Advanced Motors Channel Partner Support and Measure Package Development

Final Report

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Prepared by:

Julie Birchfield Energy Solutions
Kyle Booth Energy Solutions
Jim Hanna Energy Solutions
Ted Jones Energy Solutions
Amanda Shorin Energy Solutions
Jesse Zucker Energy Solutions
Sarabeth Erdman VEIC
Asa Parker VEIC
Cole Shea VEIC
Kelly Shin VEIC
Jonathan Thibeault VEIC

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Executive Summary

In the Advanced Motors Focused Pilot, the project team sought to overcome key barriers to the widespread adoption of advanced motors. Primary barriers include limited manufacturing, technical knowledge (by customers, contractors, and distributors), stocking, market awareness, and a lack of deemed energy savings methodologies needed to incentivize advanced motors. To help overcome these obstacles, the project team conducted a market characterization, designed education and outreach materials aimed at increasing market awareness, implemented an on-site monitoring program, and gathered data needed to develop a deemed measure package proposal for submission to the California Technical Forum (Cal TF). Some site monitoring and stakeholder engagement activities are still ongoing as of the publication of this report. This Final Report addresses each of the market barriers listed above and the likely impacts of the proposed intervention strategies. The Final Report documents data, results, and analysis from each of the intervention strategies. The findings are summarized here:

- **Market adoption levels are low for both original equipment manufacturer (OEM) and non-OEM advanced motors.** IE5 motors have long lead times and limited selection due to only a few manufacturers offering these products. The market for highly efficient IE4 motors is more mature, featuring more product options and shorter lead times, but still lacks the demand of IE3 motors.
- **Market awareness of IE4 and IE5 motors is low; providing market education through multiple pathways is a crucial step to increase market adoption.** Awareness of the benefits and availability of advanced motors, particularly IE5 motors, is low overall. We suggest a multi-pronged approach to address the obstacle of limited education: case studies, collaboration with third-party organizations (including utilities), and manufacturer-provided training materials for distributors.
- **Most non-OEM motor customers are only interested in "drop-in" replacements when they experience a motor failure. The customers that are purchasing non-OEM advanced motors are early adopters who typically have energy or sustainability goals driving this effort and are interested in planned replacement.** The "early adopters" of advanced motors are a small group but demonstrate a willingness to embrace non-OEM advanced motor technology. Marketing the savings, performance, and overall system benefits to this customer group is most likely to influence purchasing decisions
- **Energy savings witnessed through the field trials support that the advanced motor efficiency gains equal and often exceed the efficiency gains expected when using the nominal efficiency limits.** This confirms the importance of continuing work to increase market adoption of advanced motors.
- **For advanced motors requiring a variable-frequency drive (VFD), future motor measure packages and utility programs should focus on motor installations where a VFD will provide cost-effective savings.** Ultimately, the VFD needs to prove cost-effective on its own, with the advanced motor bringing incremental benefits at an incremental price.

Abbreviations and Acronyms

Acronym	Meaning
Cal TF	California Technical Forum
ECM	electrically commutated motor
eTRM	electronic technical reference manual
HP	horsepower
HVAC	heating, ventilation, and air conditioning
IEC	International Electrotechnical Commission
IM	induction motor
IOU	investor-owned utility
kWh	kilowatt-hour
NEMA	National Electrical Manufacturers Association
OEM	original equipment manufacturer
PEI	pump energy index
PMaSynRM	permanent magnet-assisted synchronous reluctance motor
PMM	permanent magnet motor
SRM	switched reluctance motor
SynRM	synchronous reluctance motor
VFD	variable-frequency drive

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Introduction

Since the electric motor was invented over 200 years ago, it has expanded into every corner of our modern work. The total number of motors in the United States is estimated at 52.5 million (Rao, Sheaffer, et al., U.S. Industrial and Commercial Motor System Market Assessment Report Volume 1: Characteristics of the Installed Base 2022). The total energy used by these motors is remarkably high, with commercial and industrial motors using about 29 percent of the energy supplied by the electric grid (Rao, Sheaffer, et al., U.S. Industrial and Commercial Motor System Market Assessment Report Volume 1: Characteristics of the Installed Base 2022). While the energy savings from higher efficiency motors alone are not as large as those coming from motors coupled with variable-frequency drives (VFDs), the scale of the motor market means even small efficiency gains could yield substantial energy and carbon savings. Excitingly, new, more efficient electric motor technology is entering the market, with potential for significant impact. These motors, referred to as "advanced motors" within this pilot, exceed the current federal minimum efficiency standards established in 2014 for low voltage polyphase electric motors (DOE 2023). A recent Department of Energy (DOE) motor market assessment estimated national advanced motor annual energy savings at 482,000 GWh/year, which corresponds to an annual greenhouse gas (GHG) emission reduction at 342 MMT/year CO_2, and annual utility bill savings of $53 billion/year (Rao, Sheaffer, et al., U.S. Industrial and Commercial Motor System Market Assessment Report Volume 3: Energy Saving Opportunity 2022) (Rao et al. 2022). Given the potential of this technology area, this focused pilot aims to understand the current market landscape, identify market barriers to widespread adoption, and test intervention strategies to address these obstacles.

Background

Motors are used in across a wide range of industries and end uses spanning the industrial, commercial, residential, and agricultural sectors. Electric motors support many systems, such as comfort heating and cooling, process heating and cooling, compressed air, commercial and industrial refrigeration, materials processing, materials handling, food processing, and more. Motor size varies greatly from small systems, typically under 10 horsepower, to much larger industrial systems over 500 horsepower. For the advanced motors pilot, the project team focused on replacement motors in non-original manufacturer equipment (non-OEM) retrofit systems that range between 1 and 50 horsepower. This scope is based on the research in the CalNEXT Technology Priority Map, which found that the OEM market is driven by codes and standards — and is thus not as well-suited to a focused pilot scope — and that 1 to 50 horsepower is the typical range in the market.

Focused Pilot Motor Eligibility Criteria

When determining which advanced motors to study during this focus pilot, we established the following motor eligibility criteria:

- Application classification: General-purpose[1]
- Availability: Commercially available in 2024 with a high potential to scale across the target power output range and supported by multiple manufacturers
- Compatibility: Motors designed for the three-phase, North American market (230/460V, 60 Hz) and available in NEMA frame sizes
- Efficiency: Exceeds the current energy-efficiency requirements established in 10 CFR Part 431.25 (DOE 2020).
- Output: Products must be rated for 1 to 50 horsepower
- Technology: The motors have been commercially available for less than 10 years

Table 1 shows motor technologies considered for inclusion in this pilot and whether they met eligibility criteria. Full descriptions are below.

Table 1: Eligibility Review of Advanced Motor Technologies

Eligibility Criteria	ECM	IM	PMM	SRM	SynRM	PMaSynRM
Application	✓	✓	✓	✓	✓	✓
Availability	⚠	✓	✓	×	×	✓
Compatibility	✓	✓	✓	✓	×	✓
Efficiency	✓	⚠	✓	✓	✓	✓
Output	⚠	✓	✓	✓	✓	✓
Technology	×	×	×	✓	✓	✓

✓ satisfies criteria, ⚠ somewhat satisfies criteria, × does not satisfy criteria.

Electrically commutated motor (ECM): ECMs can achieve IE5 efficiency levels. This technology has existed for more than 10 years, with the energy-saving benefits well documented and understood. Product availability can be challenging as products are often sold exclusively to OEMs, rather than through distributors. Horsepower is also limited, with this technology generally focused on motors of five horsepower or less, with a few exceptions.

Induction motor (IM): A limited selection of products can achieve IE4 efficiency levels, with all other products rated at IE3 efficiency or lower. This technology has existed for more than 10 years. Induction motors are considered the incumbent/baseline technology.

[1] As defined in (NEMA 2021), with no limitation that the motor is an induction motor.

Permanent magnet motor (PMM): PMMs can achieve IE5 efficiency levels. This technology has existed for more than 10 years, with the energy-saving benefits well documented and understood. There is good product availability and compatibility.

Switched reluctance motor (SRM): SRMs can achieve IE5 efficiency levels. This technology has been commercially available for less than 10 years. There are numerous case studies and one eTRM measure (SWHC041-05) documenting the energy-savings potential. SRMs are a patented technology with a single manufacturer and unconventional supply chain.

Synchronous reluctance motor (SynRM): SynRMs can achieve IE5 efficiency levels. This technology has been commercially available for less than 10 years (IE4-capable SynRMs have been available for slightly more than 10 years). SynRMs are currently only available in International Electrotechnical Commission (IEC) frames and specifications.

Permanent magnet-assisted synchronous reluctance motor (PMaSynRM): PMaSynRMs can achieve IE5 efficiency levels. This technology has been available for less than 10 years. Numerous case studies, but no eTRM measures, document the potential energy savings of this technology. Multiple manufacturers produce PMaSynRMs and supply the market via distributors.

The pilot team focused on PMaSynRM, as it was the only motor that met all eligibility criteria. This focus carried on into the field demonstration and measure package development components of this pilot. In this study, we also explore, in a limited way, super-premium efficiency (IE4) induction motors. The measure packages in development are focused exclusively on PMaSynRM technology.

In addition to the motor itself, several motor system elements are crucial to overall efficiency, including proper sizing and pairing the motor with a VFD. A VFD enables the motor frequency and voltage to be adjusted, matching the load requirement. Since many motor loads are not a continuous single-speed operation, installing a VFD can often drive significant energy savings, especially when motors operate at part load (Newkirk, Rao and Sheaffer 2021). It is notable that for most advanced motors, adding a VFD is not just a beneficial add-on feature but a requirement for the motor to function properly.

Code Requirements

Most advanced motors under investigation in this focused pilot are not currently governed by any motor efficiency standards. Current motor efficiency standards apply only to AC induction motors and exclude synchronous and inverter-only motors. The advanced motors included in this pilot are all synchronous motors — except one super-premium induction motor product — and are therefore not required to meet the federal energy conservation standard. Similarly, California state regulations impose no additional efficiency requirements on synchronous motors.

Synchronous motors were historically used in niche applications and represent a small portion of the electric motors market. As such, they have been exempted from regulation, which focuses on general-purpose electric motors. In fact, the motor efficiency standards outlined in 10 CFR 431.25 (DOE 2020) explicitly state that these standards apply only to general-purpose, single-speed, AC induction motors. The most recent direct final ruling by the DOE on 10 CFR 431 [6450-01-P] includes a recommendation (#4, p.39) “to forego establishing standards” for synchronous and inverter-only electric motors “until an updated test procedure is adopted that better captures the energy-saving benefits of these motors” (DOE 2014). National Electrical Manufacturers Association

(NEMA) and IEC technical committees are currently working on a new test procedure that will apply to synchronous motors, which will allow for future efficiency standards to apply to this product class. The new test procedure is expected to benefit advanced motors, as the current procedure ignores the performance of motors operating under part-load conditions, where advanced motors thrive.

In the meantime, motor manufacturers have been voluntarily certifying their advanced motors, using the testing standards created for AC induction motors. This approach helps demonstrate the performance and benefits of emerging advanced motor products compared with induction motors when used in general-purpose applications.

Since these advanced motors have been designed for general purpose and tested according to the current induction motor standards, this pilot requires that all eligible advanced motor products adhere to the efficiency requirement imposed on baseline, general-purpose, induction motor technology. Table 2 reviews regulations governing general-purpose electric motors.

Table 2: Applicable Federal and State Codes and Standards for General-Purpose Electric Motors

Code	Applicable Code Reference	Effective Date
CA Appliance Efficiency Regulations – Title 20	n/a	n/a
CA Building Energy Efficiency Standards – Title 24	n/a	n/a
Federal Standards	10 CFR Part 431.25	September 29, 2023

The nominal full-load efficiency for general-purpose, three-phase electric motors, as established in the federal code (10 CFR 431.25), is specified in Table 3 below.

Table 3: Nominal Full-Load Efficiency (Base Case)

Motor horsepower/ standard kilowatt equivalent	Nominal full-load efficiency (%)							
	2 Pole		4 Pole		6 Pole		8 Pole	
	Enclosed	Open	Enclosed	Open	Enclosed	Open	Enclosed	Open
1/.75	77.0	77.0	85.5	85.5	82.5	82.5	75.5	75.5
1.5/1.1	84.0	84.0	86.5	86.5	87.5	86.5	78.5	77.0
2/1.5	85.5	85.5	86.5	86.5	88.5	87.5	84.0	86.5
3/2.2	86.5	85.5	89.5	89.5	89.5	88.5	85.5	87.5
5/3.7	88.5	86.5	89.5	89.5	89.5	89.5	86.5	88.5
7.5/5.5	89.5	88.5	91.7	91.0	91.0	90.2	86.5	89.5
10/7.5	90.2	89.5	91.7	91.7	91.0	91.7	89.5	90.2
15/11	91.0	90.2	92.4	93.0	91.7	91.7	89.5	90.2
20/15	91.0	91.0	93.0	93.0	91.7	92.4	90.2	91.0
25/18.5	91.7	91.7	93.6	93.6	93.0	93.0	90.2	91.0
30/22	91.7	91.7	93.6	94.1	93.0	93.6	91.7	91.7
40/30	92.4	92.4	94.1	94.1	94.1	94.1	91.7	91.7
50/37	93.0	93.0	94.5	94.5	94.1	94.1	92.4	92.4

Source: 10 CFR 431.25, Table 5 (DOE 2020).

As stated in §431.25 paragraph (g) of the federal code:

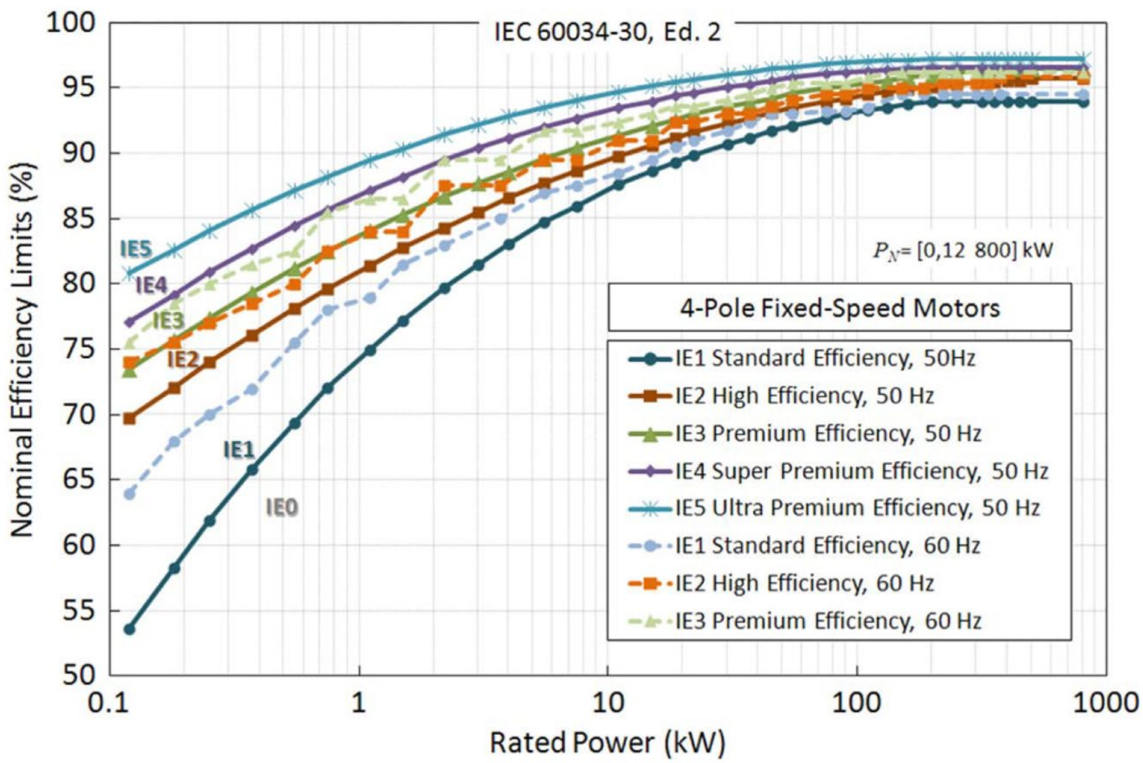
> *"The efficiency standards in the table above apply only to electric motors, including partial electric motors, that satisfy the following criteria:*
>
> - *Are single-speed, induction motors;*
> - *Are rated for continuous duty (MG 1) operation or for duty type S1 (IEC);*
> - *Contain a squirrel-cage (MG 1) or cage (IEC) rotor;*
> - *Operate on polyphase alternating current 60-hertz sinusoidal line power;*
> - *Are rated 600 volts or less;*
> - *Have a two-, four-, six-, or eight-pole configuration;*
> - *Are built in a three-digit or four-digit NEMA frame size (or IEC metric equivalent), including those designs between two consecutive NEMA frame sizes (or IEC metric equivalent), or an enclosed 56 NEMA frame size (or IEC metric equivalent);*

- *Produce at least one horsepower (0.746 kW) but not greater than 500 horsepower (373 kW); and,*
- *Meet all of the performance requirements of one of the following motor types: A NEMA Design A, B, or C motor or an IEC Design N, NE, NEY, NY or H, HE, HEY, HY motor."*

Federal code regulates a significant share of the motors market, extending beyond the subset of motors and applications investigated in this pilot. As a result, this code dictates the baseline motor efficiency used for measure package development. Copies of the measure proposal forms discussing the efficiency base case, measure case, and measure application are included as supplementary documents of this report.

