours

The research team reviewed various resources with pump and fan operating hour data to calculate average operating hours. The Northwest Industrial Motor Database[44] is a regional dataset with installation and operating characteristics of over 20,000 motor records. The team analyzed information on over 2,000 pumps and 2,500 fans and determined that average operating hours for industrial pumps

[44] "Northwest Industrial Motor Database", https://rtf.nwcouncil.org/subcommittee/northwest-industrial-motor-database-summary, accessed 2/6/2022

vary based on motor size and facility type whereas average operating hours for industrial fans vary only by facility type.[45]

The research team also reviewed the average operating hours presented in the 2018 MSMA, NEEA's Pumps Research, and DOE's Commercial and Industrial Pump and Fan rulemaking analysis. The team used the operating hour values calculated using the Northwest Industrial Motor Database because of its regional applicability, size of the dataset, and comprehensiveness of the data scope.

UEC Results

Using the UEC equation and developed inputs for each variable, the research team calculated 6,336 unique UEC values that vary based on equipment type, vintage, motor size, facility type, load type and control strategy. The three dimensions with the greatest impact on energy consumption are equipment type, control strategy, and load type. Table 7 shows the range of UECs associated with these dimensions. The difference between the minimum and maximum UECs within each grouping spans from 800 to ~2,000 kWh/HP. These ranges are mainly driven by differences in operating hours, which are dependent on motor size and facility type.

Table 7: ASD Market Model UEC Ranges, by equipment type, control strategy, and load type

Equipment Type	Control Strategy	Load Type	UEC Range (kWh/HP/year)
Pumps	Non-ASD control	Variable	2,070 - 3,860
		Constant	2,548 - 4,752
	ASD control	Variable	1,439 - 2,628
		Constant	2,167 - 3,967
Fans	Non-ASD control	Variable	3,020 - 4,502
		Constant	3,126 - 4,660
	ASD control	Variable	1,452 - 2,259
		Constant	2,973 - 4,534

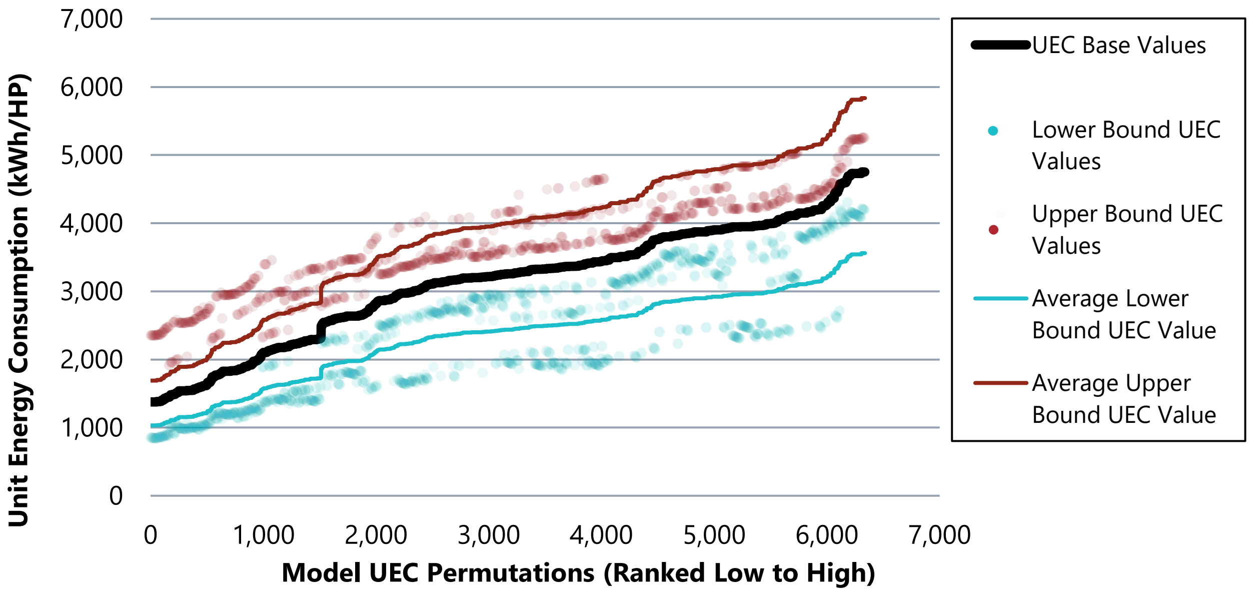
UEC Uncertainty

To understand the uncertainty associated with the UECs, the research team evaluated each equation variable independently and estimated a high value and a low value for operating hours, load profile, oversize factor, and motor, equipment, and drive efficiency. Then, using these high and low inputs for each variable, the team calculated an upper bound and lower bound for each UEC (meaning, each of the 6,336 unique UECs has an upper bound and lower bound).

Figure 5 shows the model UECs arranged from smallest to largest, with each UEC's upper and lower bound. On average, the upper bound UEC value is 23% greater than the associated model UEC, and the average lower bound UEC value is 25% less than the associated model UEC. This range represents the compounded uncertainty of all equation variables and serves to illustrate the maximum range of uncertainty on the model UECs. The Sensitivity Analysis chapter at the end of this memo discusses the impact the uncertainty associated with individual UEC variables has on the model results.

[45] The analysis assumes that facility type can serve to characterize the average equipment application in a facility.

Figure 5: Model UECs and Associated Upper and Lower Bounds



To further corroborate the model UEC values, the research team compared the model UECs with similar energy consumption estimates in existing regional resources, primarily the RTF Efficient Pump and Variable Speed Drives UES measure sets.[46] Portions of the data used in the model's UEC equation are consistent with data used by the RTF. However, there are differences in both the calculation methodology and data used (due to differences in scope and model granularity). The sections below describe the differences between the RTF UES measure sets and the model's UEC equation and compare the resulting UECs.

Comparison to RTF Efficient Pumps UECs

The RTF Efficient Pump measure set calculates energy savings associated with an increase in pump equipment efficiency rather than the installation of an ASD. The measure set uses control strategy to determine load profile, so it only has UEC estimates for pumps with constant speed/constant load equipment or variable speed/variable load equipment. Table 8 shows that the ranges of UEC values from the RTF measure set and the ASD market model are similar. The differences between these two sources stem from different operating hour data, the introduction of loading factors to replace the PEI metric, and the inclusion of an operating factor in the model UEC.

Table 8: Model Pump UEC Ranges Compared to RTF Efficient Pump UEC Ranges

Control Strategy and Load Type	RTF Pump UEC Range (kWh/HP/year)	Model Pump UEC Range (kWh/HP/year)
Non-ASD Control, Constant Load	3,371 - 4,981	2,548 - 4,752
ASD Control, Variable Load	1,740 - 2,518	1,439 - 2,628

[46]The structure of the RTF's Commercial and Industrial Fans measure set does not provide information to develop a comparison. For comparisons to other regional resources such as the draft 2021 Power Plan supply curves, see the "UEC Comparison" tab in the UEC Model Input Workbook.

Comparison to RTF Variable Speed Drives UECs

The RTF Variable Speed Drives (VSD) measure set calculates the energy savings associated with the installation of a VSD on pumps and fans. The RTF VSD measure for fans uses a calculation methodology similar to the model's UEC equation, incorporating different PLR curves associated with different control strategies. For pumps, the measure set is based on operating data from NEEA's Pumps Research.

The research team compared the RTF's UEC estimates for fans to the model UECs, acknowledging that the RTF measures used a weighted average distribution of constant load and variable load systems, whereas the ASD market model has separate UECs for the two load types. Comparing the RTF's UEC values for pumps to the model UECs is not practical, as the RTF values represent weighted average values based on the distribution of real-world pumps, whereas the ASD market model UECs represent a range of possible values, calculated individually for each pump installation.

Table 9 compares the RTF VSD measure set's calculated UECs for fans to the range of fan UECs in the ASD market model. The ranges are similar in that non-ASD controlled fans have substantially higher energy consumption than ASD-controlled fans. The difference between the RTF and model UECs is greater for ASD-controlled fans than non-ASD controlled fans because the weighted average distribution of constant load and variable load systems used by the RTF has a larger impact on ASD-controlled fans UECs.

Table 9: Model Fan UEC Ranges Compared to RTF VSD Retrofit Fan UEC Ranges

Control Strategy	RTF Fan UEC Range (kWh/HP/year)	Model Fan UEC Range (kWh/HP/Year)
Non-ASD Control	3,659 - 4,702	3,020 - 4,660
ASD Control	2,593 - 3,169	1,452 -4,534

Model Scenarios

With a UEC for each model cell, the model can calculate total annual energy consumption by multiplying each UEC with the number of motor HP in each model cell and summing energy consumption across all model cells in each year. This allows the model to calculate the energy consumption of the market as it existed (market scenario) and the energy consumption of the baseline (baseline scenario), the difference of which is total market savings. This section presents the method for determining the distribution of motor HP across model cells for the market scenario and the baseline scenario.

Market Scenario

The market scenario represents the energy consumption of the installed stock as it existed in each year of the analysis period. In calculating the market size in Question 2, the research team characterized the size and distribution of motor HP across year, equipment type, and facility type. The model accounts for three additional dimensions in distributing installed motor HP into the model cells: motor size bin, load type, and control strategy. This section addresses these three additional variables, as opposed to including them in Question 2, because they are impacted by the motor HP's control strategy, which is the stock characteristic that varies between the market and baseline scenario. As documented in the following sections, the research team used available stock information and the model's stock turnover function to understand the distribution of motor HP across these additional dimensions in each year of the analysis.

Motor Size Bin

The team used information from the 2018 MSMA to distribute in-service motor HP across motor size bins. Through a review of the information provided in the 1998 and 2018 MSMA, the team determined that the distribution by motor size bin varies based on equipment type, facility type, and control strategy. The team also determined that there was little change in the motor size distribution between the two reports, so elected to apply the 2018 MSMA's motor size distribution to all years in the analysis period.

Available regional data supports using distributions from the 2018 MSMA as representative of the regional stock and also supports the assumption that the distribution is not changing over the analysis period. BPA fielded a data collection effort in 2021 to characterize sales of industrial pumps and fans in the region.[47] The motor size distribution in the collected sales data, covering years 2014–2020, while not representative of the entire region, is similar to the 2018 stock distribution from the MSMA. This supports the assumption that the stock distribution is not changing over the analysis period since sales entering into the region have a similar motor size distribution as the stock. The 2014 Industrial Facilities Stock Assessment (IFSA) collected information on motor size for approximately 2,000 motors serving pumps and fans at over 51 different industrial sites.[48] As shown in Table 10, the distribution of motors by motor size bin in the IFSA is aligned closely with the distribution in the 2018 MSMA, both showing the majority of motors concentrated in the three smallest motor size bins. The information in the IFSA is not statistically significant, so the research team did not use this information directly in the model. However, the similarities in the IFSA and MSMA distributions corroborate the assumption that the national distribution by motor size is representative of the regional distribution.

Table 10: Distribution of Motors, by equipment type and motor size bin

Motor Size Range	Distribution of Motors, by motor size bin					
	2014 IFSA			2018 MSMA		
	Pumps	Fans	Pumps and Fans	Pumps	Fans	Pumps and Fans
1-5 HP	29%	40%	35%	35%	53%	47%
6-20 HP	31%	28%	29%	36%	30%	32%
21-50 HP	22%	17%	19%	15%	12%	13%
51-100 HP	12%	8%	10%	8%	4%	5%
101-200 HP	4%	5%	5%	4%	1%	2%
201-500 HP	1%	1%	1%	2%	1%	1%
501-1000 HP	0%	0%	0%	0%	0%	0%
1000+ HP	0%	0%	0%	0%	0%	0%
Total	100%	100%	100%	100%	100%	100%

[47] "Industrial Pump, Fan, and Adjustable Speed Drive Sales Data Collection Summary Memo," March 2022, https://www.bpa.gov/-/media/Aep/energy-efficiency/momentum-savings/220324-bpa-ind-pump-fan-asd-data-collection-summary.pdf accessed 5/24/2022
[48] NEEA Industrial Facility Site Assessment, https://neea.org/data/industrial-facilties-site-assessment, accessed 02/06/2022

The team determined that the distribution of motor HP by motor size bin is impacted by the control strategy of the motor HP. During qualitative interviews the team conducted in 2021, market actors indicated that ASDs historically have been installed on larger motor HP equipment.[49] This is due to the larger energy savings (and shorter payback period) associated with larger equipment. To account for this, the team developed a motor size distribution of motor HP for each equipment type, facility type, and control strategy. Please refer to the Stock Characterization Model Input Workbook for details on this distribution.[50]

Load Type

The team used information from the 2018 MSMA to inform the distribution of motor HP by load type. The model incorporates a unique load-type distribution for each equipment type and control strategy.

Both the 1998 and 2018 MSMA included information on load type, but the 1998 MSMA noted that its estimates were questionable. The 2018 MSMA provided information on load variability, which included the distribution by load type and load factor (load factor being a single value used by the 2018 MSMA to determine the percent loading of the system). Using this information, the team determined the distribution of motor HP by load type for each control strategy and equipment type, shown in Table 11.

Table 11: Distribution of Motor HP, by equipment type, load type, and control strategy

Load Type	Non-ASD Control		ASD Control		All Control Types	
	Pumps	**Fans**	**Pumps**	**Fans**	**Pumps**	**Fans**
Constant Load	71%	63%	23%	7%	55%	44%
Variable Load	29%	37%	77%	93%	45%	56%

The 2018 MSMA provides information on load type by facility type, but approximately half of the distributions by facility type are unknowable due to a lack of statistical significance in the values. The research team acknowledges there may be differences in load type by facility type, but without more granular information, uses a sector-level distribution as representative of all facility types. The model seeks to maintain the load type distribution across all motor HP as well as within ASD-controlled motor HP. If the ASD saturation within a facility type increases to a point where the model cannot maintain both distributions, the model prioritizes the ASD saturation input and make small adjustments to the load type distribution.

