# CHAPTER 2 ANALYTICAL FRAMEWORK

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# CHAPTER 2 ANALYTICAL FRAMEWORK

## 2.1 INTRODUCTION

This chapter describes the general analytical framework that the U.S. Department of Energy (DOE or the Department) is using to develop amended energy conservation standards for certain electric motors. This chapter describes the methodology, analytical tools, and relationships among the various analyses that are part of the preliminary analysis performed in support of DOE's potential rulemaking.

The analyses presented in this preliminary Technical Support Document (TSD) include:

- a market and technology assessment to characterize the market for electric motors and review the techniques and approaches used to produce more efficient electric motors;
- a screening analysis to identify design options that improve electric motor efficiency and to determine which ones DOE should evaluate;
- an engineering analysis to estimate the relationship between the manufacturer's selling price of an electric motor and its efficiency level;
- an analysis of the energy use and end-use load profiles of electric motors;
- a markups analysis to develop distribution channel markups to convert manufacturer selling prices to customer installed prices;
- a life-cycle cost (LCC) and payback period (PBP) analysis to calculate, at the user level, the discounted savings in operating costs (minus maintenance and repair costs) throughout the estimated average lifetime of the covered equipment, compared to any increase in purchase and installation cost likely to result directly from imposition of a given standard;
- a shipments analysis to estimate shipments of electric motors during the period examined in the analysis;
- a national impact analysis (NIA) to assess the aggregate impacts at the national level of potential energy conservation standards for the considered equipment, as measured by the net present value (NPV) of total consumer economic impacts and the national energy savings (NES); and
- a preliminary manufacturer impact analysis (MIA) to assess the potential impacts of energy conservation standards on manufacturers, such as impacts on capital conversion expenditures, marketing costs, shipments, and research and development costs.

The analyses DOE will perform for the subsequent Notice of Proposed Rulemaking (NOPR) include those listed below.  DOE plans to revise these analyses based on comments and new information received in preparing the NOPR.

- an consumer subgroup analysis to evaluate variations in customer characteristics that might cause a standard to affect particular customer subpopulations, such as small businesses, differently from the overall population

- an MIA to estimate the financial impacts of standards on manufacturers and to calculate impacts on competition, employment, and manufacturing capacity

- an employment impact analysis to assess the aggregate impacts on national employment

- a utility impact analysis to estimate the effects of proposed standards on the generation capacity and electricity generation of electric utilities

- an emissions analysis to estimate the effects of amended energy conservation standards on emissions of carbon dioxide ($CO_2$), sulfur dioxide ($SO_2$), nitrogen oxides ($NO_X$), and mercury (Hg)

- a monetization of emission reduction benefits resulting from reduced emissions associated with potential amended standards

- a regulatory impact analysis to evaluate alternatives to proposed amended energy conservation standards that could achieve substantially the same regulatory goal

## 2.2 BACKGROUND

The Energy Policy and Conservation Act (EPCA), 42 U.S.C. §§ 6291-6317, as amended by the Energy Policy Act of 1992 (EPACT 1992), established energy conservation standards and test procedures for certain commercial and industrial electric motors manufactured (alone or as a component of another piece of equipment) after October 24, 1997. Then, in December 2007, Congress enacted the Energy Independence and Security Act of 2007 (EISA 2007) (Pub. L. No. 110–140).  Among other things, that law removed the statutory definition for the term “electric motor,” updated the energy conservation standards for those electric motors already covered by EPCA, and established energy conservation standards for additional electric motors not previously covered. (42 U.S.C. § 6313(b)(2))

In May 2012, DOE published an electric motors test procedure final rule primarily focused on updating various definitions and incorporations by reference related to the current test procedure. A regulatory definition of “electric motor” was promulgated in light of EISA 2007’s removal of the statutory definition of “electric motor.” DOE also clarified definitions related to those motors that EISA 2007 added for standards coverage which were not previously regulated.