Efficiency Classes and Motor Technologies

The IEC rates motor efficiency from least efficient, IE1, to the most efficient, IE5 (Drives and Automation n.d.). See Appendix A: Nominal Efficiencies for IEC Ratings



for a table of the nominal efficiencies by power across IEC ratings. This advanced motor pilot is focused on IE4 and IE5 motors. For reference, NEMA's "premium motor" correlates to IE3 motors. The technologies encompassed within IE4 and IE5 advanced motors vary widely. They include switched reluctance, synchronous reluctance, permanent magnet synchronous motors (PMSM), and brushless direct current (BLDC) motors, also known as electronically commutated motors (ECMs). For the purpose of this pilot, specifically the Measure Package Development portion, the team narrowed our focus to permanent magnet-assisted synchronous reluctance motors. See Table 4 for a mapping of IEC efficiency standard, NEMA terminology, and motor technology.

Table 4: Efficiency Classes of Three-Phase Motor Technologies

NEMA Efficiency Class	IEC Efficiency Class	Motor Technologies
Standard	IE1	AC induction
High	IE2	AC induction
Premium	IE3	AC induction
Super-premium	IE4	AC induction, DC brushless (ECM), permanent magnet synchronous, switched reluctance, synchronous reluctance, permanent magnet-assisted synchronous reluctance
Ultra-premium	IE5	DC brushless (ECM), permanent magnet synchronous, switched reluctance, synchronous reluctance, permanent magnet-assisted synchronous reluctance

Objectives

The Advanced Motors Focused Pilot seeks to address barriers to market adoption of advanced motors in the motor replacement and retrofit market (non-OEM). The pilot focuses on advanced motor technologies, defined as IE4 and IE5 motors, and their associated energy savings. In addition to motors, this pilot also touches on VFDs because they play a critical role in overall motor efficiency and are often required for advanced motors. The primary market barriers to the adoption of advanced motors include limited manufacturing, availability, technical training, education, stocking, market awareness, and the lack of deemed energy savings methodologies needed to incentivize advanced motors. To help overcome these market barriers, the project team conducted a market characterization study and identified necessary education and outreach strategies aimed at increasing market awareness. This pilot is also implementing an on-site monitoring program and gathering data necessary for the development of a draft measure package proposal to be submitted to the California Technical Forum (Cal TF).

Methodology and Approach

Market Characterization

The project team gathered market information through a variety of methods, primarily by engaging with manufacturers and distributors in direct conversations and follow-up questionnaires (see Appendix C: Full Market Actor Questionnaire). These surveys provided the team with in-depth information on a range of topics related to advanced motors, including, but not limited to, the supply chain, market availability, common customer end-uses, key decision-makers, and market barriers to adoption. We drew supplementary information from a review of existing programs and literature.

Education and Outreach

The project team surveyed distributors and manufacturers on questions such as:

- What are your training needs?
- What training model would suit you best?
- What training materials should be included?
- What training format would be useful?
- Who would benefit most from training?
- What design topics should be included?

Through an analysis of this market feedback, the project team developed and disseminated case studies, and crafted recommendations for how investor-owned utilities (IOUs) can continue further educational endeavors after this pilot. The project team engaged with manufacturers, distributors, and other market stakeholders throughout the development of these resources for feedback and guidance regarding the format, content, and dissemination strategies that would be most impactful. The case studies and education recommendations are included in the Education and Outreach section of this report.

On-Site Monitoring

On-site equipment monitoring for this pilot is being conducted for approximately 10 motor retrofits to obtain field operation data. The intended purpose of on-site monitoring is to verify and document the energy savings (kWh) of advanced motors in real-world installations. The monitoring includes both pre- and post-installation collection periods to collect both baseline and new equipment data points. Advanced motors — and in most cases, a VFD — are installed at each location along with monitoring equipment. Data from facility energy management systems (EMS) is being collected and used if available. Primary data being gathered includes, but is not limited to, run times, motor size, load factors, and energy consumption. If preinstallation data cannot be obtained or there are other data gaps, the team will create a baseline simulation using code minimum efficiencies. Please refer to a copy of the metering plan in

Appendix E: Measurement and Verification Plan for a more detailed description of metering equipment, programmable parameters, and variables to be measured.

Measure Package Development

Measure package development preparation will be the final deliverable for this project. "Measure package" refers to the creation of supporting documentation and an approval process for establishing new statewide deemed energy-saving measures or updating existing energy savings measures to be included in the California energy efficiency portfolio. The project team will draft or update up to two measure packages and submit them to an assigned lead program administrator at Cal TF for review. The stopping point for this project will be at the draft phase of the measure package, Step 3 outlined below. Step 3 has a planned completion date of April 2025, which is after the submission of the Final Report. For the December 2024 Final Report deadline, the pilot team will complete Step 1 of measure package development as outlined below:

- Step 1 *(December 2024)*: Submit completed measure proposal forms to the Cal TF. The digital files for each measure proposal form are submitted alongside the Final Report.
- Step 2: Submit measure development, update plan, and receive Cal TF early feedback. If the proposal is approved by the Cal TF following Step 1, the project team will work with the assigned lead program administrator to complete the plan. This timeline will be based on the needs of the Cal TF lead program administrator.
- Step 3 *(Expected April 2025)*: Complete draft measure package. The project team will work with the lead Cal TF staff and respond to any comments or questions. The project team will have regular meetings with the assigned Cal TF staff members and this timeline will be based on the needs of the Cal TF lead program administrator. This will be the final step of this focused pilot; Steps 4 through 6 will be completed outside of the focused pilot scope.
- Step 4: Measure review. An assigned Cal TF staff lead program administrator will review the draft measure package, likely asking the project lead for revisions and clarification. The project team will keep open communication with the Cal TF during this process. The timeline depends on how long communication may take between the project team and the Cal TF.
- Step 5: Cal TF affirmation. The Cal TF holds 10 annual review meetings to review and vote on submitted draft measure packages. The project team will coordinate with the Cal TF and present at a review meeting. The timeline is based on the Cal TF.
- Step 6: Submit a measure for California Public Utilities Commission (CPUC) approval: The assigned Cal TF lead program administrator can submit the Final Measure Packet to the CPUC for approval.

The draft measure packages were developed with engineering calculations that use international (IEC) motor efficiency standards. Motor efficiency test results provided by the motor manufacturers and other third-party accredited test data were reviewed to ensure that the included products meet the established standards and will be submitted with the drafted measure packages. Using efficiency standards as opposed to specific product performance provides flexibility and allows for future advanced motors that meet the efficiency criteria to be covered by the measure packages in development without further amendment.

The measures for this pilot were selected based on the potential impact and scalability of the end use and sector, balanced with the constraints of the timeline and recruitment feasibility. Additionally, technology prerequisites for advanced motor adoption were also considered. Additional details regarding which savings measures are being pursued as part of this pilot are included in the Measure Package Development section.

Industry Partners

Throughout the pilot, the team engaged with several market actors across the motors industry to inform each of the deliverables included in this report.[2] Table 5 details the types of market actors engaged throughout the pilot.

Table 5: Industry Partners

Industry Partner Type	Number of Actors Engaged
Manufacturers	5
Distributors	4
Industry Trade Organizations	5

Market Characterization

Market Overview

The sections below delve into the landscape of the advanced motors market. It should be noted that advanced motors are an emerging technology and thus, only a limited number of manufacturers and distributors are equipped to speak about these motors. Appendix B lists currently available motor models by manufacturer.

Sales Process

What is the typical sales process for IE4 and IE5 motors?

The project team began market interviews by researching the sales process for IE4 and IE5 motors. The prevailing sentiment is that the market for advanced motors is still evolving and as such, the sales process varies by manufacturer, distributor, and contractor. Often, motor replacement sales are correlated with another piece of equipment, such as an HVAC unit, fan, or pump. In these cases, a business looking to replace a motor in an HVAC system, for instance, is likely to defer to their HVAC dealer, who may or may not stock motors, rather than dealing directly with the motor distributor. In this example, the HVAC distributor would likely purchase the motor from a motor distributor. For IE3 motor replacements, another common customer pathway is to rely entirely on their contractor, distributor, or an in-house facilities manager to facilitate the motor replacement. The contractor will

[2] Note that not every partner contributed to every project component.

deal directly with either a motor distributor or the equipment dealer for which they need a motor replacement (as above).

Generally, only very large commercial and industrial customers pursue retrofit advanced motors, which are often sold on a request-only basis. Installation of IE5 motors usually requires design help and both IE4 and IE5 motors have limited market availability, as they are produced by a select few manufacturers. When a customer specifically requests an advanced motor, it is typically at the directive of the customer's design engineer(s) who will often work directly with the manufacturer and distributor.

Comparative Sales Margins

What are the comparative sales margins for advanced motors and standard-efficiency motors in the 1 to 50 horsepower range?

In general, respondents reported that the sales margins between IE3 and IE4 motors are relatively similar. For IE5 motors, in comparison with IE3 and IE4 motors, the sales margins may be higher due to their high cost and the addition of a VFD, which is often sold separately from the actual motor. Another important consideration when evaluating advanced motor installation projects is that typically, these upgrades are done on a whole system rather than on one individual motor, to help justify the additional cost to the customer of pursuing the advanced motor option.

Supply Chain

Can you walk us through each step of the supply chain for motors? Does this process look any different for advanced motors?

Motor manufacturers reported that the supply chain for advanced motors is at the early stages of development. Motor production occurs both domestically and internationally, with lower demand motors typically being produced internationally, which increases equipment lead times. On the distributor side, the supply chain is largely dictated by the motor models that customers purchase. In some cases, a customer or a contractor will reach out to a motor distributor to specify the type of motor they need. More often though, customers rely on the motor distributors and specifiers to recommend motor technologies that will fit the customer's system. If the order has potential for an advanced motor technology, the manufacturer will engage engineers to ensure the motor is properly specified to fit the site. While OEM distributors tend to stock advanced motors, non-OEM distributors stock them on a very limited basis since there is lower demand for them. One non-OEM distributor reported that they do not stock advanced motors and will only purchase the equipment upon customer request. Another non-OEM distributor corroborated this, sharing that there is "not much demand for IE4 or IE5 motors.... [because] customers are unaware of these options." In summary, the supply chain for advanced motors is largely undeveloped, with a lack of customer awareness and low demand for high-efficiency models. Figure 1 below details the supply chain for advanced motors and Figure 2 shows the distribution of standard-efficiency motors compared to IE4 motors.

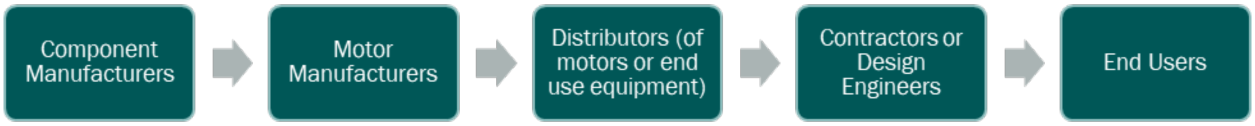


Figure 1: Motor supply chain.[3]

Source: (Lowe, Golini and Gereffi 2010).

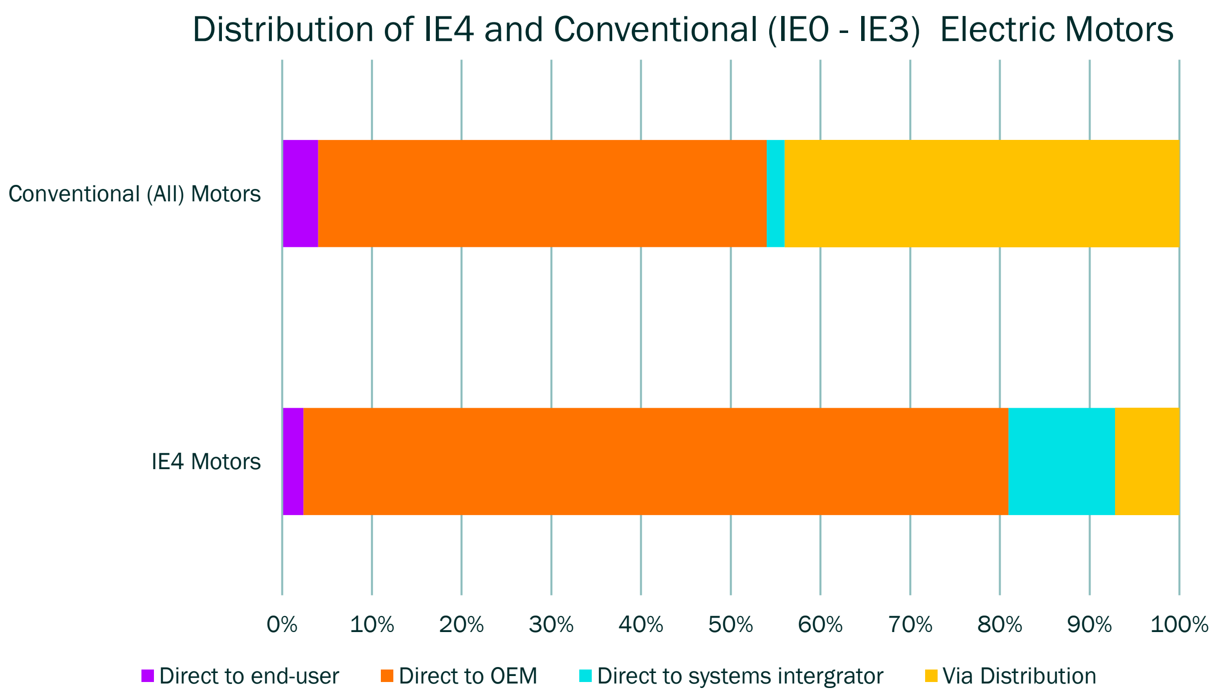


Figure 2: Motor distributor stocking practices.

Source: Source: Internally developed using OMDIA Dataset for Integral Horsepower IE4 Motors, https://omdia.tech.informa.com/OM019195/Motors--Drives-Vertical-Application-Topline-Report--3Q21-Analysis and the Electric Motors Preliminary Analysis Chapter of (DOE 2023).