Control Strategy

The model dimension "control strategy" indicates the presence or absence of an ASD, which is the driver of energy savings in the model. To determine the saturation of ASDs in the Pacific Northwest, the team calculated the national saturation of ASDs for each facility type and equipment type using information from the 1998 and 2018 MSMAs. The team then adjusted these values to account for differences

[49] "Adjustable Speed Drive Market Actor Interviews", March 2021, *https://www.bpa.gov/-/media/Aep/energy-efficiency/momentum-savings/2021-bpa-asd-market-actor-interview-findings.pdf* accessed 5/25/2022
[50] The workbook can be found at https://www.bpa.gov/energy-and-services/efficiency/market-research-and-momentum-savings/adjustable-speed-drives-market-research.

between the national and regional ASD adoption rates, as informed by region-specific proprietary market data and ASD market actors with experience in regional ASD sales and installations.

National ASD Saturation

National ASD saturation information indicated that, for pumps and fans, the adoption of ASDs increased steadily over the course of the model period. The team calculated national ASD saturation using information from the 1998 and 2018 MSMA. This data represents the best characterization of national ASD Saturation, as it presents this information as both percent of motors and percent of energy consumption, as well as indicating the uncertainty associated with the estimate.

1998 MSMA: The 1998 MSMA provided ASD saturation as a percent of energy consumption with ASDs and percent of motors with ASDs. Using these two ASD saturation values, along with information on the differences in energy consumption by motor size bin, the team calculated ASD Saturation as a percent of motor HP.

2018 MSMA: The 2018 MSMA included information on the percent of motor HP equipped with ASDs, by equipment type and facility type. This data did not require any transformation to align with the model. The report also included information on the number of motor HP for which the control strategy was unidentifiable. The team assumed 100% of this "unknown control strategy" motor HP did not have ASDs.[51]

The team calculated the annual ASD saturation for each equipment type and facility type in the analysis period by linearly interpolating between the ASD saturation values from these two data sources. Table 12 presents the resulting ASD saturations, showing that the national saturation of ASDs has increased by 32% since 2014 for fans and 35% for pumps.

Table 12: National ASD Saturation, by equipment type and year

Equipment Type	Percent of Motor HP with ASDs							
	2014	2015	2016	2017	2018	2019	2020	2021
Fans	19%	20%	21%	22%	22%	23%	24%	25%
Pumps	23%	23%	24%	25%	27%	28%	30%	31%

Regional ASD Saturation

To understand regional trends in ASD saturation, the team purchased two proprietary market reports that included information on the regional and national sales of ASDs into the industrial pump and fan market between 2010 and 2021. Prior to purchasing this data, the team assessed the reliability of each report based on the reputability of the company, the application of region-specific primary data, the methodology for extrapolating market sales, and the scope covered by the data. Through this review, the team identified two companies, Global Market Insights (GMI)[52] and Industry Arc[53] that offered reliable market data. The team preferred GMI over Industry Arc, as they provided data over a longer period and provided more information on the methodology used to extrapolate collected data to the whole market.

[51] This assumption results in a conservative estimate of 2018 ASD saturation, as it is likely that some percentage of the "unknown control strategy" motor HP is equipped with an ASD.
[52] Global Market Insights, https://www.gminsights.com/
[53] Industry Arc https://www.industryarc.com/

The team purchased both reports to facilitate a review that corroborated or refuted any regional market trends but used GMI as the data in any model input calculations.

Both proprietary market reports show that the region represents a disproportionately larger percent of national ASD sales, when compared to the size of the region's industrial sector relative to the nation. On average between 2010 and 2021, the region represents 6.5% of the nation's ASD sales but only 3.5% of the national industrial gross output.[54] Table 13 compares the regional ASD sales (as a percent of the nation) to the regional industrial gross output (as a percent of the nation), illustrating that ASDs have been adopted at a higher rate in the Pacific Northwest than nationally in the past decade. This trend is supported by market research conducted by BPA,[55] the Expert Panel, and insight from ASD market actors.

Table 13: Regional ASD Sales and Regional Gross Output, as a percent of the national value

Value	Year											
	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Regional Gross Output	3.5%	3.4%	3.3%	3.3%	3.2%	3.4%	3.5%	3.6%	3.7%	3.6%	3.7%	3.7%
Regional Sales, Fans	6.2%	6.2%	6.1%	6.1%	6.1%	6.0%	6.0%	5.9%	5.9%	5.8%	5.8%	5.8%
Regional Sales, Pumps	6.8%	6.8%	6.8%	6.8%	6.9%	6.9%	6.9%	6.9%	6.9%	6.9%	7.0%	7.0%

The team used the information presented in Table 13, as well as the national ASD saturation ((shown in Table 12)) to calculate the regional ASD saturation, accounting for the higher regional ASD adoption rate than is seen nationally. To accomplish this, the team used the following process:

1. The team calculated the number of ASD sales for pumps and fans in the region, assuming the national ASD saturation (shown in Table 12) applies to the region in each year of the analysis period. These values represent the number of ASD sales if the region adopted ASDs at the same rate as the nation.
2. The team then calculated the percent larger the region's ASD market share (the last two rows in Table 13) is compared to the region's industrial gross output share (the first row in Table 13). The team scaled the regional ASD sales (calculated in Step 1) up using the calculated percentages shown in Table 14.

[54] The team performed the same comparison using the other two macroeconomic indicators assessed in Question 2 of this document, number of employees and number of operating facilities, and saw similarly that the region's ASD market was disproportionately larger than the region's industrial sector. The team used gross output as the primary indicator in this comparison because GMI used GDP (which is derived from gross output) as a scaling factor in their methodology.
[55] "Adjustable Speed Drive Market Actor Interviews", March 2021, *https://www.bpa.gov/-/media/Aep/energy-efficiency/momentum-savings/2021-bpa-asd-market-actor-interview-findings.pdf* accessed 5/25/2022

Table 14: Percent Larger the Region's ASD Market Share Relative to the Region's Industrial Gross Output Share

Equipment	Year											
	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Fans	81%	83%	85%	84%	87%	75%	70%	67%	61%	61%	58%	54%
Pumps	97%	101%	105%	106%	111%	100%	96%	94%	89%	91%	90%	87%

3. Starting in 2010, the team introduced the scaled regional ASD sales (calculated in Step 2) into the in-service stock through a stock turnover model, calculating an adjusted regional ASD saturation for pumps and fans.

Table 15 shows the regionally adjusted ASD saturation for the analysis period, as a percent of motor HP. When compared to the national ASD saturation in Table 12, the regional has a higher baseline ASD saturation (ASD saturation in 2015), and larger increase in ASD saturation across the analysis period.

Table 15: Regional ASD Saturation, by equipment type and year

Equipment	Percent of Motor HP with ASDs							
	2014	2015	2016	2017	2018	2019	2020	2021
Fans	29%	31%	33%	35%	36%	38%	39%	40%
Pumps	37%	40%	42%	45%	48%	51%	55%	56%

The market reports did not provide granular enough information to calculate regional ASD saturation separately for each facility type. The team used information on the distribution of ASDs by facility type at the national level (from the MSMAs) and engineering judgment to determine the regional facility-type-specific ASD saturations. This disaggregation aimed to maintain the regional sector-level ASD saturation presented in Table 15.

The team started by adjusting the regional saturation of ASDs in each facility type such that the distribution of ASD-equipped motor HP by facility type in the region aligns with the national distribution from the MSMAs. Then, the team reviewed the resulting regional ASD Saturation for each facility type and identified values that were above 85%. The team assumed 85% is the maximum ASD saturation in 2021 for any one facility type to acknowledge that there will always be systems where an ASD is not beneficial. For saturation values above 85%, the team adjusted the values down using engineering judgement and vetted the values with the Expert Panel. This process resulted in a smaller spread of ASD saturations across facility types.

For fans, only two facility types, Chemical and Transportation, had regional ASD saturation rates higher than 85% in 2021. The team decreased the regional 2021 ASD saturation in Chemical from 94% to 85% and in Transportation from 85% to 83%, and interpolated between 2010 to these new 2021 ASD saturation values for the years in between. Then, the team redistributed the extra ASD-equipped motor HP from Chemical and Transportation (about 0.9% of the total ASD-equipped fan motor HP) equally across the 9 other facility types. These adjustments ensured that no facility type has unreasonably high ASD saturation and that the regional sector-level fan ASD saturation is maintained at the level shown in

Table 15. The resulting annual regional fan ASD saturation by facility type, displayed in Table 16, serve as final ASD saturation inputs to the model.

Distributing regional ASD-equipped motor HP for pumps resulted in three facility types, Food, Computer/Electronics, and Miscellaneous, having ASD saturations in 2021 higher than 85%. The team decreased the 2021 regional pump ASD saturation for Food from 139% to 85%, for Computer/Electronics from 94% to 83%, and Miscellaneous from 83% to 82%.[56] This meant the team needed to redistribute 104,347, or 15% of the ASD-equipped pump motor HP in 2021. The team redistributed these motor HP across the 5 facility types with the lowest ASD saturation, making sure that ranking of ASD saturation by facility type remains the same as before the adjustments and that the regional sector-level pump ASD saturation remains at the level shown in Table 15. Table 16 and Table 17 present the final model inputs for regional pump ASD saturation by facility type.

As part of the calibration process, the team ran the model with the developed regional ASD saturation by equipment and facility type and saw that for some facility types, more ASD-equipped motor HP were incented by utility programs than the total ASD-equipped motor HP in that industry in a certain year. To correct for this, the team adjusted the ASD saturation for those facility types to ensure the region is installing at least as many ASDs as is incented by regional utility programs. Table 16 and Table 17 flag the facility types whose ASD saturations were calibrated.

The facility type-level ASD saturations shown in Table 16 and Table 17 are direct inputs to the model. Because these saturations include the aforementioned adjustments made during model calibration, they result in slightly different sector-level ASD saturation than the values shown in Table 15. Table 18 shows the final calibrated sector-level ASD saturation in percent of motor HP.

Table 16: Model Regional Fan ASD Saturation, by facility type and year

Facility Type	Percent of Motor HP with ASDs, Fans							
	2014	2015	2016	2017	2018	2019	2020	2021
Paper	23%	25%	27%	28%	29%	31%	32%	33%
Primary Metal †	34%	34%	35%	35%	36%	36%	37%	37%
Food †	45%	49%	54%	60%	67%	77%	82%	88%
Wood †	15%	16%	17%	18%	19%	20%	22%	23%
Computer/Electronic	48%	53%	56%	60%	63%	66%	68%	71%
Chemical* †	52%	57%	62%	66%	71%	77%	81%	88%
Fabricated	14%	15%	16%	17%	18%	18%	19%	19%
Transportation*	51%	56%	60%	65%	69%	74%	78%	83%
Petroleum	27%	29%	30%	32%	34%	35%	37%	38%
Warehousing	18%	20%	21%	22%	23%	24%	25%	26%
Misc.	44%	48%	51%	54%	57%	59%	62%	64%

** Denotes values that have been adjusted to account for facility type specific ASD saturation values that exceeded 85% in 2021.*

† *Denotes values that have been adjusted to account for utility program incented motor HP.*

[56] While Miscellaneous pumps did not have an ASD Saturation above 85%, to maintain the relative ranking of facility types by ASD saturation, the team adjusted Miscellaneous to 82%.

Table 17: Model Regional Pump ASD Saturation, by facility type and year

Facility Type	Percent of Motor HP with ASDs, Pumps							
	2014	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**
Paper	24%	27%	29%	32%	34%	36%	36%	37%
Primary Metal	39%	44%	47%	51%	54%	57%	60%	63%
Food*	58%	62%	65%	69%	73%	77%	81%	85%
Wood	18%	20%	24%	26%	27%	29%	30%	32%
Computer/Electronic*	49%	54%	59%	64%	68%	73%	78%	83%
Chemical †	49%	54%	58%	62%	66%	69%	73%	79%
Fabricated	42%	47%	51%	55%	58%	62%	65%	68%
Transportation	29%	32%	35%	38%	40%	42%	45%	47%
Petroleum †	30%	28%	28%	30%	31%	33%	37%	38%
Warehousing †	40%	45%	49%	53%	53%	55%	57%	58%
Misc.*	47%	52%	57%	62%	67%	72%	77%	82%

** Denotes values that have been adjusted to account for facility type specific ASD saturation values that exceeded 85% in 2021.*

† *Denotes values that have been adjusted to account for utility program incented motor HP.*

Table 18: Model Regional ASD Saturation, by equipment type and year

Equipment	Percent of Motor HP with ASDs							
	2014	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**
Fans	28%	31%	33%	35%	37%	39%	41%	43%
Pumps	38%	40%	42%	45%	48%	52%	55%	57%

ASD Saturation Uncertainty

The team identified three aspects of the ASD saturation that introduced uncertainty into the model results. Primarily, distributing the region's sector-level ASD saturation to the facility-type level leveraged engineering judgement which inherently increases the uncertainty of the input. To understand the impact this had on the model results, the team compared the energy consumption and Momentum Savings calculated using the distributions shown in Table 16 and Table 17 to the model results when the sector-level ASD saturation in Table 15 is applied to all facility types. Results of this analysis are in the Sensitivity Analysis chapter.

The team used regional information to calculate the region-specific ASD saturations, which resulted in a different baseline ASD saturation than the one assumed in the Seventh Plan. In reviewing the information with the Expert Panel and ASD market actors, the team determined that the modeled ASD saturation was a more representative estimate of the saturation in 2015 and used it as the baseline for calculating Momentum Savings. The team used the sensitivity analysis to understand the impact differences in the baseline ASD saturation have on model results. The team created a low and high range of baseline ASD saturation by translating the baseline ASD Saturation values up (for the low estimate) 10% in all years and down (for the high estimate) 10% in all years. This held the year-over-year change in ASD saturation constant while changing the baseline saturation value in 2015.

The third aspect of uncertainty in the modeled ASD saturation is the growth rate of ASDs, or the year-over-year difference in ASD saturation. This is a major driver of Momentum Savings in the model, as it informs the number of ASD-equipped motor HP installed since 2015. While the team used the best available information on ASD saturation and region-specific proprietary market data of ASDs to calculate the ASD saturation rates, there is inherent uncertainty in those values. The team used the sensitivity analysis to understand the impact that uncertainty has on model results by increasing or decreasing (for the low and high scenarios, respectively) the annual rate of change in ASD saturation by 10%.