EPCA also directs the Secretary of Energy to publish a final rule no later than 24 months after the effective date of the previous final rule to determine whether to amend the standards in effect for such equipment. Any such amendment shall apply to electric motors manufactured after a date which is five years after –

(i) the effective date of the previous amendment; or
(ii) if the previous final rule did not amend the standards, the earliest date by which a previous amendment could have been effective. (42 U.S.C. § 6313(b)(4))

As described previously, EISA 2007 constitutes the most recent amendment to EPCA and energy conservation standards for electric motors. Because these amendments went into effect on December 19, 2010, DOE is required by statute to publish a final rule determining whether to amend the EISA 2007 energy conservation standards for electric motors. DOE will determine whether to promulgate amended energy conservation standards for electric motors and, if so, the appropriate level for those new standards based on an in-depth consideration of the technological feasibility, economic justification, and energy savings of candidate standards levels as required by section 325 of EPCA. (42 U.S.C. §§ 6295(o)-(p), 6316(a)) Any such amended standards that DOE establishes would go into effect three years after publication of the final rule. This technical support document describes how DOE conducted the in-depth analysis for this rulemaking process.

### 2.2.1 Test Procedure

On May 4, 2012, DOE published a test procedure final rule for electric motors. 77 FR 26608 The final rule clarifies the scope of regulatory coverage for electric motors and ensures the accurate and consistent measurement of energy efficiency through changes to the current test procedures. These changes clarify certain terms and language in Title 10 of the Code of Federal Regulations (CFR), part 431 by revising the definitions of certain terms related to electric motors, clarifying the scope of energy conservation standards for electric motors, and updating references to several industry and testing standards for electric motors. DOE's final rule incorporates by reference portions of test procedures and definitions from relevant sources, including the Institute of Electrical and Electronics Engineers, Inc. (IEEE), National Electrical Manufacturers Association (NEMA), Canadian Standards Association (CSA), and the International Electrotechnical Commission (IEC).

During the course of both the test procedure and energy conservation standard rulemakings, DOE received comment on the use of updated industry standards and testing procedures. Baldor suggested that DOE incorporate the most recent version of the NEMA industry standard, MG1-2009, because it represents the current practices and performance guidelines that electric motor manufacturers use in the United States.[a] (Baldor, Public Meeting

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[a] One of the key documents that relates to the scope of coverage for electric motors is the National Electrical Manufacturers Association (NEMA) Standards Publication MG1, "Motors and Generators." NEMA drafted and maintains the MG1 document, most recently revised in 2011. MG1 assists users in the correct selection and application of electric motors and generators. MG1 provides practical information to electric motor manufacturers

Transcript, No. 14 at pp. 31, 57) [b] As discussed in the test procedure final rule, (77 FR 26608) DOE believed it was prudent to update its references to the relevant standards to be consistent with the electric motor industry. The final rule on test procedures adopted the updated MG1-2009 standard because it was, at the time, the most recent version of MG1.

Baldor and NEMA inquired if the newest version of Canadian Standards Association (CSA) Standard C390-10, "Test methods, marking requirements, and energy efficiency levels for three-phase induction motors," Test Method 1, would be adopted by DOE as an acceptable test procedure. Commenters noted that the newest version is not technically equivalent to IEEE Standard 112-2004 Test Method B (IEEE 112B) because efficiency is calculated from the collected data using a different method. (Baldor, Public Meeting Transcript, No. 14 at p. 30; NEMA, No. 13 at p. 2) DOE also received input from Advanced Energy, who provided comments based upon its own testing experience that cited data from LTEE Hydro-Quebec in Canada. The comments from Advanced Energy indicated that the differences between the two standards were shown to be negligible.[c] In view of these comments, DOE reviewed the studies cited by the independent testing laboratory, Advanced Energy, and conferred with other independent experts about IEEE 112B and CSA Standard C390-10 (Test Method 1). DOE understands that the test methods are not identical, but DOE believes that the differences are minimal and both tests will result in an accurate and similar measurement of efficiency. For further discussion on this topic and how DOE made its decisions, please see the electric motors test procedure final rule at 77 FR 26622.