Equipment Lead Times

What is a typical lead time for your IE3, IE4, and IE5 motors?

According to survey respondents, a key determining factor in motor lead time is the size and horsepower (hp) of the motor. Generally, smaller motors (between 1 and 20 hp) tend to have shorter

[3] Components of motors include electrical steel, iron and steel, and raw materials such as magnets, aluminum, and copper that then become metal castings, copper wire, and scrap copper necessary to assemble the motors. These components are produced by a variety of manufacturers around the world, including in Sweden, Finland, China, Germany, the United States, England, Japan, Spain, and other countries.

lead times, while larger motors (50 hp and above) tend to have longer lead times. The lead times for advanced motors are highly dependent on manufacturer stocking practices, which are guided by customer demand. According to one manufacturer, their highest volume motor is a 5-hp premium-efficiency IE3 motor with a lead time of roughly two weeks. This manufacturer's local facilities stock as many as two dozen of these motors at a time and produce roughly 100 in a production run. The lead time for an IE4 motor, according to this manufacturer, is two to four weeks, depending on whether the manufacturer has the specific model(s) in stock at the time of the order. The average lead times for IE3 and IE4 motors are relatively similar, as one manufacturer explained, because both motors are produced using the same or very similar components.

Based on the pilot team's experience during the On-Site Monitoring portion of this pilot, the lead times for IE3, IE4, and IE5 motors between 1 and 20 hp were largely the same since each of these motors are stocked by the manufacturer. The lead times for motors that are commonly stocked by a manufacturer are roughly 1 to 2 weeks. However, when the motor stock gets low or an order exceeds the amount available in the distribution network, an order will be sent to the factory which has a maximum restocking time of six weeks. In theory, the lead time should be a maximum of six weeks for a given motor, however this is subject to variability in practice. This pilot experienced both scenarios, where one of the participating sites received their (stocked) advanced motor in a matter of days while another site had a six-week lead time because they needed a custom-order advanced motor.

Common End Uses

What are the most common end-use applications for your IE4 and IE5 motors?

The manufacturers and distributors we interviewed were reasonably aligned on the most common end-use applications for advanced motors. Survey respondents broadly identified HVAC-related applications as common end uses for motor replacements, including cooling tower water pumps, ventilation fans, supply and modulating fans, and unregulated, non-PEI pumps like boosters and air compressors. Figure 1 and Figure 3 compares common end-use applications of standard-efficiency motors (induction motors) and advanced motors (IE4 motors). As motors are widely used in a variety of sectors, the list of common end uses provided below is not exhaustive.

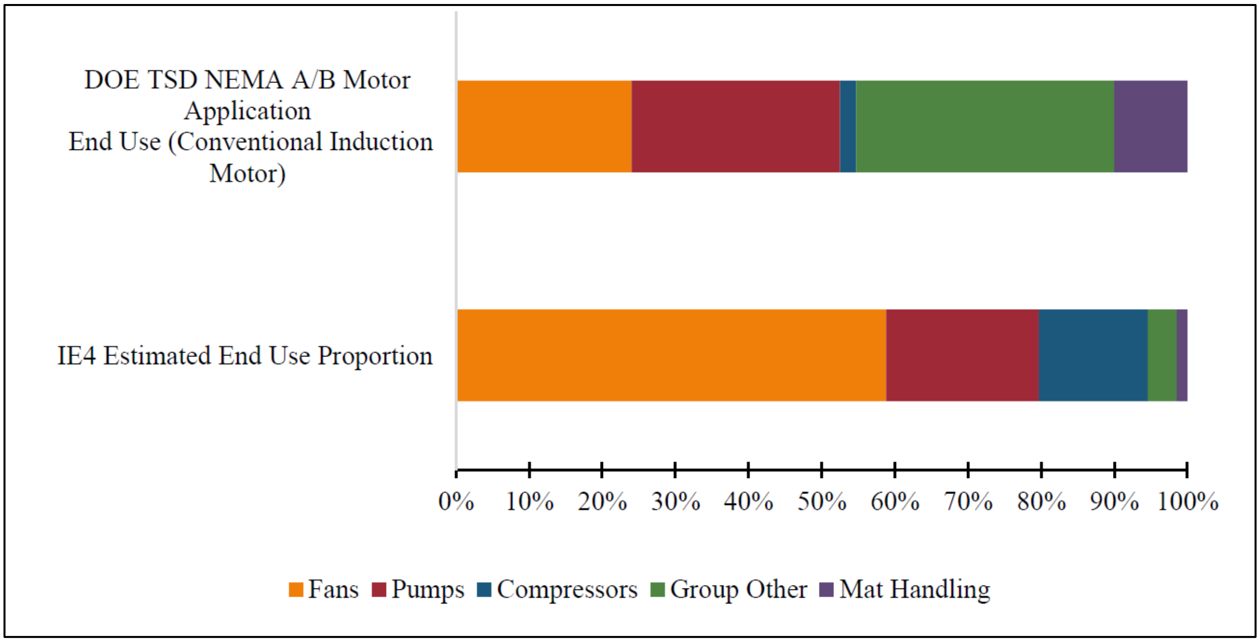


Figure 3: Common end-use applications for motors.

Source: Energy Conservation Program: Energy Conservation Standards for Electric Motors, No. EERE-2020-BT-STD-0007-0002.

Largest Customer Segments

What is your largest customer segment currently and which segment do you think has the highest potential for sales?

When asked about the largest current customer segment, survey respondents identified commercial market stakeholders such as public institutions, hospitals, large commercial office buildings, tech companies, and data centers. Installations of advanced motors occur most often for premium quality designs in new construction and major renovation projects rather than as retrofits. Interviewees noted that industries with large industrial sites such as oil and gas refineries, mining companies, power generation plants, data centers, large stadiums, and large food-processing facilities are more likely to do planned motor replacements. In contrast to the planned replacements, when a motor failure occurs, advanced motors are rarely selected due to a lack of stock and relatively long lead times, high costs, and key decision-makers' lack of familiarity with advanced motors. The customers most likely to pursue advanced motor replacements are those with large-scale operations who are motivated to meet sustainability targets. Often, these motivated customers are also big-budget companies willing to spend the extra money to cover the cost differential between a standard and advanced motor. Interestingly, one manufacturer estimated that roughly 80 percent of IE5 motor sales are in the OEM market while just 20 percent are in the non-OEM market. As the market adoption of IE4 and IE5 motors increases, it is likely that the percentage of OEM and non-OEM advanced motors sales will be more evenly split. This assumption is in part informed by the more even split of OEM and non-OEM for IE3 motors, as shown in Figure 2.

Key Decision-Makers

Who are the key decision-makers of purchasing IE4/IE5 class motors?

The key decision-makers for motor replacement projects vary depending on whether the replacement is an IE3, IE4, or IE5 motor. Generally, a replacement motors is treated as an unplanned maintenance item that is either stocked as a spare or purchased following an equipment failure. In commercial and industrial facilities, motor replacement purchases are often done at the directive of the procurement, maintenance, or facilities departments. These motor purchases tend to be “drop in” or “like-for-like” replacements, meaning the defunct motor is replaced by the same or a very similar model. The decision-makers driving these purchases are most concerned with the cost, lead time, and reliability of the replacement motor. According to one manufacturer, even if IE4 and IE5 motors had the same cost and lead times as IE3 motors, end users would still be unlikely to request the advanced models due to a lack of awareness of the benefits and reliability.

Advanced motor retrofit purchases, on the other hand, are typically driven by an operations manager, plant manager, maintenance manager, general manager, or an engineering specifier. In some cases, these decisions come directly from the plant manager, vice president, or president of the organization, often as part of a company-wide sustainability initiative. In contrast to a standard “like-for-like” motor replacement, advanced motor upgrades often require additional signoffs from a company’s engineering team and/or management team to ensure that the new motor will function properly within the system and that it is worth the additional cost. Typically, motor replacement decisions are based on an organization’s annual maintenance budget, and advanced motor upgrades are based on the whole operating cost of an organization, which includes lifetime energy costs. Some customers — typically large organizations — have in-house support to guide motor replacement projects. Other customers hire engineering consultants.

Customer Motivations for Advanced Motors over Induction Motors

What motivates a customer to opt for an IE4 or IE5 motor rather than an induction motor or lower efficiency motor?

Three of the manufacturers and distributors surveyed identified green building certifications, equipment operational improvements, and energy and carbon savings as common customer motivations for purchasing advanced motors. One respondent recounted an instance where a customer who purchased an advanced motor to achieve a building efficiency rating, paid little attention to the return on investment. For facilities with large energy loads such as arenas, data centers, or industrial processing facilities, the energy savings associated with advanced motors can present a compelling case for justifying the additional cost.

In cases where a customer is pursuing an advanced motor retrofit, it is most likely a complete system upgrade rather than a simple motor replacement and will often require input from engineering consultants. Additionally, customers pursuing an advanced motor retrofit are more likely to be doing so as part of a pre-planned maintenance or equipment replacement project rather than in response to an unplanned equipment failure.

The project team also heard in our surveys that a customer looking to cut down on energy consumption is likely to opt for other energy-efficient upgrades with a larger impact on overall energy usage, such as a VFD, before considering an advanced motor replacement. Interestingly, several manufacturers noted that they use VFDs to help sell advanced motors. Using new VFD installations as a pathway to sell advanced motors is beneficial from a technology integration and success perspective as it would allow the motor and drive to be sold in a pre-configured package, thus eliminating compatibility concerns and the need for configuration support.

As is the case with many emerging technologies, cost is a major driver of customers' motor purchasing behaviors. While this is certainly the case for advanced motors, the lack of customer, contractor, and distributor awareness, education, technical knowledge, and engineering support, particularly for non-OEM advanced motors, form the biggest obstacles to scaling market adoption. As mentioned in previous sections, even if the cost of an advanced motor was the same as a premium efficiency (IE3) model, customers are still unlikely to select an advanced motor due to a lack of awareness on its benefits, or a reticence to adopt an unfamiliar piece of equipment. As the market stands today, it is difficult for distributors, or others in the supply chain, to explain the benefits of IE5 motors compared to standard efficiency motors because awareness and adoption levels are low and there is a lack of information available to educate customers.

Market Awareness Ranking

On a scale from one to five, how would you rank customer awareness of the benefits of IE5 motors? What about market awareness generally?

When the team asked manufacturers and distributors to rank customer awareness of the benefits of advanced motors on a scale from one to five, no survey respondent ranked awareness above a three. The pilot team's post-advanced motor installation survey distributed to the sites participating in the On-Site Monitoring portion of this pilot reported a similarly low level of awareness surrounding advanced motors. In general, distributors reported lower market awareness than manufacturers did. Survey respondents consistently reported that the lack of awareness on the benefits of advanced motors is one of the key barriers to increasing market adoption. One explanation is that advanced motors are a newer technology in the United States, with few published case studies demonstrating the benefits of these motors. Another distributor noted that manufacturers have not yet prioritized upselling and educating distributors on the new motor technologies. On the other hand, some survey respondents ranked customer awareness closer to a three, because motors have such a wide breadth of applications, cutting across an array of sectors, and therefore get visibility in many markets. Finally, awareness of advanced motors varies by industry. The renewable energy sector tends to be more informed, while other markets, such as the poultry industry, may be less informed about advances in motor technology.

Market Barriers

What barriers will affect the ability to scale the deployment of IE4 and IE5 motors?

Manufacturers and distributors identified a variety of barriers that impact the ability to scale the deployment of advanced motors. The most common themes were cost, equipment lead times, market demand (or the lack thereof), engineering requirements, and technical education. These themes are interrelated. For instance, high cost and market demand are directly correlated with the high costs of advanced motors translating to low market demand, and low demand keeping the cost of the technology higher. Survey respondents also noted that the perceived energy savings generated by advanced motors alone are often not enough to justify the return on investment (ROI), especially when compared with a code-compliant premium-efficiency induction motor.

Beyond actual motor cost, there is also the cost of the motor installation which, according to one manufacturer, "can amount to two or three times the motor's price."[4] High motor installation costs can result from the complicated installation required by many advanced motors, especially when they are paired with a VFD. For many customers, motor replacements occur in response to a system failure, and in these instances, customers will often prioritize a drop-in replacement motor because of the simplicity and speed of the installation.[5] Getting a customer to take on the risk of a new advanced motor is a barrier that must be overcome. Additionally, given the nuance of installing some advanced motor models, finding a contractor familiar with installing advanced motors and drives is difficult, presenting an additional barrier. According to the feedback from one site that participated in the On-Site Monitoring portion of the pilot, their new advanced motor seems to be better suited to a new installation scenario rather than a replacement. The reason for this, the site engineer explained, is because their new advanced motor requires its own set of wiring to operate — which presented some difficulties for the setup — whereas one set of wiring could sustain several of the site's previous motors.

Finally, the lack of education and awareness surrounding advanced motors is intimately linked with each of the themes addressed above. Considering the infancy of the advanced motors market, particularly for IE5 motors, it makes sense that technology education and awareness levels are low. A key driver in scaling the deployment of advanced motors is to ensure market actors are educated on the existence, operation, and benefits of the technology.

Feedback to Increase Adoption of Advanced Motors

Do you have any feedback to help advance the deployment of IE4 and IE5 motors?

There are two themes that prevailed among survey respondents to questions about increasing advanced motor adoption. The first was that advanced motor adoption levels are higher in the OEM motor market than they are in the non-OEM market. The second was, as previously noted, that there is a need for greater market awareness on product availability, cost, ROI, and technical specifications.

In line with the first theme, motor manufacturers reported that a key step in the market development for advanced motor is to supply the technology to manufacturers in the OEM market, such as HVAC, fan, and pump manufacturers. By supplying OEM equipment manufacturers with advanced motors, the supply for advanced motors across the market will grow and eventually infiltrate the non-OEM market as well.

As it pertains to the second theme, one survey respondent postulated that many market actors likely do not have the time to investigate the impacts, costs, and feasibility of investing in an advanced motor and thus, would benefit from resources that can educate them on these matters. The team

[4] Note: Despite this quote, installation cost doesn't necessarily scale with motor price.
[5] A "drop-in replacement motor" is a motor replacement that has the same size, weight, and footprint as a customer's previous motor.

received encouraging feedback from the market that case studies would be helpful in increasing visibility of advanced motors and their benefits. There are few resources currently available to market actors that detail the performance of advanced motors.[6] As such, through this pilot, the project team created case studies for select sites participating in the On-Site Monitoring portion of this pilot as well as education program design recommendations to address the lack of market awareness surrounding advanced motors.

Recommended Building Types and Systems

The advanced motor products included in this focused pilot are well-suited to replace the general-purpose induction motors that drive variable torque loads. These types of motors and motor loads are very common in agricultural, commercial, and industrial buildings, appearing in pump, fan, blower, and compressor systems, among others. This is also the same type of load and equipment where a VFD is often recommended for saving energy, which is fortuitous, since most advanced motors require a VFD for normal operation. Advanced motors are also being adopted into OEM products such as air handlers, circulator pumps, and exhaust fans, demonstrating their ability to efficiently power variable torque loads.

Motor manufacturers have developed their advanced motor products in the same form factor, enclosure type, and ingress protection rating (IP), and with the same electrical requirements as general-purpose induction motors. The physical similarities between current induction motor and advanced motor characteristics reduce the barriers that would otherwise limit advanced motor installations, promoting efficient product substitution and technology transfer.