Baseline Scenario

The baseline scenario represents the energy consumption of the installed stock, with the variable for which the model calculates energy savings (control strategy, presented as the saturation of ASDs) held constant over the analysis period. As presented in the Background chapter, this model only calculates energy savings associated with the adoption of ASDs. It does not calculate energy savings associated with the adoption of more efficient motors or motor-driven equipment. To calculate these savings, the baseline scenario holds the saturation of ASDs for each unique combination of equipment type, facility type, motor size bin, and load type constant at the 2015 value. All other distributions are the same between the market and baseline scenarios.

By holding the baseline ASD saturation constant at the granular level mentioned above, the baseline ASD saturation at the equipment-type level sees a small increase over the analysis period. This is because the distribution of motor HP by load type (constant load vs. variable load) is shifting towards more variable load systems, and this change in distribution is incorporated into the baseline. By incorporating this fluctuation into the baseline, the model accounts for a slow adoption of ASDs within the baseline. Table 19 shows the regional baseline ASD saturation, as percent of motor HP, for both pumps and fans.

Table 19: Baseline Regional ASD Saturation, by equipment type and year

Equipment	Percent of Motor HP with ASDs							
	2014	2015	2016	2017	2018	2019	2020	2021
Fans	28%	31%	32%	33%	34%	35%	36%	37%
Pumps	38%	40%	41%	41%	42%	43%	44%	44%

Based on the data available, the model does not disaggregate ASD by installation type (retrofit or new equipment). Instead, the model tracks number of ASDs that exist in the pump and fan stock in each year and how they are distributed across model dimensions, and applies any change in ASD saturation equally across equipment vintages. Differences in equipment and motor efficiency by vintage have a minor impact on the energy consumption of new and existing installations, and the model accounts for these changes over time. While there is uncertainty in the average vintage of ASD-equipped motor HP in the region, the vintage-dependent variables have a very small impact on model results (more information on the impact of efficiency is discussed in the Sensitivity Analysis chapter). The mechanism of energy savings from an ASD is independent of those variables and has a much larger impact than those vintage-dependent characteristics.

Calculating Total Market Savings

The difference between baseline scenario energy consumption and market scenario energy consumption represents the total market savings in each year of the analysis period, show in Equation 8.

Equation 8: Annual Total Market Savings

$$TotalMarketSavings_t = (BaselineEnergyConsumption_t - MarketEnergyConsumption_t) \times BusbarFactor$$

where

TotalMarketSavings	=	Total market savings associated with the adoption of ASDs *(kWh)*
BaselineEnergyConsumption	=	Energy consumption in the baseline scenario *(kWh)*
MarketEnergyConsumption	=	Energy consumption in the market scenario *(kWh)*
BusbarFactor	=	Site to generation source energy conversion factor *(unitless)*
t	=	Year *(2016–2021)*

The busbar factor in Equation 8 converts energy savings at the customer's meter to the generation source. The model uses an average factor of 0.0749, which is consistent with other BPA market models.

Question 4: What are the program savings?

The final step in the Four Question Framework is deriving Momentum Savings from the total market savings estimated in Question 3. To do this, the research team must answer Question 4: What are the program savings? The total market savings estimated in Question 3 represents all regional savings due to the adoption of ASDs, including savings from regional program activity (regional utility incentive programs and NEEA's net market effects) and Momentum Savings. To answer Question 4, the model calculates the savings attributable to regional program activity. The difference between the total market savings calculated in Question 3 and the regional program savings in Question 4 represents Momentum Savings.

NEEA and regional utilities report energy savings resulting from program activity through the Regional Conservation Progress report (RCP),[57] which serves as a comprehensive source of program savings information in the region. While each utility's reported program savings, as shown in the RCP, are the most accurate record of program accomplishments that exist, different organizations and utilities use different operating characteristics and baselines in their savings calculations, which means incorporating the savings values reported in the RCP directly into the model requires several interim analysis steps. First, the ASD model normalizes the regional ASD program savings to an equivalent number of ASD-equipped industrial pump and fan motor HP incented through programs. The model then distributes these incented motor HP to model cells and applies the model's UECs to calculate the ASD energy savings from regional program activity. This eliminates any issue surrounding different energy savings calculations and applies consistent baselines and UEC assumptions to all program savings. The team refers to the model's calculated ASD program savings "adjusted program savings" to clarify that they represent a necessary interim calculation to account for the RCP's reported savings in the model; these "adjusted program savings" should not be used for any other reporting purposes.

[57] *Regional Conservation Progress Report;* https://rtf.nwcouncil.org/about-rtf/conservation-achievements/2020, accessed 2/6/2022

During model development, the team found that ASD related program savings were not clearly differentiated between other pump and fan related savings in the RCP. This necessitated a more in-depth analysis (as compared to other BPA market models like residential HVAC or non-residential lighting) to first identify the magnitude of ASD program savings reported regionally, before converting these savings to a number of incented units to input into the model.

This section describes how the research team calculated the number of incented motor HP from NEEA net market effects and utility incentive programs during the period for which the model calculates Momentum Savings (2016–2021).

NEEA Net Market Effects

NEEA net market effects refer to the energy savings achieved through NEEA's market transformation initiatives. NEEA has one market transformation initiative, the Extended Motor Products (XMP) Initiative, that addresses industrial motor-driven equipment.[58] The XMP Initiative aims to enable motor-driven equipment end users to specify, purchase, and realize energy savings from more efficient motor-driven equipment. The initiative focuses on both selling more efficient equipment and increasing the number of ASDs sold with equipment. Currently, the XMP Initiative directly incentivizes industrial pumps (which are included in the scope of this model), in addition to commercial pumps and commercial and residential circulators. In the 2020 Annual Savings Report to Bonneville,[59] NEEA did not report any industrial savings for the XMP Initiative during the analysis period. This eliminates the need for the model to account for NEEA net market effects in calculating the number of incented motor HP.

Regional Utility Programs

The only source of program savings associated with ASDs in the model's analysis period is through regional utility programs. Utilities incentivize ASDs through two main strategies: deemed programs and custom programs.

Deemed programs apply a consistent savings value to each unit incented, such as a kWh/HP value for ASDs, for a defined scope of measures (e.g., ASDs on commercial Air Handling Unit fans). Utilities determine deemed savings values from internal analysis or regional resources such as RTF UES measures. While the RTF offers a deemed measure for adding a VSD to industrial pumps and fans,[60] the research team reviewed BPA's internal program tracking database and found none of BPA's in-scope ASD savings came from deemed programs during the analysis period.[61] The team also conducted a review of other regional utility programs and did not find any industrial pump or fan ASD deemed programs. Three utilities with large industrial program savings[62] also confirmed that they do not run deemed ASD programs in the industrial sector. With this information, the team assumed that 0% of the regional ASD program savings are from deemed programs.

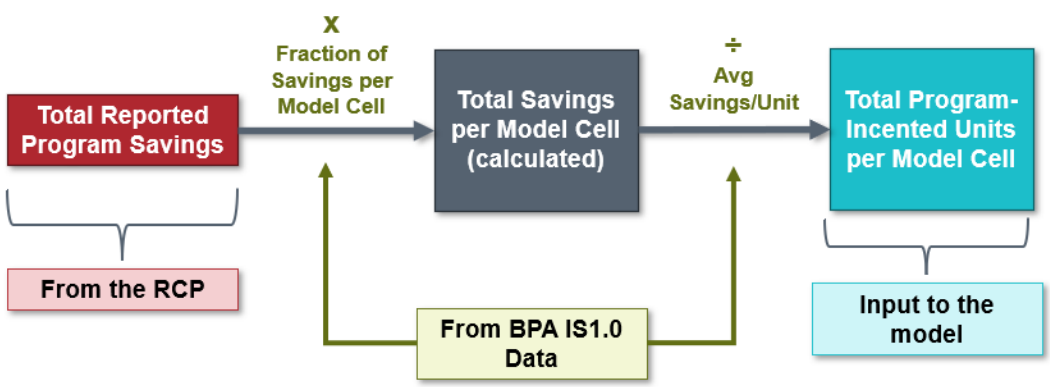
[58] NEEA also claims savings for improvements to energy code, but energy code is not applicable to the industrial sector.
[59] Provided to BPA in May of 2021, this report contained the most updated NEEA net market effects savings during the Seventh Plan Action Plan Period.
[60] RTF Variable Speed Drives UES Measure https://rtf.nwcouncil.org/measure/variable-speed-drives accessed 2/6/2022
[61] The only deemed measures reported under an ASD-related category were out of the scope of this model: "Potato/Onion Shed VFD" (which is an agricultural measure) and "Generator Block heater" (which is non-ASD).
[62] The team interviewed program staff from Seattle City Light, Puget Sound Energy, and Energy Trust of Oregon in fall of 2021. These utilities had the top five largest reported program savings in the RCP in the analysis period.

Custom programs rely on project-specific data to calculate energy savings for a particular project and can use a variety of data collection and calculation methodologies. Because each project's methodology and system characteristics vary, the kWh/HP savings between projects vary as well. The team identified that all industrial pump and fan ASD program savings come from custom programs.

The RCP tracks savings in each year using four main identifiers: (1) sector, (2) end use, (3) category, and (4) technology/activity/practice (TAP).[63] This document refers to a unique combination of these identifiers as a "TAP combination." BPA internally tracks program savings reported by its customers on the project level in the IS2.0 database (BPA IS2.0). The BPA IS2.0 uses the same TAP combinations as the RCP but provides more information on the project through fields like project description, quantity of units incented, measure type (custom or deemed), and other key characteristics.[64] As the RCP has no detail about program savings beyond the TAP combination, the BPA IS2.0 serves as a supplementary data source to further understand how utility programs incentivize and report savings within a given TAP combination.

In other market models, BPA determines the number of program-incented units by dividing the total energy savings (kWh) for each relevant TAP combination in the RCP by the average savings per unit (kWh/unit) in that TAP combination (calculated using the BPA IS2.0), as shown in Figure 6.

Figure 6: Typical BPA Market Model Program Savings Analysis Approach



For this model, neither the RCP nor the BPA IS2.0 include enough detail on ASD measures to use the analysis approach in Figure 6. This is because the TAP combinations included in the RCP do not align perfectly with the model scope. ASDs may be included in many different TAP combinations, and not all the savings reported in a given TAP combination are associated with ASDs. For example, the TAP combination *Industrial–Process Loads–Pumps and Fans–Pump System Improvements* may contain energy savings for the addition of ASDs but may also include non-ASD energy savings. Therefore, the model cannot confidently identify all program-incented savings attributed to ASDs solely using the RCP. Additionally, the BPA IS2.0 does not contain information on incented motor HP for custom projects,

[63] Regional Technical Forum, "Regional Conservation Progress Survey," Northwest Power and Conservation Council, https://rtf.nwcouncil.org/about-rtf/conservation-achievements/, accessed 2/6/2022
[64] Examples include retrofit or new construction delineators or building type designations.

which means the research team cannot rely on BPA IS2.0 to calculate the average savings per unit (kWh/HP) for each TAP combination.

To accurately calculate the number of incented motor HP occurring in the region, the research team developed a methodology unique to this model that uses aggregated data from BPA's custom projects to fill the above data gaps. The data from BPA's custom projects is also used to distribute the incented motor HP into the cells of the model. The methodology for calculating the number of incented motor HP in each cell in the model has five main steps:

1. Determine the TAP combinations that possibly include ASD savings.
2. Determine the percentage of savings within those TAP combinations associated with ASDs.
3. Determine the average savings per unit (kWh/HP) for all incented ASD projects.
4. Calculate the total number of incented motor HP.
5. Distribute the total number of incented motor HP into model cells.

ASD savings from BPA custom projects represent 64% of total regional ASD program savings developed by this methodology, so the research team knew that the characteristics of BPA custom projects were representative of the majority of regional ASD custom projects. Because of this, the team was also confident that an average BPA custom project was representative of average regional ASD projects. Additionally, the research team reviewed results of this analysis (including percent of savings associated with ASDs from Step 2 and average savings per unit from Step 3) with three regional utilities[65] and received feedback that the methodology and results aligned with their understanding of their own ASD custom projects.

Step 1: Determine the TAP Combinations That Possibly Include ASD Savings

Many TAP combinations in the RCP could include ASDs but do not have enough detail for the research team to confidently determine whether the savings reported to these TAP combinations are in-scope (savings from ASDs on industrial pumps and fans) or out-of-scope (savings from non-ASD or other equipment types). Therefore, the first step in calculating program-incented motor HP is to determine all TAP combinations that *could* have ASD savings covered by this model scope that the team then refines in Step 2.

The research team reviewed each of the four RCP identifiers and eliminated TAP combinations that definitively fall outside the scope of this model. Table 20 outlines the filtering applied, resulting in 36 remaining TAP combinations that could contain ASD savings.

[65] The team interviewed program staff from Seattle City Light, Puget Sound Energy, and Energy Trust of Oregon in fall of 2021.

Table 20: TAP Combinations Possibly Containing ASD Program Savings

RCP Identifiers	Removed	Remaining	Rationale
Sector	Agricultural, Residential, Non-residential*, Utility System Efficiency	Industrial	The model scope only covers the industrial sector.
End-Use	Compressed Air, Electronics, Facility Distribution, Utility Distribution, Lighting, Unknown	HVAC, Motors/Drives, Process Loads, Refrigeration, Water Heating, Whole Bldg./Meter Level	The removed end uses fall outside the technology scope (which only covers pumps and fans).
Category	Envelope, Compressed air, Heat recovery	11 categories including Motors, Motors/Drives Controls, Refrigeration Control Improvements**, Pumps and Fans, etc.	Removed non-motor categories and Compressed Air (out of scope).
TAP	Non-ASD, non-motor applications, embedded motor applications such as Duct Insulation and Motor Rewind	TAPs likely to contain ASD	Removed TAPs that have "(non-VFD)" in their name, or were not motor related (e.g., Insulation, and Welder Upgrades). All TAPs that may contain ASDs remain.
RCP Savings	TAP combinations with no regional reported RCP savings		Removed TAP combinations with no reported savings during the analysis period.

** "Non-residential" covers only the lighting end use, which is out of scope for this model.*
*** The "Refrigeration Control Improvements" category only includes condenser-specific fan TAPs. Evaporator fans are considered embedded fans and not included in the scope of this model.*

Step 2: Determine the Percentage of Savings Associated with ASDs by TAP Combination

After identifying all TAP combinations that could include ASD savings, the research team determined the percentage of savings in each TAP combination associated with ASDs (referred to as "percent ASD savings") using information from BPA custom projects.