## 2.3 MARKET AND TECHNOLOGY ASSESSMENT

The market and technology assessment (see chapter 3 of the preliminary TSD) characterizes the electric motor markets and existing technology options to improve electric motor efficiency. When DOE begins an energy conservation standards rulemaking, it develops information that provides an overall picture of the market for the equipment considered, including definitions, the nature of the equipment, market characteristics, and industry structure. This activity consists of both quantitative and qualitative efforts, based primarily on publicly available information.

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and users concerning the construction, testing, performance, and safety of alternating current (AC) and direct current (DC) motors and generators.

[b] "Baldor, Public Meeting Transcript, No. 14 at pp. 31, 57," refers to the transcript of the "Public Meeting to Address Rulemaking Process Framework for Electric Motor Efficiency Standards," held in Washington, DC, October 18, 2010. The elements of the footnote respectively refer to the company whose representative is making a comment, the docket number of the public meeting transcript, and the page(s) where the comment appears. For example, "(Baldor, Public Meeting Transcript, No. 14 at pp. 31, 57)" refers to (1) a statement made by Baldor at the Framework Public Meeting and recorded in the DOE Appliance Standards Program docket under "Energy Conservation Program for Certain Commercial and Industrial Equipment: Framework Document for Commercial and Industrial Electric Motors," Docket Number EERE–2010–BT–STD–0027, as document number 14; and (2) the passage that appears on page 31 and 57 of that document.

[c] Report from Advanced Energy is available at http://www.regulations.gov/#!documentDetail;D=EERE-2007-BT-TP-0008-0023

The discussion following this paragraph summarizes the analytical approach to the market assessment and key issues highlighted during DOE's preliminary interviews with manufacturers. The manufacturer interviews were conducted to gather feedback on DOE's engineering and market analysis approach, as well as to gather data on pricing, market behavior, electric motor shipments, and key concerns of manufacturers. A more detailed discussion on DOE's approach can be found in the market and technology assessment (chapter 3 of the preliminary TSD).

### 2.3.1 Current Definitions and Scope of Energy Conservation Standards for Electric Motors

EISA 2007 amended EPCA to establish energy conservation standards for four sets of electric motors: general purpose electric motors (subtype I), general purpose electric motors (subtype II), fire pump electric motors, and NEMA Design B general purpose electric motors (from 200 horsepower through 500 horsepower). The test procedure final rule codified certain definitions of general purpose electric motors (subtype I and subtype II) that helped clarify the application of the efficiency levels mandated under EISA 2007. As background, the following subsections provide some additional details about the four sets of electric motors as defined in the test procedure final rule.

Manufacturers expressed confusion over DOE's proposed definitions and interpretations of the statutory language under section 313(a) of EISA 2007. Baldor stated that it was difficult to understand what electric motors are covered under the general purpose subtype I heading and what efficiency levels apply to NEMA Design B electric motors under EISA 2007. (Baldor, Public Meeting Transcript, No. 14 at pp. 26, 46, 49, 54) Additionally, Baldor expressed concern over a *Federal Register* notice from March 23, 2009 (74 FR 12058) that codified EISA 2007 by striking the long-standing definition of the term "electric motor" from 10 CFR Part 431. (Baldor, Public Meeting Transcript, No. 14 at p. 34) That notice adopted the approach established by EISA 2007, which removed the previous EPACT 1992 definition for the term "electric motor" and inserted in its place two new categories of types of electric motors, general purpose electric motor (subtype I) and general purpose electric motor (subtype II). *See* 42 U.S.C. § 6313(b)(2). As a result of this removal by EISA 2007, DOE addressed this gap by defining the term "electric motor" through its regulations. See 77 FR at 2663 (defining the term "electric motor" as "a machine that converts electrical power into rotational mechanical power.")