The largest limitation with the use of advanced motors is the need for a VFD. However, this is often more of a benefit than a limitation given energy-saving potential when controlling variable torque loads such as pumps and fans. For systems that already feature a VFD, compatibility with an advanced motor will depend on which advanced motor is used as well as the model and age of the existing VFD. Some VFDs may prove compatible with no changes while others may need firmware upgrades or wholesale replacement. The VFDs needed to run advanced motors are off-the-shelf products, readily made by numerous manufacturers and sold through traditional sales channels. Advanced motor manufacturers also offer pre-programmed VFD and advanced motor packages to guarantee compatibility, performance, and ease of installation. Systems moving from fixed to variable speed, and new motor system installations (such as in new construction or with new equipment) are therefore likely to face the fewest compatibility challenges given the ability to plan ahead and ensure proper integration.

Eligibility Criteria for Energy-Saving Incentive Programs

Eligibility criteria for a utility- or third party-led advanced motor incentive program is likely to be guided by the efficiency classification of the motor. All eligible advanced motor products would need to exceed the federally mandated minimum energy efficiency to qualify for support, resulting in a program that is designed to support motors that exceed IE3 efficiency levels.

Incentive program designers will need to determine which among the varied motor designs to include in their incentive programs. Different advanced motor designs have advantages, disadvantages, and

[6] ENERGY STAR®'s Emerging Technology Award for Advanced Motors in HVAC equipment is a notable exception, which one manufacturer has been using to help build market awareness of the benefits of IE5 motors.

varied cost-effectiveness, so creating an incentive program based solely on efficiency ratings may favor designs with the lowest incremental cost and leave potential energy savings in the field. Incentive program designers may therefore want to consider other factors such as total resource cost (TRC) when structuring incentives.

Lastly, the baseline for comparison and the eligibility criteria for an advanced motor incentive program will likely be closely connected to the terms and conditions of federal motor regulations. A detailed description of the motor characteristics that determine whether a motor is subject to regulation is provided in the Code Requirements section. Please refer to that section for more information relevant to incentive program design.

Motor Cost

The pilot team collected price information on a variety of motor designs to determine the cost-effectiveness of advanced motor technology. Price information was collected for totally enclosed fan cooled (TEFC) motors only, since this motor enclosure is the most popular within the horsepower range of this pilot. This statement was corroborated during interviews with motor distributors, who confirmed that TEFC motors represent the majority of sales from 1 to 50 hp. Furthermore, nearly all advanced motor products reviewed in this study use a TEFC enclosure, which guarantees good alignment with the greater motor market. Additional motor characteristics that were used to qualify motors before collecting the price information are outlined below:

- Efficiency: Premium efficiency (IE3), IE4, and IE5
- Frame material: Rolled steel, cast iron, and aluminum
- Horsepower: 1–20
- Speed: 1800 and 3600 revolutions per minute (rpm)

Using the above criteria, the pilot team collected the price information for over 250 motor models. This information was collected from publicly available motor catalogs and data negotiated from enduring and effective relationships with motor distributors. Catalog (list) pricing is useful because it allows for a robust dataset to be created using the criteria outlined above. Distributor pricing is helpful as it more accurately reflects the price that end-use customers will pay. Ultimately, the advantage of each source of data was leveraged by applying the discount pricing trends observed in the distributor price surveys to the catalog prices. A more detailed description of how the baseline and advanced motor customer costs are calculated is provided in the following subsections.

COST DETERMINATION METHODOLOGY

A five-step process was created to determine the average cost of motors according to horsepower and efficiency class. A detailed explanation of the developed cost calculation methodology is provided below, with a flow chart of this process provided at the end of this section in Figure 4.

1. **Create a database for motors** where the following characteristics are defined: motor horsepower, motor rpm, NEMA frame size, frame material, efficiency level, motor manufacturer, product line, catalog number, full load efficiency, catalog (list) price, and distributor price. Distributor pricing for every motor model in their catalog was not requested nor expected as this is an unrealistic request for motor distributors. Catalog information for approximately 270 motors was collected and entered into the database.

2. **Calculate the average manufacturer price** according to product family and horsepower. Product families are specific to each manufacturer and generally align with an efficiency class (e.g., Super-E is an ABB Baldor-Reliance premium efficiency (IE3) product family). Each horsepower interval has numerous potential motor models per product family, each with a potentially unique price. Differences in price are attributed in part to the characteristics highlighted in step one above.

   By averaging motor prices according to product family and horsepower, a single price per horsepower and efficiency class can be created for each manufacturer that encompasses all relevant motor configurations. Averaging according to manufacturer also minimizes the instability in price trends caused by differing motor product counts between manufacturers and horsepower intervals.

3. **Calculate the average catalog price** for each horsepower interval and efficiency rating using the resampled product family values. For example, the average catalog price for a 1 hp premium efficiency (IE3) motor is calculated using the average prices for the "Awesome," "Excellent," and "Superior" product families, from motor manufacturers no. 1, 2, and 3 respectively (refer to the flow chart in Figure 4 for clarification). This methodology is applied for all horsepower increments within each efficiency classification. Manufacturers that feature multiple, relevant product families per efficiency class will be rolled up into one average value for each manufacturer, per horsepower and efficiency class. This approach again minimizes the disturbance to average price trends caused by varying product counts per manufacturer and provides equal price weighting for all manufacturers included in this study.

4. **Extrapolate the catalog price trend** when low product quantities cause deviations within the expected trend. For this study, the calculated average cost for 1 and 1½ horsepower IE5 motors varied from the greater trend, due to low and/or inconsistent product volumes at these intervals. The resulting prices at these low horsepower intervals were consequently more representative of the cost of a single motor or two, rather than a greater trend. To protect product anonymity, the price trend that is established in the 2- to 20-hp range is extended down to 1 hp. There are many more motors available in the 2- to 20-hp range, which allows a well-fitting trendline to be established for this horsepower range that can be extended to neighboring horsepower intervals with confidence.

   It is worth noting that PMaSynRMs are not the only 1 and 1½ hp IE5 motors on the market. In fact, this region is well covered by ECMs, which has significant overlap with the PMaSynRM market below 5 hp.

5. **Apply distributor discount** to the average catalog price (result of steps 1–4). Motor distributors were interviewed as part of the market characterization effort. Distributors were asked to provide price information on the IE3, IE4, and IE5 motors that they sell. Since the intention of collecting this price information is to represent the motor cost for the average customer, the distributors were asked to provide the median discount that reflects the price that a medium volume purchaser might pay. This distributor level price data was collected for over 100 of the ~270 motor models included in our motor database. It was not realistic to request that distributors provide motor prices for their entire catalogs.

The distributor price information was then entered into the motors database and evaluated alongside the catalog price to establish a single, market-wide distributor discount value (%) to be applied to the catalog prices established following the completion of steps 1–4. The calculated distributor discount is an average of all discounts seen in the price information for all surveyed motor distributors.

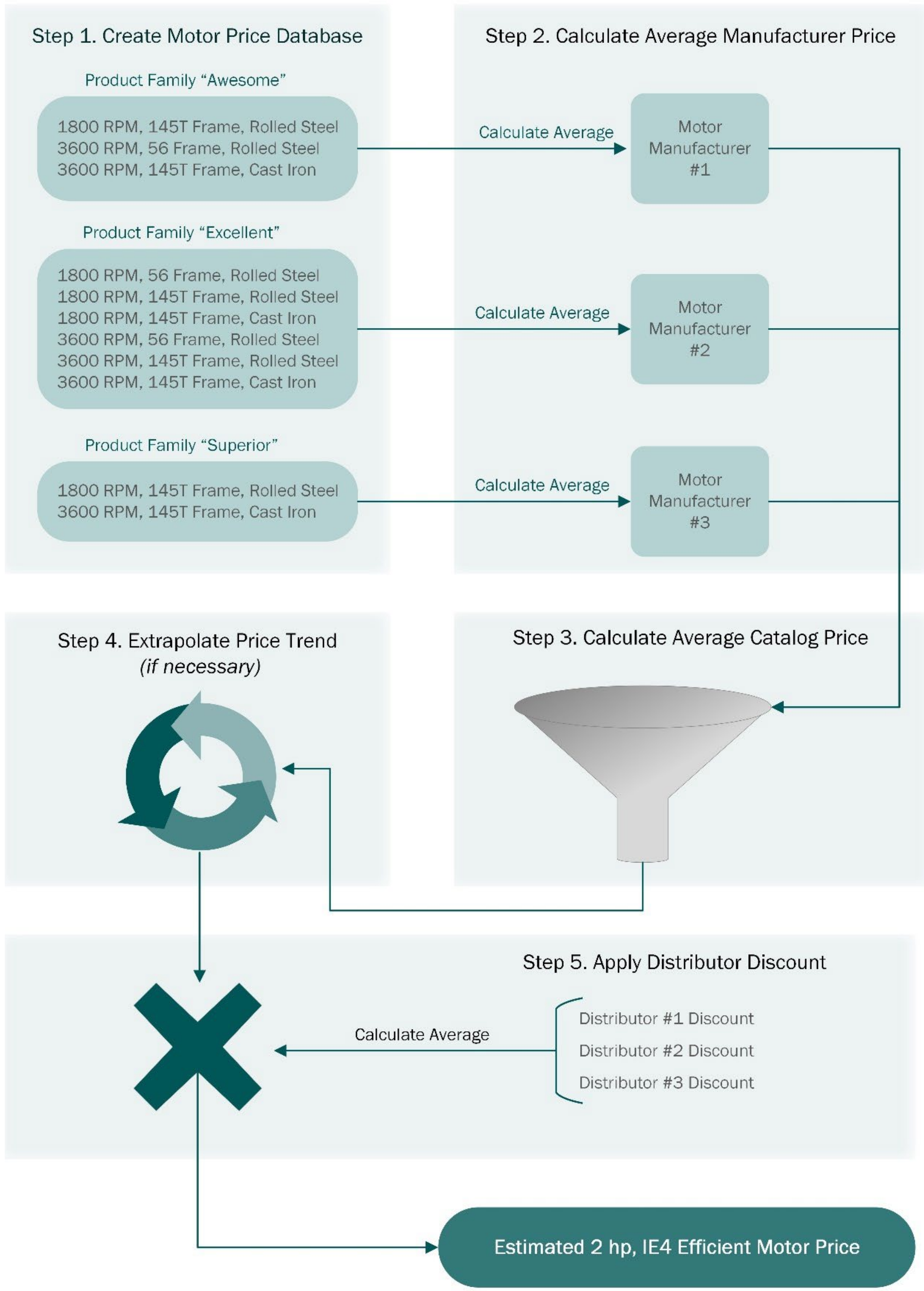


Figure 4: Cost calculation methodology flow chart (example: 2 hp, IE4 efficient motor).

ESTIMATED MOTOR COST (DISTRIBUTOR LEVEL)

The estimated distributor prices for baseline and advanced motors were calculated using the motor cost determination methodology outlined in the previous section. Results of this calculation are shown in Table 6 and Figure 5 below:

Table 6: Average Price (Distributor-Level) for Three-Phase AC Motors, by Efficiency Class

Motor Size (hp)	IE3	IE4	IE5
1	$425	$521	$578
1.5	$475	$554	$646
2	$515	$599	$706
3	$594	$671	$795
5	$700	$731	$902
7.5	$921	$1,048	$1,213
10	$1,060	$1,189	$1,478
15	$1,489	$1,787	$2,072
20	$1,804	$2,354	$2,552

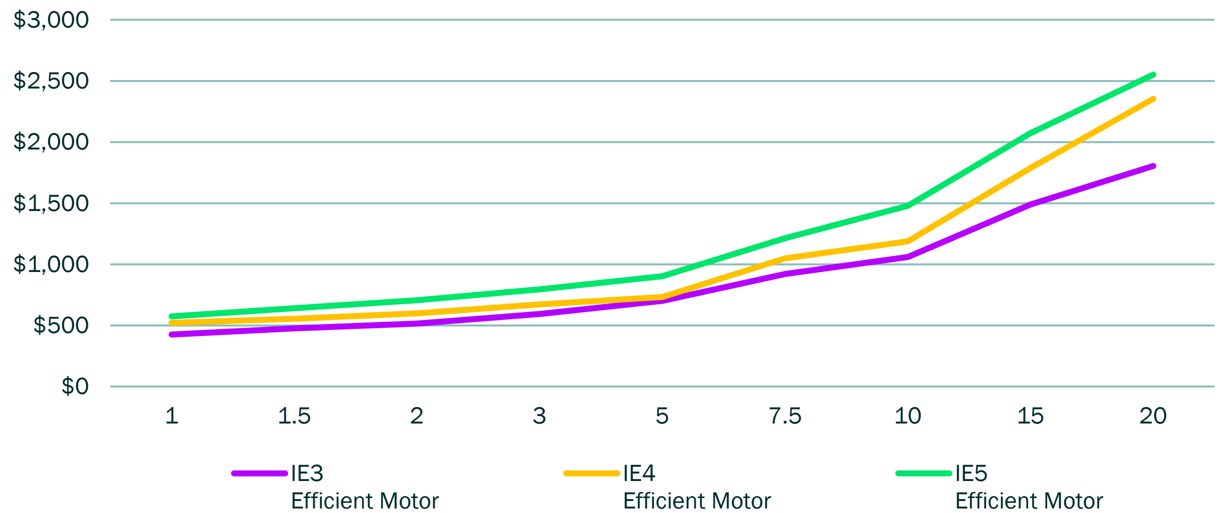


Figure 5: Average price (distributor-level) for three-phase AC motors, by efficiency class.

The prices displayed in Table 6 and Figure 5 showcase the estimated full price for a motor, according to horsepower and efficiency class. The prices shown are for the *motor only*. Although IE5 motors do require a drive to operate, this drive is in some instances required by code or may already be installed at the customer's site. The later situation proved to be true at a pilot participant site, where an existing drive was successfully reprogrammed to control a new IE5 motor. Furthermore, drives have the potential to save a significant amount of energy depending on the application, regardless of the efficiency of the connected motor. Considering the cost of the drive as integral only to the cost of an IE5 motor without accounting for the energy savings produced by the drive, would distort the true economics of these motors for all situations except applications where a drive would provide no energy savings.[7]

ESTIMATED INCREMENTAL MOTOR COST

Incremental cost describes the difference between the price of a baseline (premium-efficiency) motor and an advanced motor (IE4 or IE5). This cost is particularly relevant in situations where a motor must be purchased, such new construction, motor failure, or proactive motor replacement due to concerns about age and reliability. These scenarios present the highest appeal and cost benefit for customers, given the fractional increase in cost required to purchase a higher-efficiency motor. A table displaying the estimated incremental costs for advanced motors is provided below in Table 7.

[7] Examples of non-beneficial drive installations include when the demand placed on a motor are constant, and when the motor operates at full speed unrestricted, with no benefit to controlling the output (e.g., open-loop pumping systems).

Table 7: Average Three-Phase AC Motor Incremental Cost (Distributor-Level), by Efficiency Class

	Incremental Cost (Absolute)		Incremental Cost (Relative)	
Motor Size (hp)	IE3 – IE4	IE3 – IE5	IE3 – IE4	IE3 – IE5
1	$96	$153	122%	136%
1.5	$78	$171	117%	136%
2	$84	$191	116%	137%
3	$77	$200	113%	134%
5	$31	$202	104%	129%
7.5	$127	$291	114%	132%
10	$128	$418	112%	139%
15	$297	$582	120%	139%
20	$550	$747	130%	141%
Average			**117%**	**136%**

Measure Package Development

The pilot team has started drafting updates to two deemed measure packages to incorporate advanced motors into their measure offerings. A draft of these updated measure packages is expected to be completed in April 2025. Due to the time constraints of this project and diverse end uses of electric motors, the following criteria were used when deciding the focus of the measure packages:

- Availability: Typical horsepower of the end-use application aligns with the horsepower range of the advanced motors currently available.
- Compatibility: Advanced motors cannot run direct-on-line and require the use of a VFD for operation.
- Complexity: End-use application has a predictable operational load profile that can be defined by simple engineering calculations as opposed to complex energy modeling. Consequently, weather-dependent HVAC motor loads that require energy modeling were not considered for measure package development.