BPA's Option 1 utilities[66] report custom projects to BPA using standardized project completion reports. These reports summarize detailed project information and provide measure-level insight into the energy savings reported to BPA and eventually to the RCP. The research team developed a database of project completion reports (referred to as the CR Database) that contained all Option 1 custom projects within the model scope reported from 2016 to 2020, totaling 218 projects with 278 completed industrial measures.[67] These measures cover 23 of the 36 TAP combinations identified in Step 1.

For the 23 TAP combinations covered in the CR database, the research team used information in the database to estimate the percentage of ASD savings associated with each TAP combination. To do this, the team reviewed measure-level information in the CR database and identified each of the 278

[66] BPA has two categories of custom projects reported in IS2.0 depending on whether the utility is Option 1 or Option 2. Option 1 utilities report projects through a standardized custom project process and reporting structure. Option 2 utilities report projects using their own savings methodologies and reporting process.
[67] The CR Database also contains 192 projects that are outside the scope of this model, including projects from the commercial and agricultural sectors, as well as compressed air equipment.

measures as having either 100% ASD savings or 0% ASD savings. Then, the team calculated the percent ASD savings in each TAP combination by taking a weighted-average of the percent ASD savings for all measures within a TAP combination. When there was uncertainty in whether a given measure had partial or 100% ASD savings, the research team assumed that 100% of the savings were associated with ASDs to ensure the methodology captures the highest feasible percentage of the region's ASD program savings. Since the team assumed that a measure had either 0% or 100% ASD savings, the team considered the impact of this assumption in the program savings sensitivity analysis[68] – a 90% ASD savings for a measure (instead of 100%) is included as the low sensitivity case.

Based on the estimated percent ASD savings for each of the 23 TAP combinations in the CR Database, the research team assigned these TAP combinations into one of three groups:

- Three TAP combinations had 0% of the regional program savings associated with ASDs, based on the BPA program data (the CR Database).
- Eight TAP combinations had 100% of the savings associated with ASDs, based on the BPA program data.
- Twelve TAP combinations had a partial percentage of savings associated with ASDs (ranging from 1% to 84%) because they have both projects with 0% ASD savings and 100% ASD savings, based on BPA program data.

While the research team relied only on the BPA CR Database to determine the percent ASD savings associated with each TAP combination, the team has high confidence in the assignment of TAP combinations and assessment of ASD savings due to the majority of total regional program savings reported to the RCP for these TAP combinations. There was one TAP combination identified by the team as having low confidence in the original % ASD savings estimate (*Industrial-Whole Bldg/Meter Level-Whole Bldg/Meter Level System Improvements-Interactive Whole Bldg/Meter Level System Improvements*), because the CR database contained only two projects and these projects represented very large savings. The research team conducted a more in-depth analysis of the two BPA projects and discussed with BPA staff involved in those projects to develop a refined percent ASD savings. At the completion of this analysis, the research team raised their confidence to medium for this TAP combination.

For the 13 out of 36 TAP combinations identified in Step 1 that are not represented in the CR Database, the research team assigned 0% ASD savings to these TAP combinations after evaluating qualitative information available in the RCP and the BPA IS2.0:

- Ten TAP combinations have a TAP labeled "Unknown". Without any addition information,[69] the research team assumed that none of the savings reported to "Unknown" TAPs are attributable to ASDs. The RCP includes numerous alternative TAPs that identify ASDs, so savings reported by utilities that contained ASD savings would most likely be allocated to one of those TAPs instead of the "Unknown" TAPs.

[68] Details on this sensitivity analysis are included in the Program Savings Input Workbook, and are summarized later in this memo – section "Program Savings Uncertainty"

[69] During interviews with the three utilities, the research team asked about how utilities report savings to the RCP and when they would use an "unknown" TAP. The interviewees responded that they do not report savings at the TAP level (instead at the category level or using Reference Numbers) and therefore do not have insight into the savings reported in "unknown" TAP.

- Two TAP combinations contained savings only from IOU and Mid-C utilities. Based on engineering judgment and knowledge of industrial programs, the research team identified the savings associated with these TAP combinations as having a low likelihood of including ASDs and assumed 0% ASD savings for these TAP combinations.
- One TAP combination had no reported regional savings in the RCP. This TAP was not filtered out prior to this because Step 1 filtered based on presence of TAP combinations in the RCP.

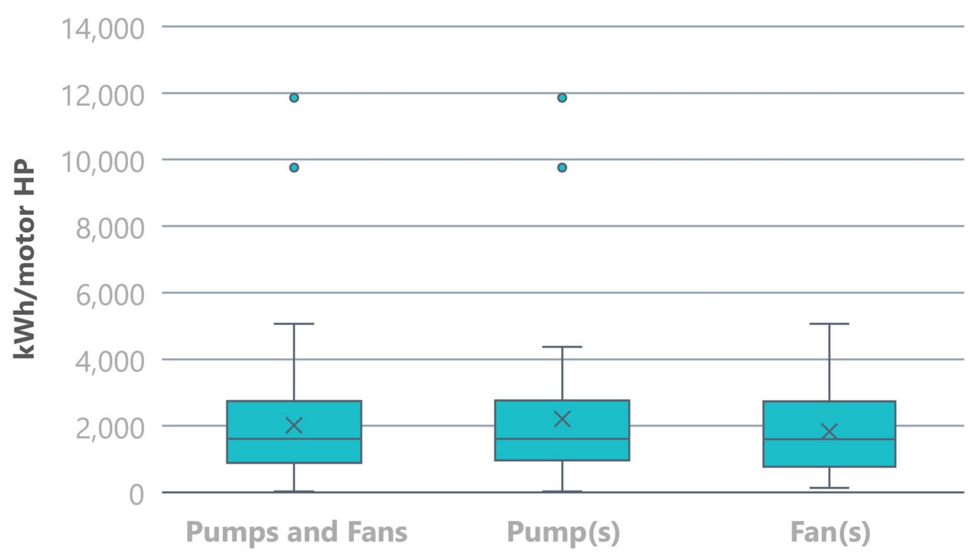
The % ASD savings by TAP combination determined in this step are used to calculate the total regional program savings associated with ASD, and then are converted to incented HP in Step 4 of this methodology.

Step 3: Calculate the Average Savings per Motor HP for ASD Projects

After calculating the percentage of savings attributed to ASDs in each TAP combination (Steps 1 and 2), the research team determined the average savings per unit (kWh/motor HP) using the CR Database. The team uses this value to translate ASD program savings (kWh) into the number of incented motor HP, which serves as the input to the market model.

The CR Database included 137 ASD-related measures, 85 of which had enough information to calculate an average savings per unit for pumps and fans.[70] The CR Database does not contain enough measures to calculate an average savings per unit value specific to each TAP combination, so the research team calculated an average savings per unit value across all measures and by equipment type. As shown in Figure 7, the research team did not see a statistically significant difference between the two equipment types and determined that the average savings per unit for pumps and fans together, 2,011 kWh/motor HP, represented the best average savings per unit for both equipment types.

Figure 7: Box and Whisker Plot for Average Savings per Unit, by equipment type



Source: Cadeo analysis of per unit savings from BPA custom project files

[70] Some project completion reports either did not include ASD savings, or did not include information on motor HP. This limited the number of measures the research team could use to estimate average savings per unit.

Step 4: Calculate Total Incented Motor HP

Using the ASD program savings from Step 2 and average savings per unit from Step 3, the team calculated the incented motor HP associated with ASDs for each TAP combination, shown in Equation 9. The team then aggregated the incented motor HP across TAP combinations to get total incented motor HP for each year of the analysis period. This step does not account for motor HP that fall out of the equipment type and facility type -scope of the model. Step 5 uses information on motor HP distribution to remove these motor HP.

Equation 9: Total Incented Motor HP Calculation

$$\text{Total Incented Motor HP}_t = \sum_{TAP} \frac{\text{Regional Program Savings}_{t,TAP} \times \text{\% ASD Savings}_{TAP}}{\text{Average Savings per Unit}}$$

where

Total Incented Motor HP	=	Total number of incented motor HP associated with ASDs
Regional Program Savings	=	Total regional program savings by TAP combination in the RCP (*kWh*)
% ASD Savings	=	% of program savings associated with ASDs by TAP combination from Step 2
Average Savings per Unit	=	Average savings per motor HP (*kWh/motor HP*) from Step 3
t	=	Analysis year
TAP	=	TAP Combination

Step 5: Distribute the Program Incented Motor HP into Model Cells

Step 5 distributes the region's total number of incented motor HP for each year of the analysis period to specific model cells. The RCP includes information on some model dimensions (like sector), allowing the model to use this information directly to distribute incented motor HP. The team used additional data sources to distribute the incented motor HP across model dimensions not identified in the RCP, as summarized in Table 21 . More information on each of these variables and how the team distributed motor HP based on the available data is presented in the associated Program Savings Input Workbook.[71]

[71] The workbook can be found at https://www.bpa.gov/energy-and-services/efficiency/market-research-and-momentum-savings/adjustable-speed-drives-market-research.

Table 21: Distributing Incented Motor HP across Model Cell Dimensions

Model Cell Dimensions	Data Source
Control Strategy	All incented model HP from Step 4 have "ASD control".
Year	The RCP and BPA's IS2.0 are reported on an annual basis and broken out by year.
Equipment	The team used the BPA CR Database to determine the distribution of program savings by equipment type (Pumps, Fans, and "Other Equipment"). ASD savings associated with "Other Equipment" (e.g. Air compressors) is excluded from the model.
Facility Type	The team mapped measure-level information from the BPA CR database on "industrial process type" to the 11 facility types in the model and determine a distribution of regional ASD program savings across these facility types. A separate facility type distribution was identified for pumps and fans, as the CR Database indicated that incented projects for different equipment are concentrated in different facility types.
Motor Size	The team used information from the BPA CR Database to create a unique distribution of motor size for pumps and fans separately.
Load Type	The team used BPA custom projects with metered data (a subset of projects in the CR Database) to distribute incented motor HP by load type. BPA's custom project data showed that ASD projects were almost exclusively applied to variable load systems (100% variable load for pumps and 97% variable load for fans), which supported using a separate distribution by load type for program savings and total market savings.

Program Savings Uncertainty

Using the 5-step methodology described above, the team calculated the number of ASD-equipped incented motor HP in each cell of the model. While the team is confident in the analysis approach, there is inherent uncertainty in the methodology. To understand the impact this uncertainty could have on model results, the team developed an uncertainty bound for the incented motor HP model input.

The team considered each step of the methodology individually and identified that the percentage of savings associated with ASDs for each TAP combination (Step 2) had uncertainty with the largest impact on the total magnitude of incented motor HP. The team considered three aspects of the Step 2 methodology with uncertainty: 1) the team had medium confidence in one TAP combination's % ASD savings (whereas the team had high confidence in all other TAP combinations), 2) there is uncertainty around the assumption that all savings reported to "Unknown" TAP combinations or TAP combinations with only IOU/Mid-C savings in the RCP contained 0% ASD savings, and 3) the assumption that if a measure has an ASD then 100% of that measure's savings are attributed to ASDs.

The team developed an upper bound sensitivity case (maximum incented HP associated with ASD's) by assuming that the TAP combination with medium confidence had 27% ASD savings (per feedback from the Expert Panel) and that the "Unknown" and "IOU/Mid-C" TAP combinations had the average percent ASD savings at the Category level (one level less granular than TAP), and the lower bound sensitivity case (minimum ASD associated incented HP) by assuming that if a measure has an ASD it has 90% ASD savings. More information on these sensitivity scenarios are in the Program Savings Input Workbook. The upper bound and lower bound for the incented motor HP model input are summarized in Table 22.

Table 22: Model Incented Motor HP and Associated Upper and Lower Bounds

Incented Motor HP	Pumps	Fans	Total
Lower Bound	15,783	27,694	43,477
Base	17,536	30,772	48,308
Upper Bound	25,920	42,194	68,114

COVID Investigation

The research team investigated the effect of the COVID-19 pandemic on program activity by comparing the ASD-related average savings per unit values calculated in Step 4, between years 2015 and 2019, with the year 2020. While the pandemic did impact the quantity of incented projects in 2020 (as discussed below), it did not have a statistically significant effect on the average savings per unit for 2020.

The team also investigated the impact of COVID on the total magnitude of savings reported in the industrial sector and the magnitude of program savings associated with in-scope ASD projects. The team found that ASD program savings varied significantly year-over-year without a clear trend but was lower-than-average in 2020, and in fact was almost half the previous minimum year. The team also discussed the impacts of COVID with utilities[72] and found that this depression in program activity in 2020 aligned with their understanding. The interviewed utilities all expected that 2021 would be similar to 2020 (though not necessarily from direct COVID impacts). Therefore, when the team extrapolated 2021 savings (which was necessary since the 2021 RCP will not publish before this market model is completed), they assumed a magnitude of savings for 2021 equal to the savings reported in 2020.

[72] The team interviewed program staff from Seattle City Light, Puget Sound Energy, and Energy Trust of Oregon in fall of 2021.

Model Results

By answering each question in the Four Question Framework, the model calculates the regional stock of industrial standalone pumps and fans as well as the Momentum Savings associated with the application of ASDs to these motor-driven equipment. The Industrial Pump and Fan Characteristics section of this chapter presents results characterizing the regional stock and energy consumption of industrial standalone pumps and fans, and the Impact of ASD Adoption section presents the market change, since 2015, created by the adoption of ASDs.

Industrial Pump and Fan Characteristics

By modeling the regional stock of industrial standalone pumps and fans in each year of the analysis period, the team can understand both how the stock is changing over time and how that change impacts energy consumption. These changes are not limited to impacts of energy efficiency but account for all quantifiable drivers of energy consumption, including variables like equipment and motor efficiency, industrial sector growth or contraction, and the adoption of ASDs. This section presents the modeled stock of industrial standalone pumps and fans, their regional energy consumption over the analysis period, and the new equipment sales calculated in the model.