*General Purpose Electric Motors (Subtype I) Definition*

As a result of the recent electric motors test procedure final rule, 10 CFR 431.12 now defines a general purpose electric motor (subtype I) as a general purpose electric motor that:

(1) Is a single-speed, induction motor;
(2) Is rated for continuous duty (MG1) operation or for duty type S1 (IEC);
(3) Contains a squirrel-cage (MG1) or cage (IEC) rotor;
(4) Has foot-mounting that may include foot-mounting with flanges or detachable feet;

(5) Is built in accordance with NEMA T-frame dimensions or their IEC metric equivalents, including a frame size that is between two consecutive NEMA frame sizes or their IEC metric equivalents;
(6) Has performance in accordance with NEMA Design A (MG1) or B (MG1) characteristics or equivalent designs such as IEC Design N (IEC);
(7) Operates on polyphase alternating current 60-hertz sinusoidal power, and:
(i) Is rated at 230 or 460 volts (or both) including motors rated at multiple voltages that include 230 or 460 volts (or both), or
(ii) Can be operated on 230 or 460 volts (or both); and
(8) Includes, but is not limited to, explosion-proof construction.

This definition fills in the statutory gap left by EISA 2007 when it removed the prior definition for "electric motor." The new definition includes updated references to International Electrotechnical Commission (IEC) and MG1 standards. This definition is functionally equivalent to the definition of "electric motor" that was codified in the CFR prior to EISA 2007. In effect, EISA 2007 renamed the electric motors that were, at that time, required to meet energy conservation standards as "general purpose electric motor (subtype I)." EISA 2007 also increased the efficiency requirements for most of those motors (the lone exception being fire pump electric motors, which are discussed later in this section, to levels equivalent to the NEMA Premium industry standard, which is found in Table 12-12 of NEMA MG1-2006 (now Table 12-12 of NEMA MG1-2011). These levels have been codified as part of DOE's regulations. *See* 10 CFR 431.25(c).

*General Purpose Electric Motors (Subtype II) Definition*

Further, the recent electric motors test procedure final rule amended 10 CFR 431.12 and defined a general purpose electric motor (subtype II) as any general purpose electric motor that incorporates design elements of a general purpose electric motor (subtype I). Unlike a general purpose electric motor (subtype I), a subtype II motor is configured in one or more of the following ways:

(1) Is built in accordance with NEMA U-frame dimensions as described in NEMA MG1–1967 (incorporated by reference, see § 431.15) or in accordance with the IEC metric equivalents, including a frame size that is between two consecutive NEMA frame sizes or their IEC metric equivalents;
(2) Has performance in accordance with NEMA Design C characteristics as described in MG1 or an equivalent IEC design(s) such as IEC Design H;
(3) Is a close-coupled pump motor;
(4) Is a footless motor;
(5) Is a vertical solid shaft normal thrust motor (as tested in a horizontal configuration) built and designed in a manner consistent with MG1;
(6) Is an eight-pole motor (900 rpm); or
(7) Is a polyphase motor with a voltage rating of not more than 600 volts, is not rated at 230 or 460 volts (or both), and cannot be operated on 230 or 460 volts (or both).

This definition provides greater clarity to the definition in EISA 2007. This definition, as with the general purpose electric motor (subtype I) definition, includes references to the most recent IEC and NEMA standards publications. Additionally, general purpose electric motors (subtype II) constituted the greatest expansion of motors covered as a result of EISA 2007. EISA 2007 required subtype II electric motors to meet energy conservation standard levels equivalent to those established by EPACT 1992, which can be found at Table 12-11 of NEMA MG1-2006 (now Table 12-11 of NEMA MG1-2011). These levels have been codified as part of DOE's regulations. *See* 10 CFR 431.25(e).

*NEMA Design B Electric Motor Definition*

Also, as a result of the electric motors test procedure final rule, 10 CFR 431.12 defines a NEMA Design B electric motor as a squirrel-cage motor that is:

(1) Designed to withstand full-voltage starting;
(2) Develops locked-rotor, breakdown, and pull-up torques adequate for general application as specified in sections 12.38, 12.39 and 12.40 of NEMA MG1– 2009 (incorporated by reference, see § 431.15);
(3) Draws locked-rotor current not to exceed the values shown in section 12.35.1 for 60 hertz and 12.35.2 for 50 hertz of NEMA MG1–2009; and
(4) Has a slip at rated load of less than 5 percent for motors with fewer than 10 poles.