- Savings potential: Efficiency gains are greatest at lower horsepower ratings (inverse relationship between horsepower and efficiency).
- Scalability: Measure is applicable to at least 1,000 motor installations in the state.

Given these criteria, the team determined that the most appropriate path for measure package development is to amend two existing VFD measure package plans to include an offering for advanced motors. The two existing measures are “VFD for Glycol Pump Motor” and “VSD for Ventilation Fan, Agricultural.” This measure package development path is validated on the instructions tab of Cal TF’s Measure Proposal Form, which states:

> *“Some measures might be more appropriate as new measure offerings to an existing measure instead of being developed as a new stand-alone measure.”*

Additionally, the project team attended a Cal TF measure screening committee meeting on June 20, 2024, to outline our measure package development path and seek guidance. The committee agreed that amending existing measure packages to include an offering for advanced motors makes sense, given the required use of VFD.

Table 8 lists the existing electronic technical reference manual (eTRM) VFD measures we considered for amendment, and our assessments.

Table 8: Existing VFD eTRM Measures Considered for Advanced Motor Scope Modifications

Version	Measure Characterization	Selection Status, Reason
SWPR002-02	VFD for Glycol Pump Motor	Selected. Good horsepower alignment, high run hours, predictable load.
SWPR005-02	VFD for Dust Collection Fan	Not selected. Dynamic operation, large horsepower range.
SWPR006-02	Variable Speed Drive (VSD) for Ventilation Fan, Agricultural	Selected. Good horsepower alignment, high run hours, predictable load.
SWWP002-03	VFD on Irrigation Pump, ≤ 300 hp	Not selected. Poor alignment with advanced motor horsepower.
SWHC041-05	Software-Controlled Switch Reluctance Motor	Not selected. Proprietary advanced motor design.
SWRE002-01	VSD for Pool and Spa	Not selected. Measure proposes use of an advanced ECM.

Version	Measure Characterization	Selection Status, Reason
SWHC018-04	VSD for HVAC Fan Controls, Commercial	Not selected. Seasonal influences, large horsepower range.
SWWP005-03	Enhanced VFD on Irrigation Pump	Not selected. Poor alignment with advanced motor horsepower.
SWHC008-02	VSD for a Central Plant System	Not selected. Measure built on complex energy modeling.
SWCR003-03	Fan Motor Retrofit for Refrigerated Display Case	Not selected. Measure proposes use of an advanced ECM.
SWFS012-03	Exhaust Hood Demand Controlled Ventilation, Commercial	Not selected. Packaged equipment (OEM motors market).
SWHC023-04	Enhanced Ventilation for Packaged HVAC	Not selected. Already includes provision for an advanced (permanent magnet) motor.

The measure titled “VFD for Glycol Pump Motor” characterizes the energy-saving benefits of utilizing VFDs on the glycol pumps used for process cooling at wineries. This measure is applicable for pump motors rated from 3 to 25 hp, which aligns well with the advanced motor products identified during market characterization. These pumps are expected to be used at every winery (of which, there are approximately 4,800) since they are used during the fermentation and storage processes, with cooling needed 24 hours per day, year-round. The cooling load varies significantly throughout the year, with the maximum cooling demand occurring during harvesting. Cooling needs during the remainder of the year are focused on keeping the products cool in storage, and for comfort cooling in the facility. This variation in cooling load presents a great savings opportunity for VFDs, which advanced motors can also exploit given their increased efficiency at reduced speeds and load factors. The planned measure package development is to amend this measure to include an advanced motor offering that will feature the energy-saving benefits of using an advanced motor with this VFD instead of a code-compliant NEMA premium motor. A copy of the draft measure proposal form is attached to this report.

The measure titled “VSD for Ventilation Fan, Agricultural” describes the use and savings of VFDs on ventilation fans in livestock barns. This measure is limited for 1 to 5 hp motors, which again aligns well with early advanced motor product offerings. Numerous ventilation fans are typically used per barn, which, given the number of barns in the state, ensures a high number of potential installations. As with the “VFD for Glycol Pump Motor” measure, the plan is to amend the existing measure to include an offering for advanced motors. A copy of the draft measure proposal form is included is attached to this report.

The next step for measure package development is to present the attached measure proposal forms at a Cal TF measure screening committee meeting for approval. The project team will work with Cal TF to present at the next available meeting. After the measure proposal is submitted and accepted by Cal TF, Cal TF will assign a lead PA to support the drafting of the measure package elements. This pilot team will submit the measure package, but another party will need to take up the approval process and any review cycles necessary with Cal TF.

It is important to note that the energy-saving potential of IE5 motors extends far beyond these two measure packages in development. The two measures being pursued as part of this pilot present a starting point for measure package development by demonstrating the cost-effectiveness of upgrading the motors as part of a larger VFD project. Similarly, future measure packages that focus on motor installations where a VFD will provide cost-effective savings would also be good measures to bundle with advanced motor upgrades. Ultimately, the VFD needs to prove cost-effective on its own, with the advanced motor bringing incremental benefits at an incremental price. Similarly, advanced motor measure packages focused on motors measures where a VFD is required by code are likely worthwhile to develop since the motor measure does not need to bear the cost of the VFD. The exception to this guidance is for IE4 induction motors, which can operate without a drive. As such, they are more flexible in application, which presents the opportunity for additional measure packages when VFDs are not required or recommended.

Education and Outreach

Based on the feedback collected from motor industry market actors, the pilot team developed two market education and awareness strategies for the education and outreach deliverable of this pilot: advanced motor case studies and market education program design recommendations.

Case Studies

Using the findings gathered during the On-Site Monitoring portion of the pilot, the team produced two case studies on the advanced motor replacement projects executed through this pilot. The case studies provide a detailed overview of the site, end-use applications, motor replacement(s), performance data, and key takeaways. The pilot team engaged with the Electrical Apparatus and Services Association (EASA), the DOE's Industrial Assessment Centers (IACs), Southern California Edison's (SCE's) Utility Training Center, motor manufacturers, and motor distributors for feedback on content and dissemination strategies. In collaboration with these groups, the pilot team plans to disseminate the case studies by posting them online for review and direct distribution to a variety of motor industry market actors. The case studies can be found in Appendix H:.

Education Program Design Survey

Through the education program design portion of this focused pilot, the team sought to understand how best to educate the motors industry on the availability and benefits of advanced motors, with the ultimate goal of increasing adoption of non-OEM advanced motors. We surveyed manufacturers, distributors, and industry trade organizations for feedback on the type of education and training materials that would be most impactful. The sections below include the feedback collected from market actors on education strategies as well as detailed recommendations for an advanced motors education program design.

Education Gap in the Motor Industry

Where do you see the largest education gap in the industry around IE4/IE5 motors and drives?

The project team sought to first understand where the largest need for training exists within the diverse motor market, which includes segments with varying levels of visibility on advanced motors. Survey respondents identified distributors and motor end users as the first groups that would benefit from advanced motor education and training efforts, such as case studies, demonstrations, and technology introductions in collaboration with motor manufacturers. On the customer side, most motor end users are not up to date on the latest motor technology and mostly "they are driven by what [motors] will keep their facility and day-to-day operations up and running," as one respondent noted.

Interestingly, manufacturers and distributors pointed to electrical contractors and design engineers as the groups with the most visibility on the advances in the motors industry. This is not to say that these groups are fully aware of advanced motors, but more so than end-use customers. One distributor noted that their company is already working with electrical and design-build contractors to educate them on the latest motor technologies. However, the education gap on advanced motors extends to distributors as well. Tellingly, one distributor commented that "if you say the words 'IE4' or 'IE5' to most distributors, they won't know what you're talking about."

One of the key findings highlighted in these conversations was that there are limited advanced motor training resources available to distributors. In response to this feedback, the pilot team followed up with distributors to learn more about types of trainings they would find beneficial.

What kinds of motor trainings do you think distributors will find most helpful? What specifically do you want to see in trainings for advanced motors?

Distributors could identify a few existing training resources related to advanced motors but noted that these trainings are general in nature and do not address the concerns of end users. Interestingly, distributors specified that the most helpful training resources would be ones they can pass along to the end users, because it is customers who drive demand. More specifically, distributors mentioned that advanced motor trainings should include topics such as a technical overview of the technology, installation information, rating specifications (IE3, IE4, and IE5), market potential by sectors, and an overview of the benefits of advanced motors compared to standard-efficiency models.

Through these conversations, the pilot team learned that distributors need to be well-positioned to educate end users on topics that motor purchasers do not have the time or energy to concern themselves with, such as efficiency ratings and how to assess the best fit for your site's motor application.

What type of resources do you think would help educate the motors market on the benefits of advanced motors?

To be most effective, programs should distribute multiple types of resources at various strategic points throughout the supply chain. Survey respondents provided a variety of suggestions on how to educate different target groups within the motors industry. One manufacturer noted "real-world case studies that show energy and carbon savings [of advanced motors]" would help distributors educate end users by providing data on the savings potential of advanced motors. Case studies that demonstrate viable end-use applications for advanced motor retrofits that exist in the market today will help businesses in the same or related sectors better understand the benefits and attainability of advanced motors.

In addition, a distributor informed the team that they already conduct regular trainings on motors and drives for electrical design consultants and design-build contractors, which has helped foster more awareness of the advanced motor and drive technology. Interestingly, one manufacturer stipulated that given the progress of advanced motors in the OEM market, trainings should be delivered in conjunction with OEMs as this will help increase adoption, create a larger supply of advanced motor equipment in the field, and ultimately trickle down to the non-OEM side. As previously mentioned, distributors also serve to benefit from training sessions that better position them to sell advanced motors.

The pilot team concluded that developing case studies and recommendations for advanced motor training sessions, including dissemination tactics, would be a high-impact way to help accelerate the adoption of advanced motors through education and awareness.

Do you think motor industry professionals would find a QPL useful and informative? Do you currently have existing documentation on motor and drive compatibility for your IE4/IE5 motors?

When the project team first began developing this Advanced Motors Focus Pilot, we hypothesized that a qualified products list (QPL) detailing motor and drive compatibility would help bridge the knowledge gap that exists in the motor industry. However, as the team began engaging with industry professionals, it became apparent this was not the case. Direct feedback from market actors suggested that the market is too dynamic for a QPL, which would likely become outdated shortly after dissemination. Moreover, many manufacturers have already developed resources that detail compatibility between different types of motors and drives. For instance, ABB-Baldor, WEG, and Greenheck all have documentation and motor comparison/selection tools with their motor specifications and compatibility with different types of drives (Appendix D: Motor and Drive Manufacturer Reference Materials).

Which groups in the motors industry do you think are best positioned to develop and deliver effective trainings?

Through discussions with market actors, the pilot team determined that the dissemination of education materials is equally important to actual education content. For instance, one distributor said that "case studies could be helpful…but it won't move the needle unless it's in the hands of a knowledgeable person…with a captive audience." Likewise, manufacturers commented that although they have hosted training sessions in the past, engagement has been a challenge largely due to limited engagement from distributors and industry professionals.

For end-use customers, particularly those in facility and operations management roles, it is particularly challenging to garner engagement given the limited availability of these market actors. Of their own volition, end-use customers are highly unlikely to notice or invest time in learning about utility programs or resources, according to one distributor. This distributor, along with others, has designated staff to engage customers on topics like incentive programs, training materials, and other industry resources.

Beyond distributors, market actors also identified third-party organizations and groups such as NEMA, EASA, the IACs, the Hydraulics Institute (HI), and the Air Movement and Control Association (AMCA) that can support industry education efforts by disseminating and promoting advanced motor education resources to their network of members. Survey respondents were unanimous in noting that manufacturers are the most well-equipped to deliver advanced motor trainings to distributors. However, manufacturers should tap into the support that third-party organizations, a utility sponsor, and perhaps a program implementer can provide in marketing these trainings to the right industry actors.

Education Program Design Recommendations

The sections below provide a detailed overview of the pilot team's recommendations for an advanced motors education program, including an outline of key education topics, key partnerships, target audiences, and dissemination strategies.

Market Education Strategy

The team recommends an advanced motor training course targeting distributors and manufacturers' representatives using both in-person and remote formats and recording the training modules for market actors that cannot attend during the specific training dates. The training course should offer a comprehensive overview of advanced motors technologies, the benefits the technology offers, and market availability (see Appendix F: Education Program Design Content Recommendation for more details).

To bolster the appeal of an advanced motor education training course and lower the incremental cost of an advanced motor, the pilot team recommends an advanced motors incentive program be coupled with the education program design outlined in this report. An advanced motors training course, if offered without an accompanying incentive program, may attract only the most motivated market actors to invest the time and energy required to participate in a training course. However, a training course paired with an incentive program will have more widespread market appeal and is more likely to attract less motivated market actors. The pilot team recommends incentive program design as an area for further study to complement the education strategies listed here.

Key Education Topics

Bulleted below are the topics the pilot team recommends for an advanced motors training course.

- Three-phase AC motor technology overview
- Selling advanced motors
- IE4/IE5 motor control (drive) requirements
- Market availability
- Installation
- Advanced motor maintenance

Please see Appendix F: Education Program Design Content Recommendation to find recommendations for advanced motors education content.

KEY PARTNERSHIPS

The pilot team recommends partnerships with advanced motor manufacturers to support the development of the education content and the promotion of the training course among distributors and manufacturers' representatives. Additionally, the pilot team recommends partnerships with third-party implementers to support the development, promotion, and delivery of an advanced motors training course. Lastly, a vital piece in the execution of an advanced motors incentive program and accompanying training course is a program sponsor to fund this work.

TARGET AUDIENCE

The pilot recommends an education program design that targets motor distributors and manufacturers' representatives. Distributors and manufacturers' representatives tend to be the ones who interface with the customers pursuing motor retrofits and thus, have the greatest opportunity to educate and influence motor purchases. On the distributor side, customer-facing job titles may include inside sales representatives, branch managers, and local account representatives, among others. On the manufacturers' representative side, outside sales representatives, owner sales representatives, and sales engineers were a few examples of customer-facing job titles the pilot team encountered. Other job titles that tend to operate within design or engineering consultancy firms are design consultants, specifiers, and contractors.

Dissemination Strategies

As part of the broader education program design, the pilot team recommends that industry trade groups, such as those previously mentioned, are consulted in the formation, design, development, and delivery of advanced motor training resources. Industry trade organizations such as EASA, IACs, and utility training centers can play an important role in disseminating advanced motor education materials to their networks. The pilot team spoke with EASA members, an IAC representative, and the SCE education training center to socialize the objectives of this pilot and assess interest levels in supporting the advanced motors market education effort. Each group expressed a willingness and excitement to support promotion and dissemination of advanced motor education materials to their networks.

Site Monitoring

Site Recruitment

The intended purpose of on-site monitoring is to verify and document the energy savings (kWh) of advanced motors, while detailing what we learn about the barriers to — and motivations for — adoption in real-world installations. Accordingly, we tried to select monitoring sites with installations where the motor performance could be isolated. Changes and optimization efforts on the load side of the motor, such as changes made to the pump, fan, distribution system, or control set points, are not ideal for this focus pilot.

We also prioritized finding existing motor installations that are dynamically controlled using VFDs. Motor installations already featuring a VFD designed to adjust the motor speed to hold a control parameter constant (e.g., temperature, pressure) will automatically correct for the difference in rotating speed between the baseline asynchronous motor and advanced synchronous motor. Selecting sites that already use a VFD will also help us isolate the energy savings of the advanced motor itself, which might otherwise be obscured by the VFD savings if moving from fixed-speed to variable-speed motor operation. In the rare instance where a VFD is used but manually controlled, or a pilot participant is changing from a fixed-speed to a variable-speed motor (with no other changes), we will use a stroboscope to measure the rotating shaft speed of the baseline motor. This will allow us to normalize energy-saving calculations for the difference in motor load imposed by the difference between asynchronous and synchronous motor speeds.