Industrial Pump and Fan Stock

While the unit of account in this model is motor HP, it calculates regional stock in both motor HP and number of motors. This facilitates the comparison of trends in motor size characteristics across different dimensions. Figure 8 shows the in-service stock for each equipment type, by motor HP and number of motors. In-service stock represents all equipment that operate (that is, consume energy) in the identified year; it does not include out-of-service equipment. [73]

[73] Because in-service motor HP represent the energy consuming motor HP installed in each year, this figure and all other figures in this section are in terms of in-service stock. Trends between facility types and across years are consistent between total installed stock and in-service stock.

Figure 8: Number of In-Service Motors and Motor HP, by equipment type and year

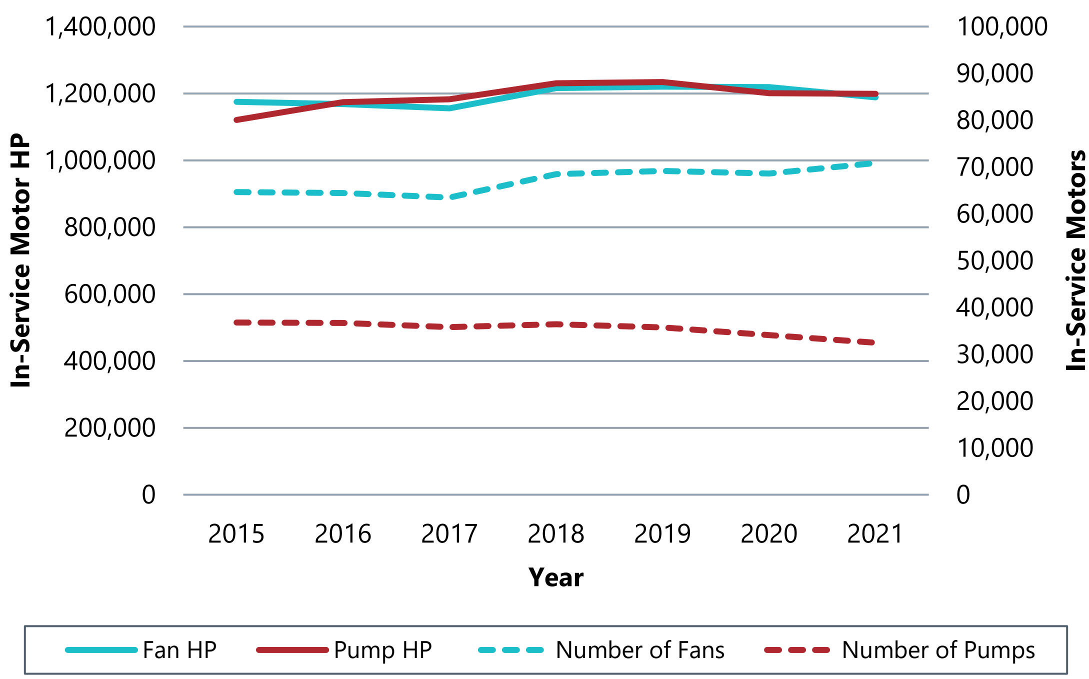


Figure 8 shows that both fans and pumps experienced growth in in-service motor HP over the analysis period. In-service motor HP of fans increased by 5% between 2015 and 2021, and pumps increased by 9% over the same time period. Growth in in-service motors, however, does not align with growth in in-service motor HP. While the growth in number of in-service motors on fans is consistent with the fan motor HP growth (6%), the number of in-service pumps decreased by 7% over the analysis period. This increase in pump motor HP but decrease in pump motors indicates that the average pump size in the region has increased. Table 23 shows that the average motor size for pumps increased by 23% over the analysis period. This change is a function of the growth and contraction of different facility types. Facility types with, on average, large pumps are growing, and facility types with smaller pumps are contracting. The net effect of this change is an increase in the number of in-service pump motor HP, but a decrease in the number of in-service pump motors.

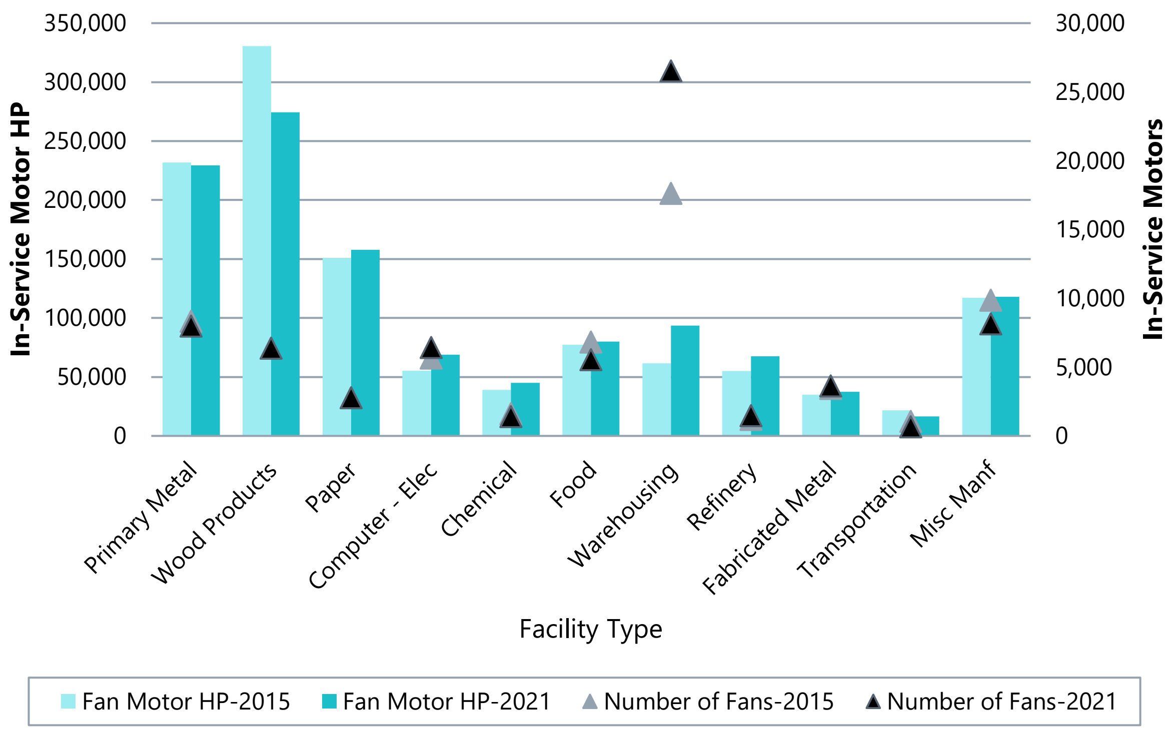
Figure 8 also shows that there are nearly twice as many fans in-service in the region as there are pumps, but the number of motor HP for the two equipment types is nearly equal. This indicates that, on average, industrial pumps are much larger than industrial fans. Table 23 shows that, on average, pumps are almost double the size of fans.

Table 23: Average In-Service Motor Size, by equipment type in 2015 and 2021

Equipment Type	Year	
	2015	2021
Fans	18 HP	17 HP
Pumps	30 HP	37 HP

Figure 9 and Figure 10 investigate changes in average in-service motor size at the facility type level. These figures look at in-service motor HP (shown by the bars) and number of motors (shown by the triangles) to illustrate how these two units do not always move in the same direction.

Figure 9: In-Service Fan Motors and Motor HP, by facility type in 2015 and 2021



Looking at Figure 9, one can see that the Warehouse facility type has the largest number of fans (the triangles), but a relatively average number of fan motor HP (blue bars). This indicates that fans in the warehousing industry are small on average, relative to other facility types. Conversely, Metal, Paper, and Wood Products facility types represent the largest concentration of connected horsepower (blue bars), but a relatively small amount of number of fans. This indicates that fans in these industries are concentrated in the larger sizes. Comparing the number of fans in 2015 (grey triangle) and the number of fans in 2021 (black triangle), we can see that the Warehouse facility type also experienced the largest growth in the number of in-service fans across the analysis period. An ever-increasing trend towards online order-and-deliver services may be responsible for this growth in the Warehouse facility type. All other facility types experience a relatively small change in the number of in-service fans.

Figure 10: In-Service Pump Motors and Motor HP, by facility type in 2015 and 2021

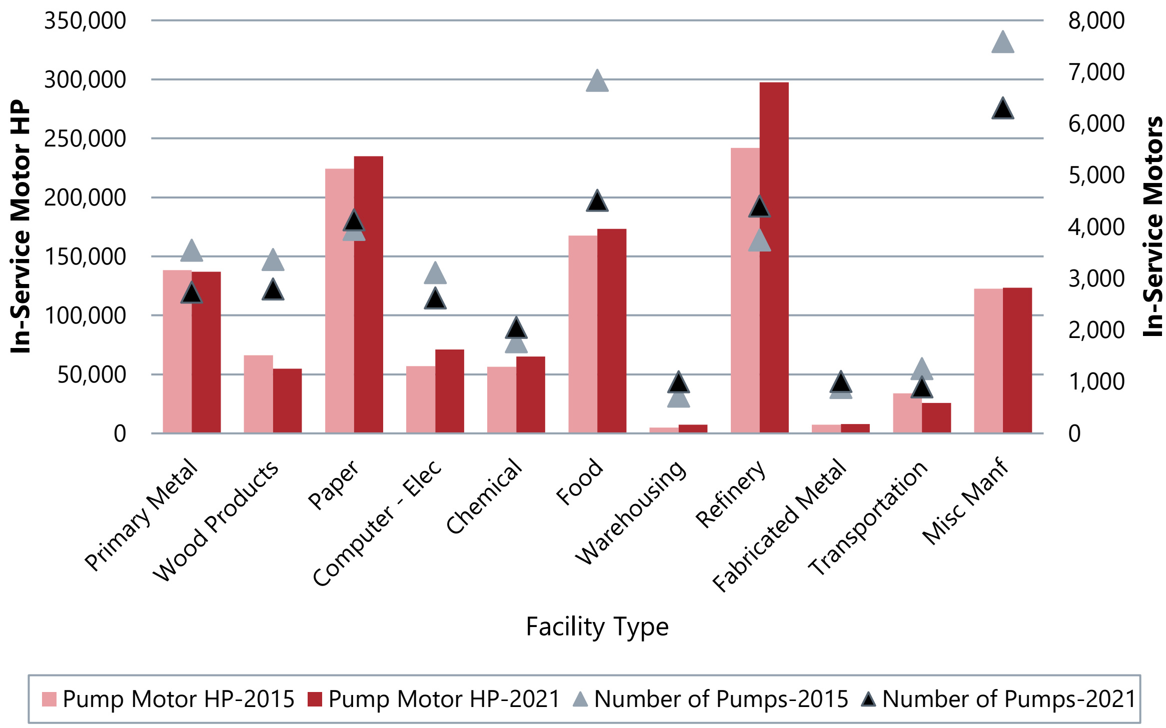


Figure 10, read similarly to Figure 9, shows that most pumps are installed in the miscellaneous manufacturing facility type[74] and that these tend to be smaller pumps. There are also many pumps in the paper, food, and refinery industries. In miscellaneous manufacturing and food facilities – facility types with small average pump sizes – the number of pumps decrease over the analysis period. In the paper and refinery facilities – industries with larger average pump sizes – the number of pumps increased.

The team compared the modeled motor stock to external estimates of motor stock. Table 24 compares the model's installed stock (in-service and out-of-service) values in 2018 to motor stock from the 2018 MSMA (which also includes both in-service and out-of-service stock), scaled to the Pacific Northwest using facility type-specific Gross Output. This comparison shows that the model values are within 11% and 13% of the 2018 MSMA estimate for total number of installed fans and pumps. While the team used the MSMA as a model input to calculate in-service motor HP, the team used other data sources to estimate the out-of-service stock. The relative closeness of the model's bottom-up calculation of installed stock to the MSMA's estimate of installed stock supports the model's method for calculating out-of-service motor HP.

Table 24: Number of Installed Motors, by equipment type in 2018

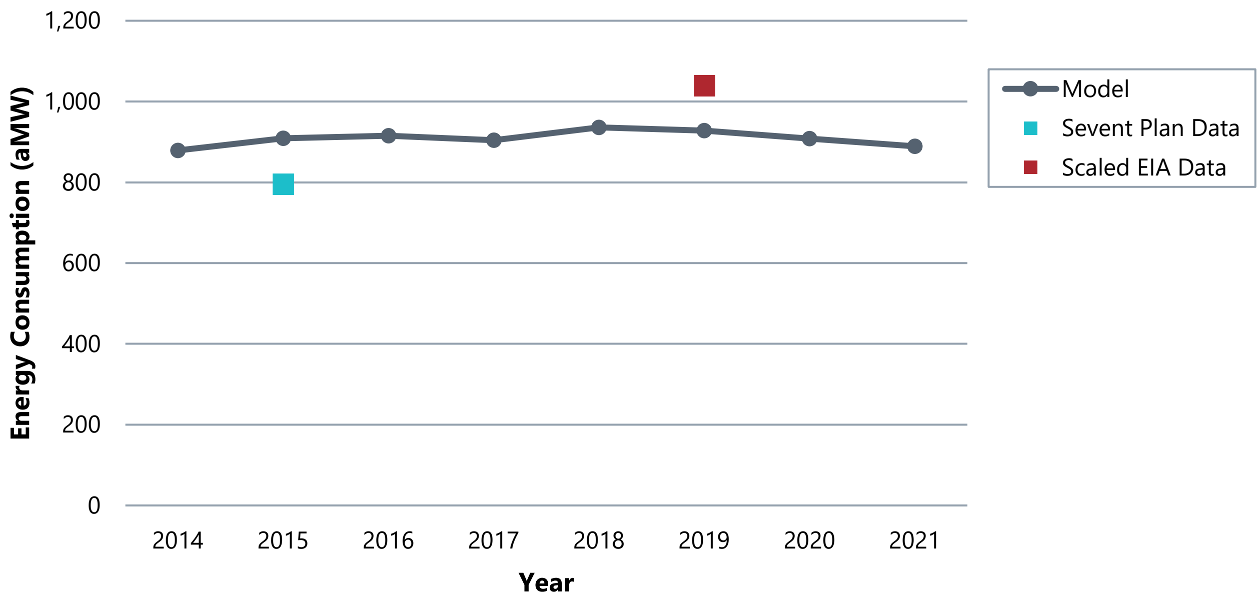
Data Source	Number of Installed Fans (2018)	Number of Installed Pumps (2018)
Model	89,254	47,322
2018 MSMA	80,612	41,716
% Difference	**11%**	**13%**

[74] The miscellaneous facility type contains 9 separate NAICS code industries. See Table 2 for a list of the NAICS codes covered.