NEMA MG1-2009 establishes the same torque requirements for both NEMA Design A and NEMA Design B electric motors. However, NEMA Design B electric motors must be designed such that their locked-rotor (or starting) current is less than that established for NEMA Design A electric motors. Unless the application specifically requires a NEMA Design A[d] electric motor design, NEMA Design B electric motors are often used instead of Design A electric motors because of the smaller spike in startup current. NEMA Design B electric motors are designed for continuous-duty operation and are commonly used in pumps, fans, blowers, and compressors.

During the framework document public meeting, the Appliance Standards Awareness Project (ASAP) stated that it did not want "legal" definitions (i.e., DOE adopted) to be in conflict with those that are used by the industry. ASAP continued, stating that NEMA Design B electric motors should not be defined within a certain horsepower range. (ASAP, Public Meeting Transcript, No. 14 at p. 52) DOE understands ASAP's concern and notes that the Design B definition noted above does not explicitly limit the horsepower rating of an electric motor. Additionally, DOE's definition is consistent with the industry version of the definition found in NEMA MG1-2009. The only difference between the definition in 10 CFR 431.12 and the

[d] Locked-rotor current, sometimes called in-rush current, is the spike in current occurring when power is first applied to the motor and lasting until a certain rotor speed is reached. NEMA Design B motors have limits on locked-rotor current (specified in NEMA MG1-2011 Section 12.35.1). NEMA Design A are not subject to locked-rotor current limits and the ensuing larger locked-rotor current spike may require special hardware, such as larger-gauge power connections or larger electrical system fuses.

definition from MG1 is that the DOE definition corrects minor typographical errors that appear in that industry-based document. 77 FR 26616-17

As clarified in the DOE test procedure (77 FR 26616-17), DOE interprets EISA 2007 as establishing energy conservation standards for NEMA Design B motors (greater than 200 horsepower, but less than or equal to 500 horsepower) that also meet the definition of either subtype I or II. These motors would then be required to meet the energy conservation standard levels found in Table 12-11 of NEMA MG1-2006 (now Table 12-11 of NEMA MG1-2011).

*Fire Pump Electric Motors Definition*

Finally, the electric motors test procedure final rule, amended 10 CFR 431.12 by defining a fire pump electric motor in the following manner:

*Fire pump electric motor* means an electric motor, including any IEC-equivalent, that meets the requirements of section 9.5 of National Fire Protection Association (NFPA) Standard 20 (incorporated by reference, see §431.15).

Before the test procedure final rule was published, Baldor expressed concern about a potential conflict between the long-standing industry definition of fire pump electric motors and a new definition for the purpose of establishing energy conservation standards. (Baldor, Public Meeting Transcript, No. 14 at pp. 54-55) In the test procedure final rule, DOE considered these comments and adopted a definition incorporating NFPA 20-2010 in an effort to clarify the definition. NEMA noted that while DOE has identified fire pump electric motors as polyphase motors with NEMA Design B performance characteristics, these electric motors are not simply NEMA Design B electric motors because fire pump motors have additional performance requirements, such as being able to start a minimum of 12 times per hour. (NEMA, No. 13 at p. 6) NEMA noted this concern because the additional requirements for fire pump motors affect a motor's utility and ability to meet the same efficiency standards when compared to the more typical NEMA Design B electric motors, which have no additional performance requirements. DOE is aware of the similarity in performance requirements between these two types of electric motors and, as will be discussed, DOE has separated fire pump electric motors from other general purpose electric motors into separate equipment class groups for this rulemaking. Finally, as mentioned, fire pump electric motors were covered by energy conservation standards for electric motors prior to the enactment of EISA 2007. However, unlike the rest of the electric motors that were previously required to meet energy conservation standards, the efficiency levels for fire pump motors were not raised above their pre-EISA 2007 levels, although DOE did modify the horsepower range of covered motors from 1 through 200 to 1 through 500. (77 FR 26636)

### 2.3.2 Expanded Scope of Coverage

The four categories of electric motors discussed in the previous section represent the entire scope of coverage for current electric motor energy conservation standards in subpart B of 10 CFR part 431. For purposes of this document, DOE's discussion of expanding the scope of coverage refers to the proposal to analyze energy conservation standards for electric motor types that currently do not have such standards. DOE has the statutory authority to establish such standards without first promulgating a coverage determination rulemaking based on the lack of a statutory definition for "electric motors." When DOE began updating standards for these electric motors it held a public meeting to discuss its framework document on October 18, 2010. During that meeting, DOE received comments regarding the energy saving potential from expanding the scope of coverage beyond subtype I, subtype II, and fire pump electric motors.