Lastly, we gave priority to customer sites and motor installations that align with the measure packages being drafted for this pilot. While data from the site monitoring is not used directly in measure package development, including verified savings from the field to the measure packages would increase the confidence in the estimated savings.

The project team reviewed more than 20 site nominations from SCE account management contacts, past CalNEXT program participants, industry organizations, industrial assessment centers, “cold” outreach, participating contractor contacts, and other sources. Interested sites submitted a site nomination form, participated in an introductory call with the pilot team, and engaged in discussion with the pilot’s engineering team about various technical details.

The sites outlined in Table 9 are those participating in the On-Site Monitoring portion of the pilot. When the sites finish participating in the program, they will take the survey detailed in

Appendix G: Site Monitoring Participant Survey. Thus far, two out of the four sites have completed the survey, and their responses are incorporated into the Market Characterization and Case Studies sections of this report.

Table 9: Sites Participating in the On-Site Monitoring

Site Name	Site Type	Motor Application	Number of Motors	Motor Size	Expected Motor Model for Upgrade
AC Foods	Citrus nursery	Ventilation fan (greenhouse)	6	1	PMaSynRM
Drake's Brewing Company	Brewery	Glycol pump	1	7.5	PMaSynRM
Kite — a Gilead Company	Pharmaceutical	Hot water pump	1	15	PMaSynRM
South Coast Winery	Winery	Glycol pump	4	3	IE4 Induction Motor

Site Monitoring Results

At the time of report submission, only the site monitoring at Drake's Brewing Company and AC Foods had concluded. These two sites provide real-world performance data on seven individual motors, with results showing that the actual savings exceed the theoretical savings arrived at when using the efficiency thresholds (nominal efficiency limits) established in IEC TS 60034-30-2:2016. These sites therefore demonstrate not only the practical installation and operation of these advanced motors but also confirm the energy saving potential of this technology. Motor data analysis can be found in the supplementary materials submitted with this report.

It is important to note that the baseline condition at both complete sites included the use of fixed speed motors (no VFD) whereas the new, efficient condition included the use of VFD's. Furthermore, both sites migrated from asynchronous to synchronous motors, which resulted in an increase in motor speed at all electric power frequencies (Hz). These influences on motor rpm were normalized for each motor to allow for efficiency comparisons based on the amount of work performed by the motor. Savings due to the use of a VFD were also tabulated separate from the motor savings, to allow for a consistent comparison of motor efficiency between the baseline and efficient motor technologies. Additional considerations relevant to the results at each site are discussed below.

- Drake's Brewing CompanyExisting (measured baseline) motor: 7.5 hp, 2-pole (3600 RPM), ODP, 184JM Frame, NEMA Efficient (IE2). Nominal efficiency value of 87.5%.
- Existing motor operating direct-on-line (no VFD)
- New (advanced) motor: 7.5 hp, 3600 RPM, TEFC, 184TC Frame, IE5 Efficient. Nominal efficiency limit (value) of 92.6%.
- New motor operating via a VFD.

Table 10: Drake's Brewing Company Site Monitoring Results

	Average Demand (kW)	Energy Usage (kWh/yr)
Baseline Motor	4.73	37,728
Advanced Motor	4.28	34,128
Savings	0.45	3.601
Percent Savings	9.54% (motor only)	

DISCUSSION OF RESULTS

The results of the field trials at Drake's Brewing shown in Table 10 above show that the motor-only energy savings were greater than expected. The difference in motor efficiency, according to efficiency classification, suggested that the motor savings should be around 5.1% for the given motors, yet the actual results show a savings of 9.5%. The difference between the expected and actual savings could be due to:

- motor wear and/or past repairs
- difference between nominal and guaranteed minimum energy efficiencies
- actual motor efficiency at reduced load factors
- actual advance motor efficiency exceeding the nominal efficiency limit

While the exact reason for the greater than expected savings cannot be deduced from this field trial, it is worth noting that the nominal efficiency values cited for the advanced motor represent that minimum efficiency value required to achieve the IE5 efficient designation. The actual motor may therefore by design achieve a higher efficiency value, resulting in the greater than expected savings. Similarly, NEMA specifies nominal and minimum energy efficiency values for motors, with the latter being the true minimum acceptable performance value for any individual motor. The baseline motor could potentially be performing closer to the minimum efficiency value, as opposed to nominal, which would also increase the spread between the baseline and advanced motor efficiency. Bench testing of these exact motors would be the only way to confirm the actual efficiencies of the baseline and advanced motors studied at this site, which is not included in the scope of this focus pilot.

AC Foods

- Existing (measured baseline) motors:

    - G10 Fans: 1 hp, Single-phase, 4-pole (1800 RPM), TEAO, 56H Frame, Cap-start/cap-run, assumed NEMA Premium Efficient. Nominal efficiency value of 80.0%.
    - Head House Fans: 1 hp, Three-phase, 4-pole (1800 RPM), TEFC, 143T Frame, NEMA Premium (IE3) efficient. Nominal efficiency value of 85.5%.

- All existing motors operating direct-on-line (no VFD)
- New (advanced) motors: 1 hp, 1800 RPM, TEFC, 143T Frame, IE5 Efficient. Nominal efficiency limit (value) of 88.2%.
- New motors operating via a VFD.

Table 11: TreeSource Citrus Nursery Site Monitoring Results

	G10 Building (2) 1 hp Fans	Head House Building (4) 1 hp Fans
Baseline Motor Demand (kW)	1.57	2.612
Advance Motor Demand (kW)	1.44	2.46
Demand Savings (kW)	0.13	0.16
Energy Savings (kWh)	211	245
Percent Savings *Motor-only*	8.5%	6.0%

DISCUSSION OF RESULTS

The results of the field trails at AC Foods shown in Table 11 above show that the motor-only energy savings were equal to or greater than expected. The difference in motor efficiency, according to efficiency classification, suggested that the motor savings should be around 8.2% for the G10 motors, with the actual results showing a savings of 8.5%. For the head house, the difference in efficiency was expected to be 2.7% according to nominal efficiency class values, yet the real results show a savings of 6%. This difference between the expected and actual savings could be due the same reasons highlighted and discussed in the “Discussion of Results” for Drake’s Brewing above.

Summary of Key Findings

The following list highlights several of the key findings from the pilot thus far. For the full Market Actor Questionnaire, please see Appendix C: Full Market Actor Questionnaire.

- **Market awareness of new IE4 and IE5 motors is low; market education through multiple pathways is a key step in increasing market adoption.** Awareness of the benefits and availability of advanced motors, particularly IE5 motors, is low overall. Additionally, confusion exists in the market between mature (PMAC) and emerging (PMaSynRM) advanced motor technologies, which strains customer and distributor receptiveness given the perceived cost of the former. We suggest a multi-pronged approach to address the obstacle of limited education: case studies, collaboration with third-party organizations (including utilities), and manufacturer-provided training materials for distributors.
- **Market adoption levels are low for both non-OEM and OEM advanced motors, but the lead time for IE4 and IE5 motors is rapidly decreasing.** IE5 motors have long lead times, limited selection, and only a few manufacturers because these motors are still an emerging technology. However, as more manufacturers enter the market and increase their stocked inventory of advance motors, the leads times will continue to decrease.
- **Most non-OEM motor customers are only interested in "drop-in" replacements when they experience a motor failure. The customers purchasing non-OEM advanced motors are early adopters who typically have energy or sustainability goals driving this effort.** Efforts to increase non-OEM advanced motor adoption should first focus on this early adopter segment. Marketing the savings, performance, and overall system benefits to this customer group is most likely to influence purchasing decisions. Third-party institutions like NEMA, AMCA, and HI are excellent potential partners for spreading this message
- **Energy savings witnessed through the field trials support that the advanced motor efficiency gains equal and often exceed the efficiency gains expected when using the nominal efficiency limits.** This confirms the importance of continuing work to increase market adoption of advanced motors.
- **For advanced motors requiring a VFD, future motor measure packages and utility programs should focus on motor installations where a VFD will provide cost-effective savings.** Ultimately, the VFD needs to prove cost-effective on its own, with the advanced motor bringing incremental benefits at an incremental price.

Recommended Areas of Further Study

- **Initiatives to increase advanced motor adoption in the OEM market.** Throughout this pilot, it has become apparent that the non-OEM advanced motors market would benefit greatly from increased adoption in the OEM market. A future CalNEXT project dedicated to investigating strategies to increase OEM adoption of advanced motors would be highly beneficial.
- **A non-OEM advanced motors incentive program coupled with the education program design recommendations.** As mentioned in the Education Program Design Recommendations section, the non-OEM advanced motor market would benefit greatly from a program design that incorporates incentives along with market education components targeting non-OEM motor distributors.

- **Increased coverage for advanced motors in the California eTRM.** A key market engagement and adoption strategy for any emerging technology is the development of a deemed measure package in the California eTRM. Given the limitations of this pilot, the team is only able to develop two measure package drafts. However, the advanced motors market would benefit from further coverage in the California eTRM across additional motor end-use applications. This could be achieved through proposing new measures or adding onto existing measures.
- **A follow-up study to investigate additional advanced motor applications.** In addition to qualitative research, this would include recruiting additional customers – with site or application types not covered in this pilot – for on-site monitoring. The data collected would be used to quantify energy savings. The results of this study would support pursuit of additional eTRM coverage, as noted in the previous recommendation.

Appendix A: Nominal Efficiencies for IEC Ratings

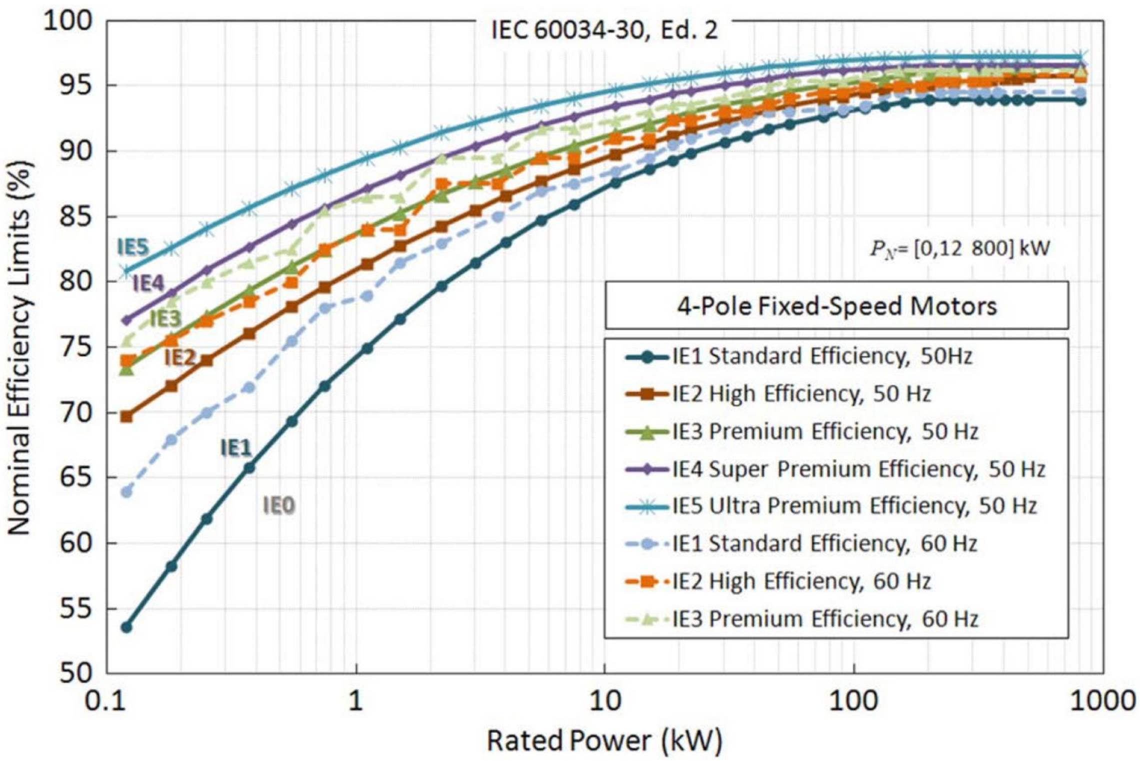


Figure 6: Nominal efficiencies for IEC ratings.

Source: de Almeida et al. (DeAlmeida, Ferreira and Baoming 2013)

Appendix B: Advanced Motor Models in the Market

Manufacturer	Models	Technology Type	IEC Rating
ABB (Baldor-Reliance)	SP4	Induction motor	IE4
ABB	RPM AC and XE	Permanent magnet synchronous motor	IE4, IE5
ABB	EC Titanium	Permanent magnet-assisted synchronous reluctance motor	IE5
Infinitum	Aircore EC	Axial flux, printed circuit board motor	IE4, IE5
Lafert	Stand Alone Motor — High Performance Range	Permanent magnet synchronous motor	IE4, IE5
Nidec (US Motors)	SynRA	Synchronous reluctance motor	IE4, IE5
Regal Rexnord (Marathon)	SyMAX	Permanent magnet synchronous Motor	IE4
Siemens	1FZ1, Simotics Reluctance Motor	Synchronous reluctance motor	IE5
Turntide	VX Series	Switched reluctance motor	IE5
WEG	WECM	Permanent magnet ECM	IE5
WEG	W22 Magnet	Permanent magnet synchronous motor	IE5
WEG	W22 Super Premium	Induction motor	IE4
WEG	W23 Sync +	Permanent magnet-assisted synchronous reluctance motor	IE5

Appendix C: Full Market Actor Questionnaire

Market Overview (sales process, market barriers, supply chain)

1. What IE4 and IE5 motors do you manufacture and sell to distributors (non-OEM customers)?
2. What is the typical sales process for IE4 and IE5 motors?
3. Can you walk us through each step of the supply chain for motors? Does this process look any different for advanced motors?
4. What is a typical lead time for your IE3, IE4, and IE5 motors?
5. What is your largest customer segment currently? What segment has the most potential for sales?
6. Who are the key decision makers of purchasing your IE4/IE5 motors?
7. What are the comparative sales margins for advanced motors and standard efficiency motors (in the 1-50 hp range)?
8. How do you price your IE5 and IE4 motors? Alternatively, can you help us understand what the incremental measure cost is between IE3 motors, IE4 motors, and IE5 motors?
9. What are the most common end use applications for your IE4 and IE5 motors?
10. What is your largest customer segment currently and which segment do you think has the highest potential for sales?
11. Who are the key decision makers of purchasing IE4/IE5 class motors?
12. What motor application types can most benefit from IE4 and IE5 motors?
13. What motivates a customer to opt for an IE4 or IE5 motor rather than an induction motor or lower efficiency motor?
14. What do you see as a price point for an incentive that would move the market from IE3 motors to IE4 motors? What about IE5 motors?
15. On a scale from 1–5, how would you rank customer awareness of the benefits of IE5 motors? What about market awareness generally?

Barriers

1. What barriers will affect the ability to scale the deployment of IE4 and IE5 motors?
2. Why are IE4 and IE5 motors often not in stock?
3. Do you have any feedback to help advance the deployment of IE4 and IE5 motors?

Education

1. Where do you see the largest education gap in the industry around IE4/IE5 motors and drives?
2. What kinds of motor trainings do you think distributors will find most helpful? What specifically do you want to see in trainings for advanced motors?
3. Which group within the motors industry do you think would benefit most from training on the benefits of IE4/IE5 motors and drives?
4. What type of resources do you think would help educate the motors market on the benefits of advanced motors?
5. Energy Solutions is considering developing a draft Qualified Products List (QPL) that details motor and drive compatibility, do you think motor industry professionals will find useful and informative?
    a. Do you have existing documentation on motor and drive compatibility for your IE4/IE5 motors?
6. Which groups in the motors industry do you think are best positioned to develop and deliver effective trainings?