Energy Consumption

The model estimates that industrial standalone pumps and fans consume between 818 and 871 aMW per year (at the meter), across the analysis period. As Figure 11 shows, this range of energy consumption aligns well with the high-level external estimates of energy consumption.

Figure 11: Regional Industrial Pump and Fan Energy Consumption (aMW at meter), by year



The team compared the model results to the Seventh Plan and Energy Information Agency's (EIA) estimates of industrial standalone pump and fan energy consumption. To derive the Seventh Plan's estimate of industrial pump and fan energy consumption in 2015 (796 aMW), the team multiplied the Seventh Plan's estimate of total industrial electricity consumption in 2015 by the Seventh Plan's end-use disaggregation for pumps and fans. Compared to the Seventh Plan estimate, the model's 909 aMW in 2015 is approximately 10% larger. The Seventh Plan used a top-down approach to calculate industrial pump and fan energy consumption, relying on both public data and confidential information on the distribution of energy within the region, leveraging the best available data in 2015. This contrasts with the bottom-up approach used by the ASD Market Model, calculated industrial pump and fan energy consumption at the facility type level from the bottom-up using stock data and detailed unit-energy consumption estimates. Despite the differences in calculation methodology between the model and the Seventh Plan, the most aggregated estimate of energy consumption between the two sources aligns well.

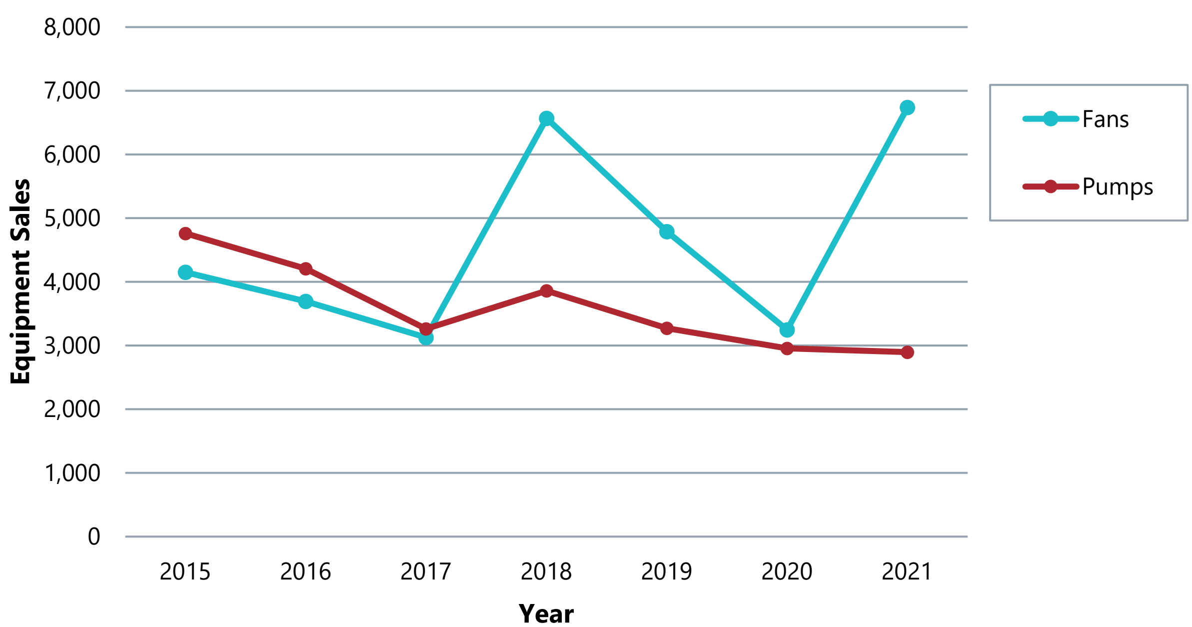
The team also used the Energy Information Association's (EIA's) most recent State Energy Database Systems (SEDS) data for industrial sector electricity consumption and scaled this value to the model's scope (as defined in Question 1) using information from the EIA's Manufacturing Energy Consumption Survey (MECS) and the 2018 MSMA. The scaled EIA data estimates approximately 1,040 aMW of energy consumed by industrial standalone pumps and fans in the region in 2019. This estimate is within 17% of the modeled energy consumption. With significantly different calculation methodologies, data sources, and data vintages, the model's energy consumption estimates falling between these two external estimates builds confidence in the model's inputs (stock and UEC estimates) and methodology.

New Equipment Sales

As mentioned in Question 2, the model also calculates number of regional equipment sales in each year. There is currently no primary data available representative of industrial standalone pump and fan sales in the region. By characterizing how the stock of pumps and fans is changing overtime, this model serves as a great source for understanding the flow of new equipment sales into the region. Figure 12 shows the modeled sales of fans and pumps in each year of the analysis period. Equipment sales range between 3,000 and 7,000 units per year, with fans showing more year-to-year variability than pumps. Pump sales also appear to be decreasing slightly over the five-year period, a trend corresponding with the number of pumps in the stock decreasing.

The large fluctuations in fan sales stood out as unexpected to the team. In reviewing the results with ASD distributors and installing contractors, the team asked if the year-to-year variability in sales aligned with their experience. Of the market actors that had insight into this topic (four of the five market actors surveyed), all indicated that this variability in sales is realistic and occurs year-to-year. One market actor cited the construction of new facilities or dramatic increases in production as events that do not occur every year and can have a dramatic impact on number of motors sold in some years but not in others.

Figure 12: Regional Equipment Sales, by equipment type and year



Because no regional data is available on pump and fan sales, the team compared modeled sales to rough estimates of equipment sales calculated from secondary data sources. These external estimates of 2020 sales rely on information from DOE's rulemaking analyses for pumps and fans[75], as well as U.S. Census

[75] *Rulemaking Docket: Energy Efficiency Standard for Pumps*, https://www.regulations.gov/docket?D=EERE-2011-BT-STD-0031, accessed 2/6/2022

information on historic equipment sales.[76] These estimates were then scaled to the Pacific Northwest using information on industrial water usage[77] for pumps and national manufacturing sales[78] for fans. Table 25 shows both the modeled and external estimate of equipment sales in 2020, highlighting that the two estimates are orders of magnitude different.

Table 25: Comparison of Modeled Pump and Fan Sales to Secondary Data Estimates in 2020

Data Source	Equipment Sales (2020)	
	Fans	Pumps
Model	3,245	2,957
Secondary Data	13,833	22,518

The dramatic difference between the modeled sales and secondary data estimates led the team to investigate if the model structure was artificially depressing sales. Sales are affected by two model components: equipment retirement rates and the return of out-of-service motor HP to in-service.

Retirement Rates: As discussed in Question 2 of the Methodology chapter, the model's retirement rates are based on equipment lifetime information from DOE's rulemaking analyses for pumps and fans. While vetted as a reliable source of information, these estimates may have overestimated the lifetime of industrial standalone pumps and fans in the region. However, the team determined that for the model sales to align with external estimates but the installed stock to grow based on gross output, 100% of pumps would have to retire every 3 years and 100% of fans every 5.5 years.

Return of out-of-service motor HP to in-service: The model currently prioritizes the reintroduction of out-of-service motor HP over the introduction of new sales into the region. This assumes an industrial facility would give precedence to motors they already own over purchasing new equipment, but the constraints on the out-of-service motor HP may be incorrectly estimating that prioritization. However, the team tested this by adjusting the model so all increases to in-service motor HP were filled via new sales and determined that the reintroduction of out-of-service motor HP had a negligible impact on total sales.

Outside of these model components, the industrial pump and fan stock would have to be an order of magnitude larger, or the industrial sector would have to have seen dramatically larger growth than indicated in the macroeconomic data, to justify these secondary sales estimates. On the other hand, the model's estimates of stock and total energy consumption align well with external data sources, leading the team to have more confidence in the modeled sales than the secondary sales estimates. In addition, when the team asked several ASD market actors to provide independent reviews of the modeled sales, the ASD market actors indicated that the modeled sales seemed low but were in range of the single-digit thousands that they expected.

[76] *US Census Bureau MA333P: Pumps and Compressors* https://www.census.gov/data/tables/time-series/econ/cir/ma333p.html, accessed 2/6/2022

[77] USGS Circular 1441: Estimated Use of Water in the United States in 2015. County Level Data Set Revised June 19, 2018, https://www.sciencebase.gov/catalog/item/get/5af3311be4b0da30c1b245d8, accessed 2/6/2022

[78] National Association of Manufacturers State Manufacturing Data, https://www.nam.org/state-manufacturing-data/2020-united-states-manufacturing-facts/ accessed 2/6/2022

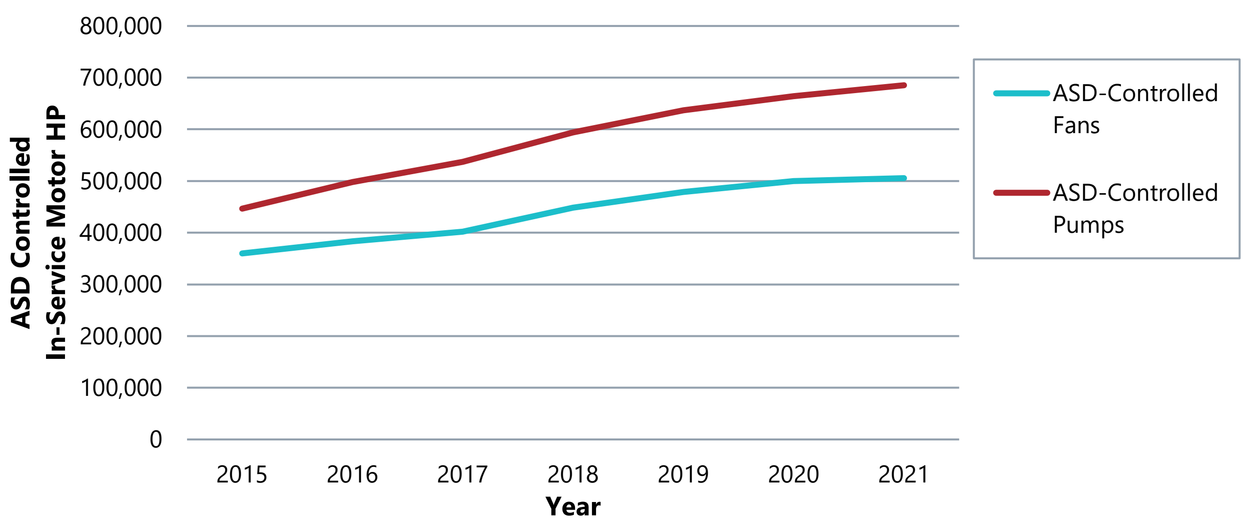
Impact of ASD Adoption

The purpose of this model is to quantify Momentum Savings from the adoption of ASDs on industrial standalone pumps and fans. To do this, the model compares the energy consumption of industrial pumps and fans (described in the Industrial Pump and Fan Characteristics section above) in each year of the model period with the energy consumption that would have occurred in each year had the ASD saturation not changed since 2015. This section presents how ASD adoption changed since 2015, the impact that has had on energy consumption, and the portion of ASD energy savings that are Momentum Savings.

ASD Adoption

Understanding where and how ASDs are installed allows the model to characterize the energy savings due to the adoption of ASDs on industrial pumps and fans. Figure 13 shows the ASD-controlled in-service motor HP calculated in the model, for each year of the analysis period. ASD adoption in both industrial pumps and fans increased significantly over the analysis period – 40% for fans and 53% for pumps. Comparing Figure 13 to Figure 8, we can also see that ASD adoption is growing at a much faster rate than installed stock of pumps and fans.

Figure 13: In-Service ASD-Controlled Motor HP, by equipment type and year



The increase in ASD-equipped in-service motor HP over the analysis period is driven by both program activity and market forces such as decreasing costs and greater recognition of the energy and non-energy benefits associated with ASD control throughout the industrial sector. Figure 14 and Figure 15 show that a portion of ASD-equipped in-service motor HP installed is attributable to the baseline, a portion is incented through utility programs, and a portion is adopted by the market without utility incentives. Baseline ASD-equipped in-service HP represent all in-service HP that would have been equipped with ASDs if the ASD saturation in every year was held constant at the 2015 value. These are shown in light blue and light red in Figure 14 and Figure 15. While the ASD saturation is held constant at the 2015 value, because the size of the industrial sector has generally increased over time, the number of ASD-equipped motor HP in the baseline has also increased over time. Program-incented ASD-equipped motor HP, shown in grey, represent the portion of motor HP that were incented through utility programs to install ASDs. The remaining portion of ASD-equipped motor HP installed since 2015 represent market momentum, or the adoption of ASDs above the baseline, outside of program activity.