In response to the September 28, 2010, framework document, NEMA, ASAP, Baldor, and the American Council for an Energy-Efficient Economy (ACEEE) suggested that DOE expand its regulatory coverage to include other electric motors besides those that have already been specifically enumerated in EPCA. These commenters believed that excluding only certain definite and special purpose electric motors -- and including all others -- would simplify compliance and enforcement. The commenters also stated that such an approach could save more energy than simply increasing the stringency of those electric motors that are already covered by specific energy conservation standards. (ASAP and NEMA, No. 12 at p. 1; ACEEE, Public Meeting Transcript, No. 14 at p. 62; ACEEE, No. 4 at p.2; Baldor, Public Meeting Transcript, No. 14 at pp. 65-66) ASAP and NEMA calculated that establishing standards for other electric motors beyond the four groupings already addressed would save more energy than increasing the required efficiency levels of currently regulated motors because it would expand the number of motors that would be subject to the NEMA Premium[e] levels and would increase the efficiency of unregulated motors by 2.2 percent to 5 percent. (ASAP and NEMA, No. 12 at pp. 1, 4) Baldor, ASAP and NEMA all supported this approach along with the adoption of a standard level equivalent to NEMA Premium levels. In their view, this approach avoids imposing unmanageable costs and marketplace disruptions on manufacturers because they already have the tooling to reach these levels. (ASAP and NEMA, No. 12 at pp. 1-2; Baldor, No. 8 at p. 2) ACEEE commented that this move would be in the best interest of consumers, domestic manufacturers, and the economy. (ACEEE, Public Meeting Transcript, No. 14 at p. 22)

Utility companies also supported this approach. California Investor-Owned Utilities (IOUs), consisting of Pacific Gas and Electric Company, Southern California Gas Company, the San Diego Gas and Electric Company, and Southern California Edison submitted a joint comment supporting an expanded scope that would require most electric motors to meet NEMA Premium efficiency levels and require a compliance date to commence 18 months after the issuance of the final rule for new electric motors standards. (IOUs, No. 11 at pp.1-2)

On March 30, 2011, DOE published a Request for Information (RFI) in the *Federal Register* seeking additional public comments about an increased scope of coverage for the electric motors listed in Table 2.1. (76 FR 17577 (March 30, 2011)) DOE compiled the list based on submitted comments, manufacturer interviews, and discussions with subject matter experts. Many of these electric motors have similar electromechanical properties to those general purpose electric motors currently subject to regulation. Therefore, many interested parties believed that many of these motors could be incorporated into the current scope of coverage without a major overhaul of the electric motor test procedure.

[e] NEMA Premium efficiency levels refer to the efficiency values in NEMA MG1-2011 Table 12-12.

**Table 2.1 Unregulated Electric Motors Addressed in the Request for Information**

| Electric Motor Description | |
|---|---|
| NEMA Design A from 201 to 500 horsepower | Inverter duty |
| Brake | Totally enclosed, air-over |
| Integral shafted partial and-partial ¾ | Totally enclosed, non-ventilated |
| Vertical hollow shaft and vertical motors of all thrust configurations | Multispeed |
| Integral gear | Direct current |
| Single phase | Liquid cooled |
| Electronically commutated | Switched reluctance |
| Interior permanent magnet | Intermittent-duty |
| Submersible | Immersible |

DOE received comments responding to the RFI advocating that DOE regulate many of the electric motors discussed in the RFI as well as many additional motor types and devices. The Copper Development Association (CDA) suggested setting standards for gearboxes[f] included in integral gear electric motor sets. (Copper Development Association, No. 18 at pp. 1-2) ASAP and NEMA recommended that DOE regulate many of the motors in Table 2.1 and all of the electric motors listed in Table 2.2, which are motors not addressed in the RFI (ASAP and NEMA, No. 20 at pp. 2-3).