Technology

1. What applications or load types is this motor designed for?
2. Are there any applications beyond variable torque loads for which this product is recommended?
3. Are there applications or conditions for which the product is NOT recommended?
4. What is the expected useful lifetime for the major components of the IE5 power drive system (PDS)?
5. Is the expected lifetime affected by the operating speed and applied torque? If so, by how much?
6. What are the regular maintenance requirements for IE4 and IE5 motors?
7. Are there any built-in energy/demand metering capabilities? If yes, please describe.
8. Are there non-energy benefits that customers realize with your product?
9. What warranty do you offer?
10. Aside from drive requirements, are there any limiting physical or operational characteristics (i.e., rpm, torque, frame size, stack length, etc.) that would prevent your IE4/IE5 motors from being used in place of a NEMA premium induction motor?

Appendix D: Motor and Drive Manufacturer Reference Materials

Technical data

BALDOR • RELIANCE
SHAFT GROUNDING BRUSH
INSTALLED

IP54

Drive specification	
Voltage & power requirements:	110V - 115Vac (+/- 10%) - 1-phase
	200V - 240Vac (+/- 10%) - 1-phase
	200V - 240Vac (+/- 10%) - 3-phase
	380V - 480Vac (+/- 10%) - 3-phase
Input frequency:	50/60 Hz
Overload capacity:	150% for 1 minute (most models)
Switching frequency:	4kHz, 8Khz, 12kHz, 16kHz, 24kHz, 32kHz
NEMA frames:	140, 180 & 210
Mounting:	Foot, C-Face Foot, C-Face Footless
Analog references:	0-10Vdc, 0-20mAdc, 4-20mAdc
Digital inputs:	24Vdc - (1 = 8 - 30Vdc; 0 = 0 - 4Vdc)
Input configurations:	2 Fixed DI's; 2 Configurable (AI or DI)
Output relay:	No contact; 250Vac, 6A / 30Vdc, 5A
Standards & certifications:	UL 580C, cUL 580C

Environmental	
Enclosure	TEFC/IP54 Motor with UL
	Type 12/IP54 Drive
Operating temperature	-10 to 50°C
	(de-rate output 2% per °C above 40 °C)
Storage temperature	-40 to 70°C
Relative humidity	0 95% (non-condensing)
Vibration (operating)	1 G Peak at 20 Hz
Vibration (non-operating)	0.2G Peak at 20 to 50Hz
Maximum elevation	Up to 1000 meters
Elevation for de-rated operation	Up to 2000 meters De-rate above 1000 meters-1% for every 100 meters

Motor features:
- IE5+ motor efficiency
- FASR - Ferrite Assisted Synchronous Reluctance Rotor
- Class F insulation with Class B motor temperature rise
- IP54 motor enclosure with shaft seal
- Internal grounding brush for bearing current mitigation on DE retainer ring
- For inverter use only per NEMA MG1 Part 31.4.4.2
- 1.5 service factor design
- Designed for longevity with 3-year motor warranty

Applications:
- Fans
- Pumps
- Compressors
- Blowers
- Unit handling
- HVAC systems
- Variable speed applications
- General purpose applications

Drive features:
- Permanent magnet PWM AC drive control
- Serial modbus RJ45 interface
- 2 Digital inputs, 2 configurable inputs (analog or digital), 1 relay output
- Designed for longevity with 2-year drive warranty

Standard product, motor and drive:
- IP54 gasket plastic drive enclosure and fan cover
- Built-in ABB Ability and bluetooth communications

Plenum use product, motor and drive:
- IP54 gasket aluminum drive enclosure and fan cover
- Non-bluetooth drive

Figure 7: Drive details for ABB EC titanium motor.

Source: ABB.

Financial Return Report

Calculator Option: **Replacement of a Running Motor**

Equipment Data

Equipment: **Axial Fan**

Energy Cost ($/kWh): **0.08**

Hours per Day: **8**

Days per Year: **365**

Current System Data

Motor Output Power: **20 HP**

Number of Poles: **4**

Grid Voltage (V): **460**

Efficiency (%): **93.9**

Motor Age (years): **1**

Number of Rewinds: **0**

Number of Motors: **1**

Driven by Frequency Inverter

NO

Proposed System Data

WEG Motor Line: **W22 Super Premium Efficiency**

Efficiency (%): **93.6**

WEG Motor Average Price: **$ 1.00**

WEG VFD Line: **CFW11**

Speed (%): **85**

WEG VFD Average Price: **1000.00**

Consider Replacement Plan

NO

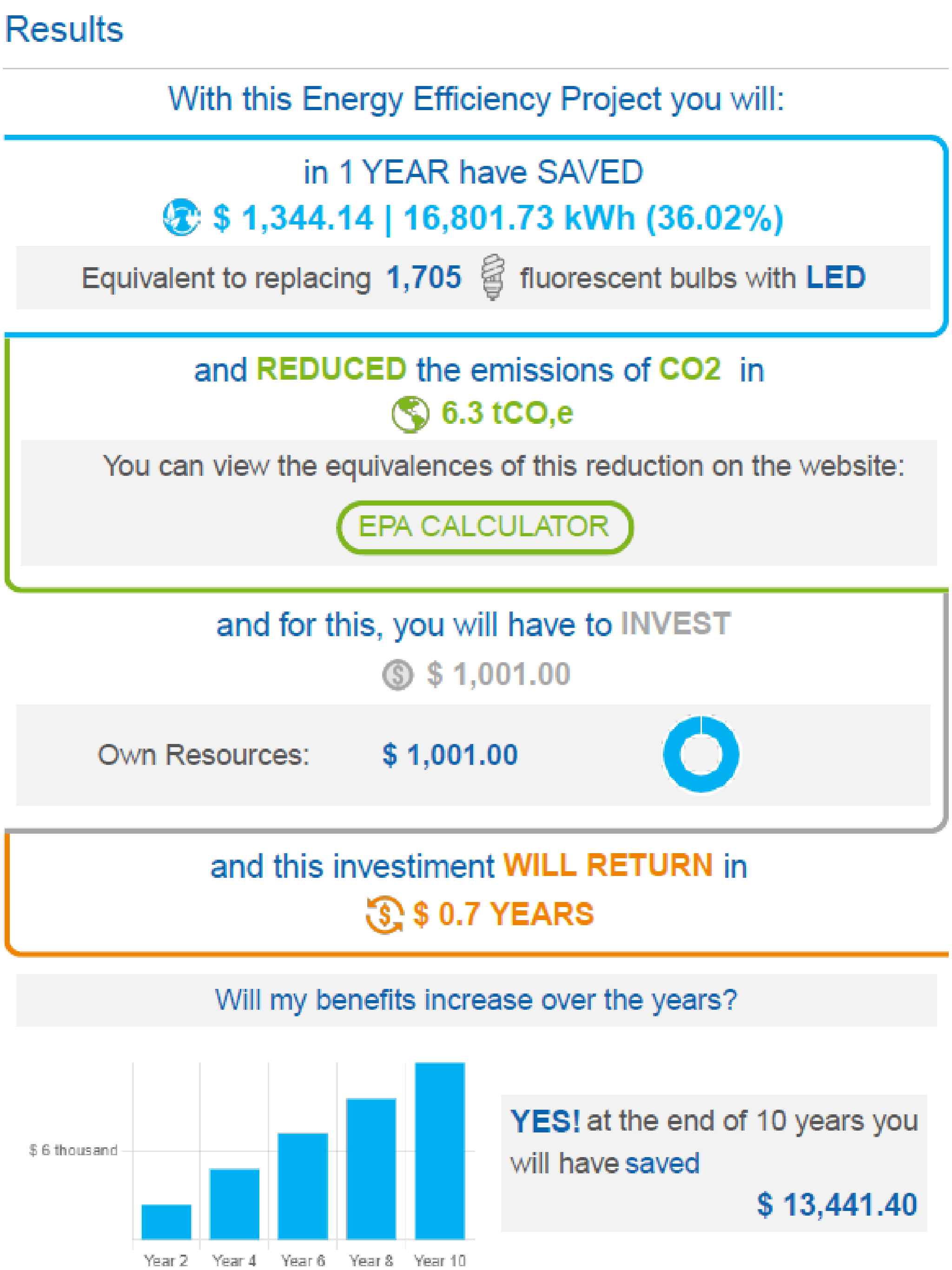


Figure 8: WEG financial return calculator.

Source: WEG.

Appendix E: Measurement and Verification Plan

Introduction

This Measurement and Verification (M&V) plan describes in detail how energy and demand savings will be quantified for this project. The M&V plan presented here adheres to the specifications set forth in the International Performance Measurement and Verification Protocol (IPMVP) Core Concepts.

M&V involves the process of using measurements to reliably quantify actual energy savings and/or beneficial load shifting from an energy and demand optimization project within a facility, a process, a building, or a building subsystem. M&V is used to verify that an energy optimization project is achieving its intended objectives and describes how savings are determined from the measurements of energy use before and after implementation of the project intervention, with appropriate adjustments made for changes in conditions. Such adjustments may be routine and expected, while others are non-routine and due to factors unrelated to the project.

This M&V Plan describes how baseline energy use and demand are documented, how they vary, and what factors are its primary drivers. The M&V plan also describes how adjustments to baseline use are made for unexpected events, such as added equipment or loads, or other unforeseen events that materially affect use and savings.

The M&V Plan is required to document and describe the approach to quantifying savings, the key measurements required and computation methods, the timing of these activities, roles and responsibilities of involved parties, and the quality assurance requirements associated with the process.

Project Description

The proposed technology involves advanced electric motors, defined as electric motors with energy efficiency levels above current federal conservation standards published by DOE in 2014, which encompasses those listed on the 2022 Focused Pilot TPM as well as additional advanced motor technologies. The technologies encompassed within advanced motors include motor technologies with efficiencies greater than current federal minimum standards: switched reluctance motors (SRM), synchronous reluctance motors, permanent-magnet (PM), PM alternating current (AC) (PMAC) motors, PM synchronous motors (PMSM), and Brushless DC Motors (ECM). This pilot will address the non-OEM market, which focuses on motor replacements and retrofits in non-residential systems, with emphasis on variable torque motor-driven systems, such as pumps and fans.

The focused pilot will involve onsite equipment monitoring for approximately 10 projects to obtain data on field operation and used to understand and quantify energy savings resulting from advanced motor installations. Projects will be selected for monitoring that are representative of the key customer types and for this type of equipment in California. Onsite monitoring equipment will be installed by the focused pilot team and monitoring will include both pre- and post-installation collection periods to collect baseline and new equipment data points.

Measurement and Verification

IPMVP Option and Measurement Boundary

The International Performance Measurement & Verification Protocol (IPMVP) provides four M&V options to accommodate a variety of work scope, with each option outlined in the figure below. IPMVP Option B (Retrofit Isolation: All Parameter Measurement) will be used for savings determination. Savings will be calculated based on directly measured energy usage of the systems covered by the scope of work before and after the measure has been implemented. Option B was selected because the equipment affected by the retrofit can easily be separated from the energy use of the rest of the facility.

M&V Option	How Savings Are Calculated	Typical Applications
A. Partially Measured Retrofit Isolation Savings are determined by partial field measurement of the energy use of the system(s) to which an ECM was applied, separate from the energy use of the rest of the facility. Measurements may be either short-term or continuous. Partial measurement means that some but not all parameter(s) may be stipulated, if the total impact of possible stipulation error(s) is not significant to the resultant savings. Careful review of ECM design and installation will ensure that stipulated values fairly represent the probable actual value. Stipulations should be shown in the M&V Plan along with analysis of the significance of the error they may introduce.	Engineering calculations using short term or continuous post-retrofit measurements and stipulations.	Lighting retrofit where power draw is measured periodically. Operating hours of the lights are assumed to be one half hour per day longer than store open hours.
B. Retrofit Isolation Savings are determined by field measurement of the energy use of the systems to which the ECM was applied, separate from the energy use of the rest of the facility. Short-term or continuous measurements are taken throughout the post-retrofit period.	Engineering calculations using short term or continuous measurements	Application of controls to vary the load on a constant speed pump using a variable speed drive. Electricity use is measured by a kWh meter installed on the electrical supply to the pump motor. In the baseyear this meter is in place for a week to verify constant loading. The meter is in place throughout the post-retrofit period to track variations in energy use.
C. Whole Facility Savings are determined by measuring energy use at the whole facility level. Short-term or continuous measurements are taken throughout the post-retrofit period.	Analysis of whole facility utility meter or sub-meter data using techniques from simple comparison to regression analysis.	Multifaceted energy management program affecting many systems in a building. Energy use is measured by the gas and electric utility meters for a twelve month baseyear period and throughout the post-retrofit period.
D. Calibrated Simulation Savings are determined through simulation of the energy use of components or the whole facility. Simulation routines must be demonstrated to adequately model actual energy performance measured in the facility. This option usually requires considerable skill in calibrated simulation.	Energy use simulation, calibrated with hourly or monthly utility billing data and/or end-use metering.	Multifaceted energy management program affecting many systems in a building but where no baseyear data are available. Post-retrofit period energy use is measured by the gas and electric utility meters. Baseyear energy use is determined by simulation using a model calibrated by the post-retrofit period utility data.

Instrumentation

Baseline and post-installation data will be collected using the equipment in the table below. The DENT power logger (or equivalent) will monitor energy consumption through three voltage leads and three current transducers (CTs) (one CT per phase). All data will be collected in one-minute averaged intervals.

Variable	Equipment	Accuracy	Frequency
Motor Power Data: True power (kW), voltage, amperage, power factor, cumulative energy (kWh)	Dent power logger or Equivalent	+/- 1% of full scale	1 min average

Baseline Period and Conditions

The baseline period will start at least two weeks before the planned installation of technology. Key conditions during this baseline period that may change in the reporting period are outlined in section 4.2. These conditions, if different in the reporting period from these baseline conditions, may necessitate non-routine adjustments to the baseline energy use.

Reporting Period

The reporting period will start immediately after the installation and commissioning of the technology and last at least two weeks.

Data Quality

The data will be assessed for gaps and outliers. Outliers are data beyond the expected range of values (e.g., a data point more than two standard deviations away from the average of the relevant data). Outliers will be defined based on sound engineering judgement as well as common statistical practice. Before a data point is eliminated, an explanation for the unexpected data will be sought, and if there is reason to believe that the data are abnormal because of specific mitigating factors, then the data point may be eliminated from the analysis. If a reason for the unexpected data cannot be found, the data will be included in the analysis and will be explained as such.

Data gaps will be filled by the best method available, which may include interpolation or comparison with similar days for all the input data received. Data preparation activities will be fully documented in the savings report.

Handling of Non-Routine Adjustments

Non-routine adjustments are factors that were not expected to change, but that will affect the system's energy use, not as a result of the energy conservation measures installed as part of the retrofit.

Non-Routine Application Process

The M&V effort will require the identification of any non-routine adjustments that need to be quantified. The first step is to ensure that the system's conditions and operations are well documented during the baselining efforts so that the M&V resource can continuously track for possible changes in operation or loads during the reporting period.

The next step is to identify any changes in the reporting period from the baseline period. This can be accomplished through interviews with the system owner, site visits, observation of unexpected energy use patterns, or other methods. It is important to bear in mind that not all changes in the system operation need to be (or can reasonably be) accounted for in the M&V effort. Identifying changes that warrant adjustment is a critical part of the process.

The third step in the process is to establish a method to accurately quantify how the identified changes will affect the system's energy use. Sometimes these effects can be estimated within the energy modeling that was used to calculate the energy savings for the project. In other cases, side calculation methods must be employed. Applying the appropriate level of rigor and sound engineering principles is key.