Figure 14: Stock of In-Service ASD-Controlled Industrial Fans, by category and year

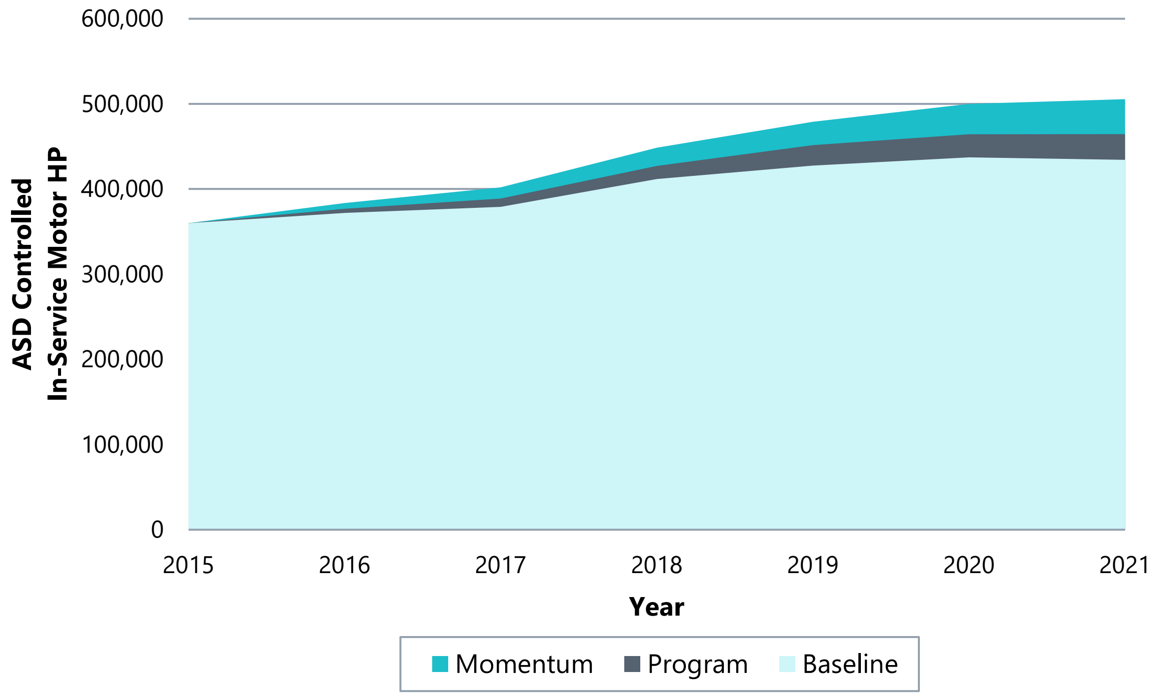


Figure 15: Stock of In-Service ASD-Controlled Industrial Pumps, by category and year

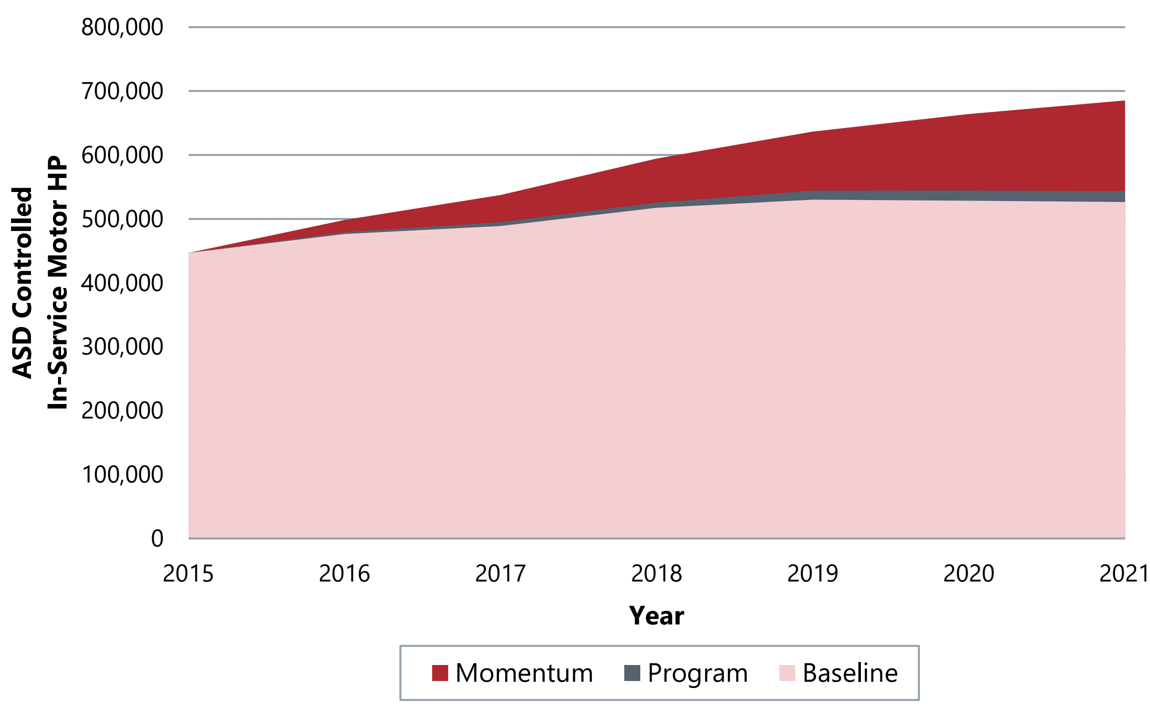


Figure 14 and Figure 15 show the total ASD-equipped motor HP that existed in the region's stock of motors, and how it has changed year-by-year. The team also reviewed the total ASD-equipped motor HP installed since 2015, independent of installation year. Figure 16 and Figure 17 show the pumps and fans that became equipped with ASDs since 2015, both as number of motors and number of motor HP. When viewed as percent of motors, programs make up 8.0% and 2.3% of the fans and pumps equipped with ASDs since 2015, respectively. However, when viewed as percent of motor HP, these same programs represent 20.8% and 7.3% of the motor HP equipped with ASDs since 2015, for fans and pumps respectively. This difference indicates that program activity is more concentrated on larger equipment types. This finding aligns with the anecdotal evidence of the market, as ASD-specific utility programs are exclusively custom programs, which require large savings to justify the measurement and verification cost.

Figure 16: ASDs Installed on Fans since 2015, by category

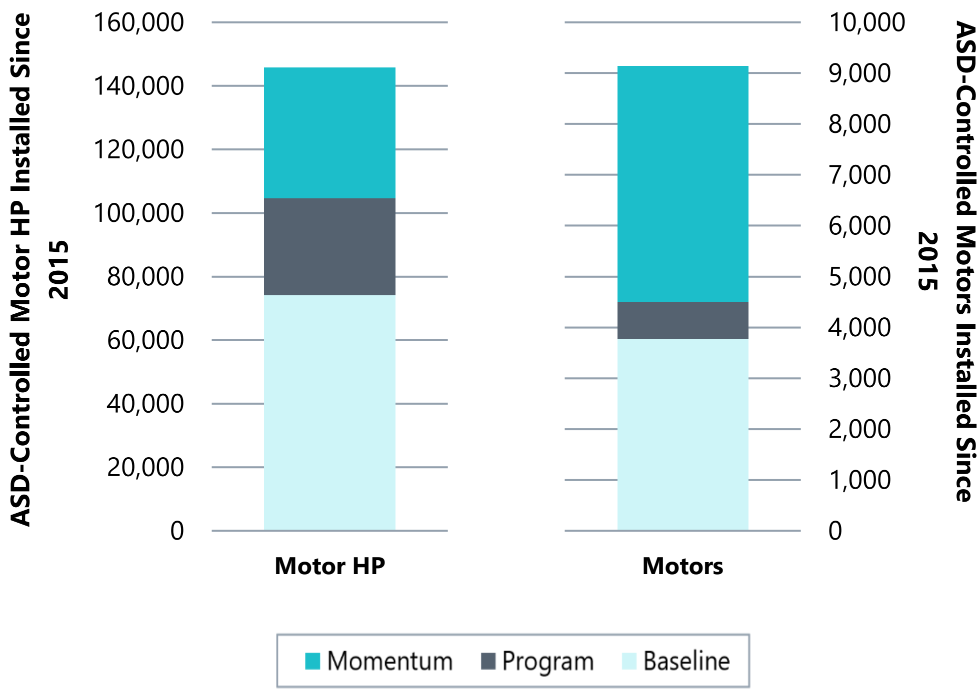
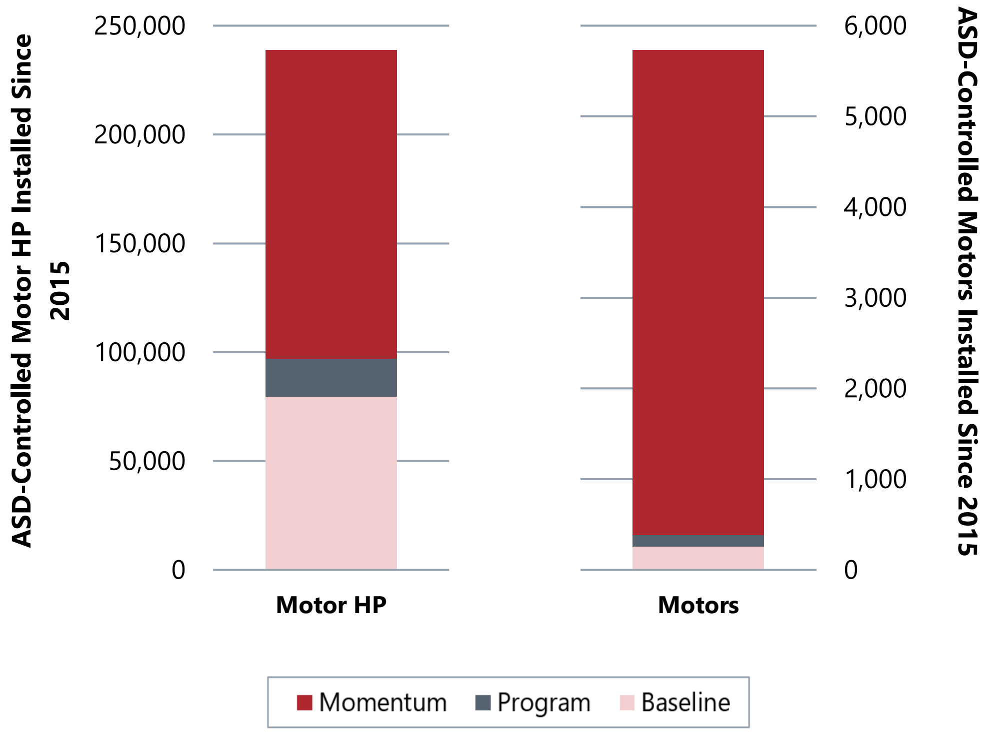


Figure 17: ASDs Installed on Pumps since 2015, by category



Energy Savings

The total number of Program and Momentum ASD-controlled fan and pump motor HP shown in Figure 16 and Figure 17 represent a change in control strategy, above the baseline, that created energy savings. The model calculates the total market savings (first-year energy savings of all ASD-equipped motor HP installed above the baseline) and subtracts the adjusted program savings to calculate the Momentum Savings associated with the adoption of ASDs. Table 26 shows the Momentum Savings results for the region and for BPA (representing 42% of the region).

Table 26: ASD Energy Savings (aMW at busbar), by year

Savings Source	2016	2017	2018	2019	2020	2021	Total*
Total Market Savings**	4.3	4.5	5.1	5.4	4.7	3.6	27.7
Adjusted Program Savings**	1.5	1.3	1.5	2.7	0.9	0.9	8.8
Regional Momentum Savings	2.8	3.2	3.6	2.7	3.8	2.8	18.9
BPA-portion Momentum Savings	**1.2**	**1.4**	**1.5**	**1.1**	**1.6**	**1.2**	**7.9**

**Years do not sum to total due to rounding.*

*** These are interim results in the calculation of Momentum Savings; they are not intended to be used for other purposes outside of this analysis.*

Sensitivity Analysis

To calculate total market energy consumption and Momentum Savings, the model relies on multiple different data sources, with different levels of uncertainty. Certain model inputs are subject to statistical uncertainty, such as the operating hours estimate calculated from the Northwest Industrial Motor Database, while other inputs are estimated using data sources combined with expert input and engineering judgement, whose uncertainty is not statistically quantifiable. To assess the impact these different types of uncertainty have on the model results, the team developed and tested nine different sensitivity scenarios, each varying a specific model variable. This analysis helps the team determine how the uncertainty of each variable impacts total energy consumption and Momentum Savings. With this analysis, the team can focus future research on components that have the biggest effect on decreasing uncertainty in model results.

Sensitivity Analysis Scenarios

For the sensitivity analysis, the team established high and low ranges for each of the four primary model inputs: stock, unit energy consumption, program savings, and ASD saturation. For each of these primary model inputs, the team selected a specific variable (or multiple variables) to vary. The team selected these variables based on their impact on the calculated input (preferring variables with significant impact on the calculated model input), as well as the estimated uncertainty in that variable. For each variable, the team selected a "high" and a "low" bound to represent the range of values the variable could reasonably, or even theoretically take. The "high" values align with increases in energy consumption, whereas the "low" values align with decreases in energy consumption. Where these values are not linked to statistical uncertainty, the team used assumptions that predicted the maximum reasonable impact of a variable's uncertainty. Table 27 identifies the model inputs and specific variables associated with the different sensitivity scenarios, as well details on the scenario.

Table 27: Sensitivity Scenarios

Model Input	Scenario	Description
Stock	**Motor Stock**	The model uses national in-service motor HP, scaled to the region, to determine the motor stock in each year. To test the impact this variable has on model results, this analysis varies the national in-service motor HP by the relative precision at 90% confidence interval, presented in the 2018 MSMA (+/- ~11%).
Unit Energy Consumption	**Operating Hours**	This analysis investigates the impact of operating hours by using the relative precision at 90% confidence interval, calculated in the Northwest Industrial Motor Database (ranging between +/- 1% and +/-7% depending on motor size and facility type).
	Load Profile	The team used engineering judgment and Expert Panel input to establish high and low load profiles. The "low" load profile represents a more variable load profile, with the equipment spending more of its time further from the design point (consuming less energy). The "high" load profile spends more time concentrated closer to the design point (resulting in higher energy consumption).
	Oversize Factor	The team established high and low values for oversizing factor based on the relative precision at 90% confidence interval in NEEA's Pumps Research (+/- 2%).
	System Efficiency	The team used information from DOE to estimate motor, equipment, and drive efficiency. To test the impact these components have on energy consumption, this scenario varies these values by between +/- 1% and +/- 5%, depending on the vintage, equipment type, motor size, and control strategy.
Program Savings	**% ASD Savings**	The team uses BPA-specific information to determine the percent of RCP-reported savings that is from ASD-specific projects. As detailed in Program Savings Uncertainty, this scenario tests the impact different assumptions in this process have on the model results, by varying the ASD-specific savings by +43% and -10%.
ASD Saturation	**ASD Saturation by Facility Type**	The team used national data and engineering judgment to disaggregate the sector-level ASD saturation by facility type. As discussed in ASD Saturation Uncertainty, this analysis tests the impact that disaggregation has by comparing it to a scenario where the sector-level ASD saturation is applied to all facility types.
	ASD Baseline Saturation	The team used the modeled ASD saturation in 2015 as the baseline ASD saturation on which savings were calculated. To test the impact of the uncertainty in the model's baseline ASD saturation, this scenario shifts the ASD saturation, across the entire model period, +/- 10%, while keeping the change in ASD saturation over the analysis period constant.
	ASD Saturation Growth Rate	The model uses information from national ASD saturation and regional ASD proprietary market reports to calculate the baseline and growth rate (the slope or rate of change) of ASD saturation in the region. This scenario varies these growth rates for each facility type by +/- 10% in each year, while holding the baseline ASD saturation constant.