**Table 2.2 Unregulated Electric Motors Not Addressed in the Request for Information**

| Electric Motor Description | |
|---|---|
| Customer-defined endshields | Special flanged endshields |
| Shaft of non-standard dimension or additions | Special base or mounting feet |
| Double Shaft | Electric motors with thrust or sleeve bearings |
| Encapsulated | All Mounting Configurations |

DOE agrees that many of the electric motors in Table 2.1 and Table 2.2 have electromechanical similarities relative to those motors that are already regulated. Additionally, DOE recognizes the energy savings potential of expanding the scope of regulated electric motors and has preliminarily decided to adopt this approach. DOE plans to set energy conservation standards for all of the NEMA Design A, B, or C motors[g] discussed below. Historically, DOE has not covered motors deemed "definite purpose" or "special purpose" (as defined by EPCA) from energy conservation standards. These motor types were excluded from coverage under the "electric motor" energy conservation standards established in EPACT 1992. However, with the elimination of the prior statutory definition of the term "electric motor" and the required new energy conservation standards mandated by EISA 2007, coupled with the continued national interest to seek greater national energy savings, DOE is contemplating applying minimum efficiency standards to any electric motor type exhibiting all of the characteristics listed in Table 2.3.

[f] The electric motors currently subject to energy conservation standards are constant speed electric motors. The speed depends on pole configuration, slip, and operating frequency. Gearboxes allow users to run equipment at a speed that is different from the nameplate.
[g] Including IEC equivalents.

**Table 2.3 Characteristics of Motors Regulated Under Expanded Scope of Coverage**

| **Motor Characteristic** |
|---|
| Is a single-speed, induction motor, |
| Is rated for continuous duty (MG1) operation or for duty type S1 (IEC), |
| Contains a squirrel-cage (MG1) or cage (IEC) rotor, |
| Operates on polyphase alternating current 60-hertz sinusoidal power, |
| Is rated 600 volts or less, |
| Has a 2-, 4-, 6-, or 8-pole configuration, |
| Has a three-digit NEMA frame size and is less than 500 horsepower, and |
| Is a NEMA Design A, B, or C motor (or an IEC equivalent) |

Some motor types with all characteristics listed in Table 2.3 may be considered "special purpose" or "definite purpose" motors. However, should DOE expand its scope of coverage, it would no longer be excluding such motor types from energy conservation standards. Assuming that DOE decides to set minimum standards for all electric motor types with the characteristics listed in Table 2.3, their standards would likely be based on their respective equipment class groups. For a discussion of which characteristics determine a motor's equipment class group, see section 2.3.5. Motor types that exhibit all characteristics shown in Table 2.3, but which DOE does not believe should be subject to efficiency regulations at this time, either because of testing difficulty or other reasons, are addressed in section 2.3.3.

ASAP and NEMA suggested that DOE use the NEMA definitions of electric motors whenever possible and offered to work with DOE "to develop new, clear definitions to help characterize exempt motors." (ASAP and NEMA, No. 20 at p. 5) In an attempt to harmonize relevant terminology, DOE has provided definitions that are based at least in part on the applicable industry-developed definitions. These motors, and their definitions, are listed in chapter 3 of the preliminary TSD. DOE attempted to define certain motors that may be regulated because there is no formal industry-based definition for them (e.g., partial motors and inverter-duty motors). DOE requests feedback on the preliminary definitions outlined in chapter 3 of the preliminary TSD.

Finally, for those motor types that DOE has not previously regulated but is now considering regulating as part of this rulemaking, DOE is not proposing at this time to make changes to the underlying test methods used to determine these motors' efficiencies. In other words, DOE currently believes that all of these new motor types would still be tested using either IEEE 112B or CSA C390. In some instances, additional preparatory steps may be needed to test a motor using either test procedure. DOE believes that this is an appropriate approach because all of the motors that DOE is considering expanding coverage to are single-speed, polyphase induction motors like those currently subject to energy conservation standards, and they all function using the same general principles. DOE has provided a preliminary discussion of some of the modifications and preparatory steps that it believes will be necessary for some of these motor types and requests commenter feedback on each approach. Additionally, DOE plans to conduct a separate test procedure rulemaking in which it will incorporate such feedback and seek to codify the additional steps necessary to test all of these additional motors.