Typical Non-Routine Adjustments

Non-routine adjustments that are typically encountered may include, but are not limited to:

- A change in operating hours or equipment operation (overrides, sequence of operation)
- A change in product type served by motor driven machinery
- Added loads (additional product)
- A change in production volume

Defining Eligible Non-Routine Adjustments

The table below represents examples of eligible categories, adjustments, triggers, and actions. However, this list is not exhaustive or applicable to all projects.

Adjustment	Example Trigger	Action
Operational Changes		
Change in Operating Hours	Motor overridden during normally loading hours	kW x additional hours of operation
Change in Production Volume	A third production shift added to manufacturing facility	Develop relationship between production volume and energy use. Use relationship to develop regression and calculate energy impact.

Calculating Non-Routine Adjustments

In general, quantifying the effects of non-routine adjustments on the site's energy use involves the use of the original calculation methods used to determine energy savings. For example, if a dynamic methodology is used to calculate the energy savings associated with the energy conservation measures, this same methodology could be used to calculate the impact of loading on the motor driven system.

If the original calculations used to estimate energy savings associated with the energy conservation measures are not appropriate to quantifying the effects of the non-routine adjustments, separate calculations will need to be performed to quantify these effects. Calculation methods (regression analysis, temperature bin analysis, etc.) similar to those used to estimate energy savings associated with the energy conservation measures would need to be employed to determine the impact that these non-routine adjustments will have on the building's energy performance.

Once the non-routine adjustment effects have been quantified, these annual, monthly, or hourly values are then applied to the baseline, to “adjust” the delta between the baseline energy use and reporting period energy use, to determine savings.

Acceptance of Proposed Non-routine Adjustments

The M&V agent proposes a non-routine baseline adjustment to the building owner or investor. This should include a reference to this document and the applicable pre-agreed to adjustments (table above).

Appendix F: Education Program Design Content Recommendation

Topics	Details
3-Phase AC motor technology overview	• Motor efficiency terms, definitions, testing and metrics (DOE, IE, NEMA) • IE4-IE5 technology overview: (see Appendix B) • Differences and similarities between induction and reluctance motors, with and without permanent magnets. • Performance comparisons different between motor types

Selling advanced motors	• Recommended end-use applications and retrofit scenarios
	  ○ What to look for in a motor retrofit scenario
	  ○ Retrofit scenarios: VFD vs. advanced motor
	• ROI at different horsepower ranges
	• Energy and non-energy benefits of advanced motors

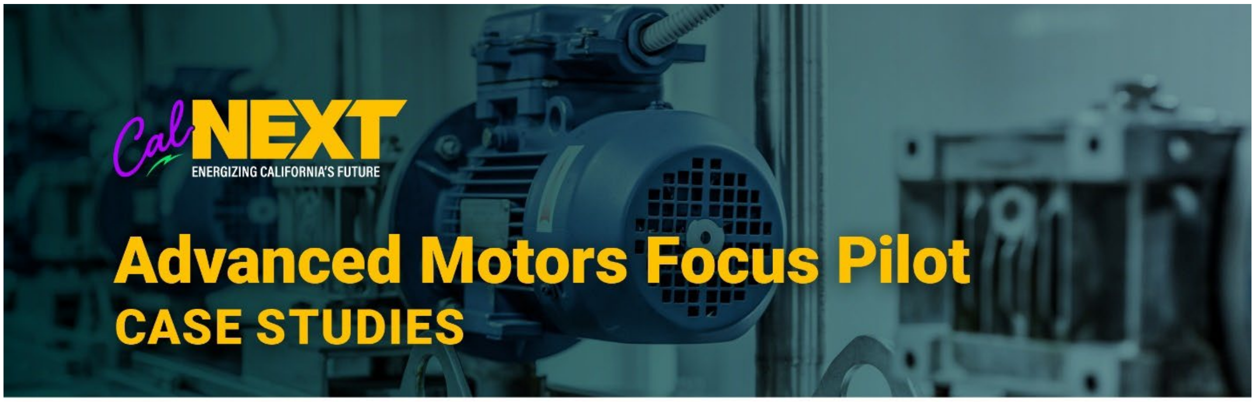
IE4/IE5 motor control (drive) requirements	• Advanced motor/drive configuration and compatibility
Market availability	• Advanced motor manufactures (see Appendix B) • Cost estimates • Approximate lead time • Incremental measure cost
Installation	• IE4 and IE5 motor case studies • OEM and non-OEM applications • Limitations of IE4/IE5 motor installations • Replacement scenarios: Failure/burnout (replacement) or new install • Common installation considerations
Advanced motor maintenance	• Maintenance for induction vs advanced motors • Required expertise to advanced motor maintenance

Appendix G: Site Monitoring Participant Survey

1. Please rank the following on a scale from 1 (least) to 5 (most) on how important each consideration is to you when assessing new motor equipment:
    a. Reliability
    b. Initial cost
    c. Ongoing energy costs
    d. Ongoing maintenance costs
    e. Ease of use
    f. Ease of installation
    g. Cutting edge technology
    h. Equipment availability (including lead time)
    i. Previous experience with the equipment
    j. If there are other factors key to your decision making, please elaborate.
2. Please describe your usual purchasing habits as they pertain to motors at your facility. Do they align with any of the following options?
    a. Replace in-kind upon equipment failure or reaches end of useful life
    b. Replace with more efficient equipment upon equipment failure or reaches end of useful life
    c. Early retirement (before equipment fails/reaches end of useful life) with more efficient equipment
    d. Other (please describe)
3. Please describe your experience installing your new motor. Did you experience any challenges during the process?
    a. Did the advanced motor installation process differ much from a typical motor installation?
4. How satisfied are you with the new motors installed at your facility? Please provide any comments/feedback you have for the Program and/or manufacturer/installer.
5. Please rank the following on a scale from 1 (least) to 5 (most) on your satisfaction with the new motor equipment:
    a. Reliability
    b. Initial cost
    c. Ongoing energy costs
    d. Ongoing maintenance costs
    e. Ease of use
    f. Ease of installation
    g. Cutting edge technology
    h. Equipment availability (including lead time)
    i. Previous experience with the equipment
    j. If there are other aspects you're satisfied with, please elaborate:
6. Are any of the aspects in 5a-5j notably better or worse than the regular efficiency technology?
7. How likely are you to replace additional motors within your facility with advanced motors, given the performance of the new motors? How will this influence your purchasing or operational habits going forward?

8. Any additional comments/questions for the Program?

Appendix H: Case Studies



Contents

Advanced Motors Focus Pilot

The objective of the Advanced Motors focus pilot is to study the market barriers that exist for non-OEM (replacement) IE4 and IE5 efficient-rated motors ("advanced motors")[1]. One component of the pilot was to identify and partner with sites to test the performance of IE4 and IE5 motors. This test includes monitoring pre- and post-installation data to document the performance of the system before and after the advanced motor installation. Using this data, the pilot team developed case studies documenting the outcomes of this on-site installation effort.

CalNEXT Overview

CalNEXT identifies, tests, and grows electric energy technologies and delivery methods that have the potential to make major impacts on achieving California's climate goals. Project categories include research and development addressing appliances, HVAC, lighting, process loads, water heating, and whole buildings.

Advanced Motors Overview

The current baseline efficiency for motors, also known as "NEMA Premium" correlates to an IE3 motor.

NEMA Efficiency Class	IEC Efficiency Class	Motor Technologies
Standard	IE1	AC induction
High	IE2	AC induction
Premium	IE3	AC induction
Super-Premium	IE4	AC induction, DC brushless (ECM), permanent magnet synchronous, switched reluctance, synchronous reluctance, permanent magnet-assisted synchronous reluctance
Ultra-Premium	IE5	DC brushless (ECM), permanent magnet synchronous, switched reluctance, synchronous reluctance, permanent magnet-assisted synchronous reluctance

[1]The International Electrotechnical Commission rates motor efficiency from least efficient (IE1) to most efficient (IE5). (Source: IEC Electric Motors).

CalNEXT Advanced Motors Focus Pilot Case Studies 1

CASE STUDY

TreeSource Citrus Nursery (AC Foods)

About the Site

TreeSource Citrus Nursery, owned by AC Foods, is a full-service commercial citrus nursery located in Woodlake, CA, that supplies the California citrus industry and greenhouse growers around the world with citrus nursery stock. TreeSource Citrus Nursery has approximately 1.2 million citrus trees over 12 acres of indoor greenhouses and seven acres of outdoor growth land. The facility operates eight hours per day, employing 150 employees during the March to September grow season. TreeSource has a total of 133 fans which collectively consume approximately 267,786 kWh annually. TreeSource is one of eight citrus nurseries in California.[2]

TreeSource was motivated to participate in this pilot because they were keen on the efficiency gain of the advanced motors and the low maintenance cost in comparison to their existing motors. The site's existing motors were declining in performance yearly and the cost of maintenance increasing to the point that they were already planning to do a motor replacement. Additionally, the site had several single-phase motors that are not variable speed, and they were interested in evaluating high efficiency motors as they optimized for variable speed operation.

Site Energy Usage

Facility Energy Usage
785,338
kWh annually

Exhaust Fan Energy Usage
166,212
kWh annually

Equipment Details

TreeSource replaced six exhaust fans in two locations, two motors in their "G10" Greenhouse and four motors in their "Head House" Greenhouse.

Application	Previous Motor	Upgraded Motor
"G10" Exhaust Fans	(2) NEMA Premium IE3 Motors: 1hp, 1755 RPM, 3-phase (fixed speed)	(2) Permanent Magnet-assisted Synchronous Reluctance Motors: 1hp, 1800 RPM, 3-phase and VFD with Two Port Adapter
"Head House" Exhaust Fans	(4) NEMA Premium IE3 Motors: 1hp, 1725 RPM, 1-phase (fixed speed)[3]	(4) Permanent Magnet-assisted Synchronous Reluctance Motors: 1hp, 1800 RPM, 3-phase and VFD with Two Port Adapter

Procurement and Installation Process

Procurement

The procurement for TreeSource's new motor required coordination between the on-site facility manager and the manufacturer to specify the application, number of motors, horsepower, rpm, frame size, and an overview of the site's existing motor-exhaust fan system. Additionally, the site provided photos of the nameplates for their existing

[2] UCCE Foothill Farming: Citrus Nurseries in California

[3] The site had 3-phase power available and prior to learning about the pilot, they were planning to replace their motors with 3-phase induction motors with variable speed capabilities.

Continued on next page

motor, drive, and panel. The new motors arrived within one week while the accompanying drives took an additional three weeks to arrive.

Installation Detail

The installation of the new motor was performed by the site's in-house facility manager. The site found the installation process to be similar to a typical motor installation with a few additional steps. One difference the facility manager highlighted was that the motor control drive can only run one new advanced motor, in comparison to TreeSource's previous motors which had as many as five (5) motors connected to one control drive. As a result, the initial installation cost is much higher for an advanced motor than a premium efficiency motor. However, the site also noted that once they got their new motor up and running, "the efficiency was evident. The drive shows you all of the energy consumption…in comparison to the old drive, the savings are easy to see."[4] The site also commented that if they had pursued an advanced motor as a new install, rather than a replacement, it would be easier to justify. That said, the site said they are "very likely" to replace motors in their facility with advanced motors because of the amount of energy savings they provide.

Energy Savings Data

Motor + VFD	G10 Fans	Head House Fans
Total Reduction in Energy Demand (kW)	0.13	0.84
Estimated Annual Energy Savings (kWh)	211	1,318
% of Savings Attributed to the Motor	16%	11%

Return On Investment

	G10 Fans	Head House Fans
Estimated Measure Cost	$1,448	$2,895
Estimated Annual Energy Savings ($)	$408	$685
Estimated Simple Payback (years)	3.50	4.20

Key Takeaways

- The lead time for the advanced motors was only one week because the manufacture had the motor in-stock.
- The motor installation was relatively similar to a standard premium efficiency motor.
- The site is satisfied with the performance and efficiency of their new advanced motor and interested in pursuing advanced motors for future replacement projects.

[4] Manufacturer is developing an updated drive that will be able to control multiple advanced motors.

Drake's Brewery

About the Site

Drake's Brewing Company is a brewery with three locations across the San Francisco Bay Area. Drake's Brewery produces approximately 40,000 barrels of beer (~1.25 million gallons) annually. Drake's has one production facility with two brew houses, a cellar and a packaging hall which is managed by their 32-person production staff. The brewery operates year-round and has two chillers systems which combined, consume approximately 278,000 kWh annually.

Drake's Brewery strives to embrace emerging technologies to help them achieve their sustainability goals and improve their processes. This pilot presented Drake's with an opportunity to replace a legacy, mission-critical motor that was nearing the end of its life, with a new IE5 motor. Furthermore, the addition of a VFD into Drake's chiller 1 system helped them to optimize performance by modulating the motor speed to meet their process demands. Prior to this pilot, Drake's was not aware of advanced motors and the benefits they offer.

Site Energy Usage

Facility Energy Usage

1,000,000

kWh annually

Chiller 1 Distribution Pump Energy Usage

37,700

kWh annually

Equipment Details

Application	Existing Motor	Upgraded Motor
Chiller 1 Distribution Pump	(1) NEMA Premium: 7.5hp, 3600 RPM, 184JM, 3-phase	(1) Permanent Magnet-assisted Synchronous Reluctance Motor: 7.5hp, 3600RPM, 182/4TC, 3-phase

Procurement and Installation Process

Procurement

The procurement for Drake's new motor required coordination between Drake's on-site engineer and the motor manufacturer to specify the application, load type, speed range, voltage, mounting and frame size of Drake's existing motor system. The lead time for the motor and drive was approximately six weeks. The original lead time estimate was five weeks, but the initial VFD that was shipped to the site was undersized which caused a one-week delay.

Installation Detail

The installation of the new motor was performed by Drake's in-house engineers who reported that the motor was difficult to install due to the specifications of their chiller system. The site engineer also noted that the VFD installation "required more technical support from the motor company than we've previously experienced when commissioning a motor and drive." However, once the motor install was complete, the site commented that "the

Continued on next page

motor runs great." Interestingly, though the installation of the new motor and drive proved challenging, Drake's is finding their new motor and drive system to be easy to use.

Energy Savings Data

Annual runtime for the motor is 7,975 hours per year.[5]

	Average Demand (kW)	Energy Usage (kWh/yr)
Baseline Motor	4.73	37,728
Advanced Motor	4.28	34,128
Savings	0.45	3,601
Percent Savings	**9.54% (motor only)**	

Return On Investment[6]

The formula used to calculate the payback period is: Estimated Measure Cost of 7.5hp motor IE3 to IE5 divided by Site's Estimated Annual kWh Savings multiplied by the Average kWh Cost in California.

Payback Period = ($291 ÷ (3,601 × $0.31))

	Payback Period
Estimated Measure Cost of 7.5hp motor (IE3 to IE5)	$291
Annual Site's kWh Savings	3,601
Average kWh Cost in California	$0.31
Total	**0.26 years**

Key Takeaways

- Currently, lead times for advanced motors and drives are long but projected to decrease as the market matures.
- Drake's on-site engineering team was able to install the new motor and drive with technical support from the manufacturer.
- The payback period for the IE5 motor installed in the site's Chiller 1 Distribution Pump is approximately three (3) months.
- The site is satisfied with their new motor and interested in monitoring the long-term reliability and efficiency of the motor.

[5] Used average runtime from baseline and advanced motor monitoring periods for comparative analysis; no changes to system operation.

[6] This payback calculation only includes the incremental cost of an IE5 7.5hp motor because the Drake's previous motor was nearing the end of its life, and they had already planned to replace their motor. The cost of the drive and drive set-up is not included in this calculation because the site had planned to purchase a VFD with their motor replacement.

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