Sensitivity Analysis Results

The team calculated the impact each of these scenarios has on the modeled regional industrial standalone pump and fan energy consumption. Figure 18 presents a tornado chart of the high and low energy consumption for each scenario, averaged across all years in the analysis period, as percent deviated from the average modeled energy consumption of 845 aMW. The team looks at the impact on average energy consumption because energy consumption changes over time, which causes the impact to fluctuate across years. Figure 19 presents the impact the same uncertainty has on total regional Momentum Savings across 2016–2021, with the order of scenarios from Figure 18 maintained. In these figures, the orange bars represent the impact the low value has on model results and the green bars represent the impact the high value has on model results.

These charts cover the entire scope of the model and do not show the uncertainty impact by equipment type. While the uncertainty associated with each variable may vary between equipment types, the relative ranking of the uncertainty's impact (as shown in the below charts) would not vary between equipment types.

Figure 18: Uncertainty Impact on Average Annual Energy Consumption

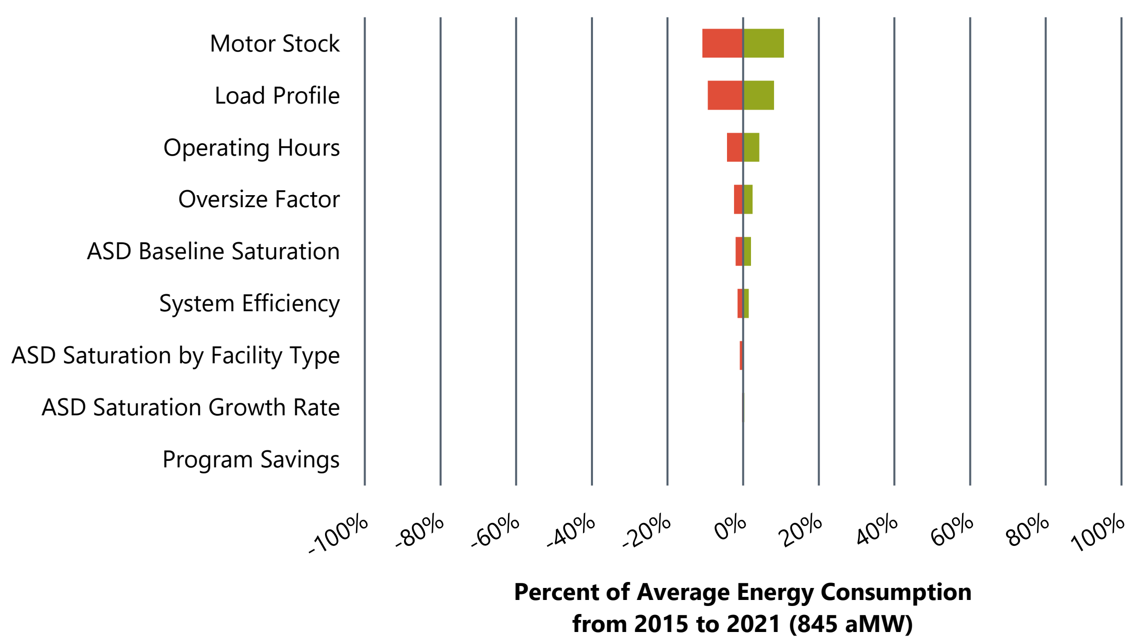
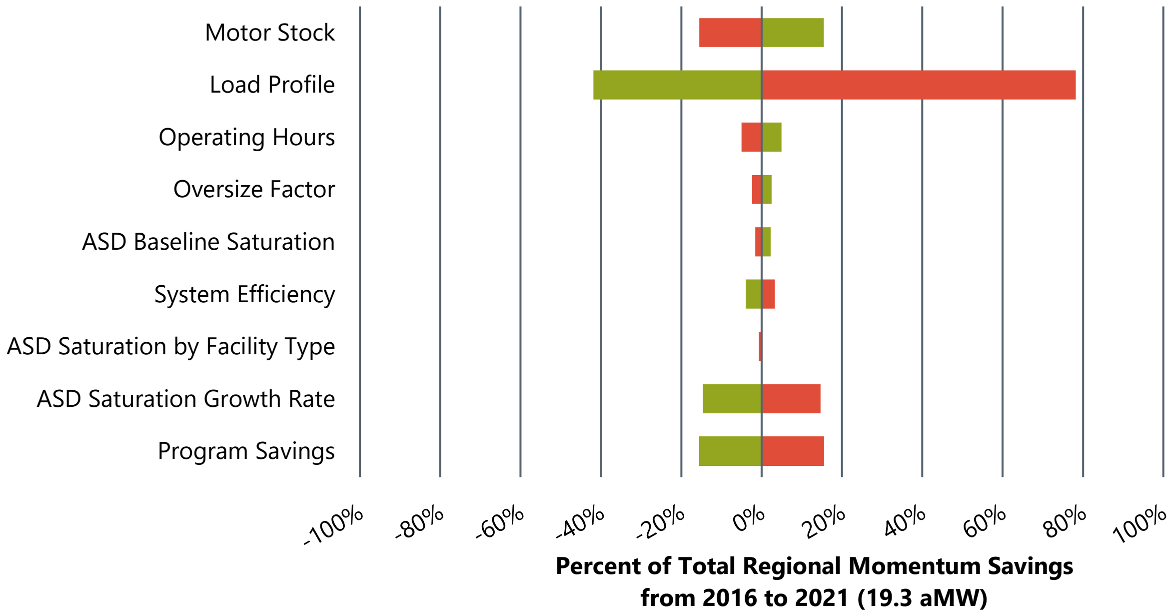


Figure 19: Uncertainty Impact on Total Regional Momentum Savings



This analysis showed that energy consumption and Momentum Savings are differentially impacted by each scenario. In Figure 18, the high value (green bar) increases energy consumption in all scenarios and the low value (orange bar) decreases energy consumption in all scenarios, as the team established the low and high values based on their impact on energy consumption. However, this relationship doesn't hold for all scenarios in Figure 19. For motor stock, an increase in energy consumption corresponds to an increase in Momentum Savings, but for load profile, an increase in energy consumption corresponds to a decrease in Momentum Savings. Three scenarios (Load Profile, System Efficiency, and ASD Saturation Growth Rate) show an inverse relationship between energy consumption and Momentum Savings.[79]

Uncertainty in the motor stock and load profiles have the largest impact on energy consumption in the model. These two components have a large impact on Momentum Savings as well, along with the ASD growth rate and program savings. These four model inputs are the main drivers for uncertainty in the model, with the other scenarios varying energy consumption and Momentum Savings by less than +/- 5%. The following sections explore the impact uncertainty in these four model inputs have on the model results.

Installed Stock of Motors

Uncertainty in motor stock varies energy consumption by +/- 10%, whereas Momentum Savings varies by +/- 15%. The impact to Momentum Savings is larger than the impact on energy consumption because this model input (in-service stock of motor HP) impacts the number of ASDs installed in each year but does not change the number of program-incented motor HP. Therefore, the resulting changes in total in-service ASD-equipped motor HP above the baseline is directly translated to a change in Momentum Savings.

[79] While Figure 19 shows the colors of the Program Savings scenario as inverse, this scenario has no impact on energy consumption, The high and low values represents an increase and decrease in program-incented motor HP, respectively, which has an inverse impact on Momentum Savings.

Load Profile

Uncertainty in the load profiles impact both energy consumption and Momentum Savings. The team used the best available data, as well as Expert Panel input, to inform the modeled load profiles. Without a quantifiable uncertainty around the modeled load profiles, the team used engineering judgement and Expert Panel feedback to develop the "low" and "high" load profiles to capture the maximum possible level of uncertainty the load profiles could have. The "high" load profile represents a load profile concentrated at higher load points, resulting in larger energy consumption. The "low" load profile represents a load profile concentrated at lower load points, resulting in less energy consumption.

This scenario varies energy consumption +/- 9%, but has a disproportionately large, and inverse, impact on momentum saving, varying it by +78% and -42%. The impact of load profile on Momentum Savings is inverse, in direction, to the impact it has on energy consumption. That is, as uncertainty increases energy consumption, it decreases Momentum Savings, and vice versa. This is because a load profile that produces higher energy consumption will be more concentrated at higher load points. While this increases energy consumption, it decreases the energy savings associated with an ASD (as an ASD has greater impact on a system's energy consumption at lower load points). Figure 4 presents the relationship between load point and power consumption.

This relationship also drives the magnitude of impact load profile uncertainty has on the results. Because the power draw of a motor decreases cubically as load decreases, load profile has a dramatic impact on the effect of an ASD. This is an impact the team identified during model development, leading to the incorporation of "load type" as a model dimension, which allowed the model to characterize the different impact an ASD has on equipment with different load profiles.

ASD Saturation Growth Rate

ASD saturation is the driver of energy savings in the model, it has a relatively small impact on both energy consumption and Momentum Savings. The team modeled the three different scenarios related to ASD saturation, as presented in Table 27. The ASD saturation by facility type and ASD baseline saturation had minor impacts on energy consumption and Momentum Savings, but the growth rate (the slope or rate of change) of ASD saturation varied Momentum Savings by +/- 15%. While this represents one of the top four drivers of uncertainty in Momentum Savings, it has a small impact on total energy consumption.

Program Savings

The program savings have no impact on energy consumption but has a +/- 15% impact on Momentum Savings. The uncertainty in this model input stems from the need to calculate the portion of reported savings associated with ASDs because ASD-related program savings were not clearly differentiated in the RCP.

Decreasing Model Uncertainty

The sensitivity analysis aims to highlight areas of potential uncertainty that have the biggest influence on model results and identify the best opportunities for future model refinement and research. To decrease the uncertainty associated with the model, the team recommends prioritizing research that focuses on:

(1) better characterizing the regional installed motor stock, (2) refining the estimated load profiles for pumps and fans, and (3) verifying the growth rate of ASDs in the region.

Installed Stock of Motors

This model relies on national stock rates from the MSMA, scaled to the Pacific Northwest based on gross output. The available information from the MSMA also has inherent uncertainty in it. As the installed stock of motor HP (including in-service and out-of-service motor HP), and their attendant characteristics, are a primary driver of energy consumption and savings in the region, better information on how motor HP is distributed throughout the region would improve model accuracy, especially at higher levels of granularity within the model and provide important market insights that could inform future potential assessments or program development.

A stock assessment serves as an effective tool to understanding installed stock in a given sector. However, there are difficulties associated with fielding a stock assessment in a sector as large and diverse as the industrial sector. The region has fielded an industrial stock assessment in the past, but the study did not result in a publicly available dataset due to a relatively small sample size achieved.[80] The breadth of different facility types and systems that exist on industrial sites makes fielding a stock assessment a large undertaking. A successful industrial stock assessment could decrease uncertainty of motor stock characterization in this model, as could a more targeted primary data collection activities such as only collecting motor stock information or limiting a stock assessment to highly engaged or high energy consuming facility types.

Load Profile

Load profile is the defining characteristic of the savings associated with ASDs. The load a pump or fan serves determines the impact adding speed control has to a system, with more variable systems seeing larger savings than less variable systems. Better understanding of load profile of pumps and fans would have the biggest impact on decreasing uncertainty in the momentum saving estimates from this model. Researching this variable also directly supports the RTF's measure research needs on fans and ASDs and increases the body of information to support deemed measures for different applications of ASDS.[81,82]

The team identified two activities associated with decreasing uncertainty around load profile: 1) collecting more data to inform the estimate of load profile, and 2) working with experts in the field to better define the variability associated with different load profiles.

Collecting more data on load profile requires engaging with equipment end users to understand the operation of their equipment. A stock assessment represents a natural point to collect this information, as researchers will already be working with end users. However, adding operational data to a stock assessment greatly increases the level of engagement and risks deprioritizing a complete understanding of the installed stock. One method to decrease this likelihood is to avoid primary metering of equipment and leverage existing data collection systems. Distributed Control Systems (DCS) and Building Automation Systems (BAS) track and log the operation of equipment on industrial sites. Collecting

[80] NEEA Industrial Facility Site Assessment, https://neea.org/data/industrial-facilties-site-assessment, accessed 02/06/2022

[81] *RTF Research Strategy: Commercial and Industrial Fans May 19, 2020; ComInd_Fans_FEI_ResearchStrategy.docx* https://nwcouncil.app.box.com/v/ComIndFansResearchStrat2020 accessed 2/16/2022

[82] RTF Research Strategy: Variable Speed Drives Approved July 21, 2020; VSD_ResearchStrategy202007.docx, https://nwcouncil.app.box.com/v/072020VSDResearchStrat accessed 2/16/2022

logged data from these systems would accurately characterize their load profiles while not requiring a dramatic increase in engagement from the research team or end user.

Better understanding the variability in load profile also offers an avenue to decreasing uncertainty. Conducting a survey of equipment and ASD operators and installers would allow the team to better define reasonable bounds on the load profiles associated with different equipment. This engagement may confirm our current load profiles or result in refinements based on the experience of individuals in the field.

ASD Saturation Growth Rate

The ASD model currently leverages national ASD saturation information and the relative difference between regional and national ASD sales to calculate the regional saturation of ASDs in each year of the analysis period. Refining these values would decrease the uncertainty in how ASD saturation changes over time and more accurately model ASD saturation at a more granular level. Through engagement with manufacturer reps, ASD distributors, and installing contractors, the team determined that manufacturers and manufacturer reps do not have insight into where their equipment is being installed. Large national distributors typically mask both the equipment ASDs are being installed on and the geographic region in which they are installed. This information indicates that, to understand the rate of ASD installation in the region, engagement with regional distributors and installing contractors is necessary. Surveying installing contractors could potentially allow the research team to better characterize what equipment ASDs are being installed on in the region and investigate the ability of collecting data on installations to inform a region-specific ASD growth rate. This research could also potentially serve as an avenue to refine the load profile seen on different equipment.