*Motors with Encapsulated Stator Windings*

Encapsulated motors have special insulation protecting the stator winding from condensation, moisture, dirt, and debris. This insulation typically consists of a special material coating that completely seals off the stator's copper windings. Encapsulation is generally found on open-frame motors, such as open dripproof (ODP) motors, where the possibility of contaminants getting inside the motor is higher than on an enclosed-frame motor, such as a totally enclosed, fan-cooled (TEFC) motor.

DOE received comment regarding motors with encapsulated windings. NEMA and ASAP commented that, with the exception of designs for submersible applications, encapsulated motors should be subjected to minimum standards. (ASAP and NEMA, No. 20 at p. 4; ASAP and NEMA, No. 12 at p. 9) DOE further discussed encapsulation with industry and subject matter experts to determine if encapsulated stator windings affect the efficiency of a motor and determined that encapsulated motors could be included in the list of regulated motors.

DOE previously categorized encapsulated motors as "special purpose" because of their special construction and excluded them from standards because the EPACT 1992 electric motor standards explicitly did not apply to definite- or special-purpose motors. 62 FR 59978, 59984 (November 5, 1997) However, DOE does not believe that whether or not a motor has encapsulated stator windings affects the efficiency of a motor because the encapsulation does not significantly inhibit heat dissipation from the stator windings. (Heat dissipation plays a significant role in affecting the overall efficiency of an electric motor. Excessive heat build-up can reduce the efficiency of a motor while good dissipation of heat can help improve it.) Therefore, DOE is considering setting standards for motors with encapsulated windings, unless covering them would not be warranted because of other criteria (e.g., a submersible motor with encapsulated windings, see section 2.3.3). DOE also believes that encapsulated windings do not interfere with the DOE test procedures[h] because the encapsulated windings do not prevent the motor from being attached to a dynamometer and running like a typical general purpose motor. Therefore, DOE has no plans at this time to alter the current test procedure to specifically address these types of motors.

DOE requests comment on its tentative plan to include motors with encapsulated windings as part of its efforts to more broadly address efficiency levels for electric motors generally, and its preliminary view that encapsulated motors can be tested using the existing DOE test methods.

*Single- and Double-Shaft Motors of Non-Standard Shaft Dimensions or Additions*

DOE understands that NEMA Standard MG1-2011 and IEC Standard 60072-1 (1991) specify tolerances for the shaft extension diameter and keyseat that relate to the fit between the shaft and the device mounted on the shaft. DOE is aware that shafts of special diameter, length, or design are often provided at a customer's request for use in particular applications. DOE has

[h] DOE approved test methods are IEEE 112 Test Method B and CSA C390.

also learned that some manufacturers utilize shafts of special dimensions in the belief that electric motors with special shaft dimensions are not covered under EPCA. In the proposed test procedure rule published in January 2011, DOE proposed guidance on shaft diameter, length, shoulder location, and special designs. 76 FR 671-672.

DOE received comments that advocate covering a motor with a single- or double-shaft extension that may otherwise be constructed according to non-NEMA standard dimensions or additions in an effort to preclude loopholes and thereby circumvent compliance. (ASAP and NEMA, No. 12 at p. 8) Baldor expressed a similar concern during the public meeting when it mentioned that large manufacturers had approached them about using shaft alterations as a means of skirting EISA requirements. (Baldor, Public Meeting Transcript, pp. 96-97) ASAP and NEMA submitted comments in response to the RFI on scope expansion and suggested that manufacturers could demonstrate compliance for these motors by testing similar models that could more easily be attached to a dynamometer. (ASAP and NEMA, No. 20 at p. 4)

In DOE's view, shaft alterations do not affect a given motor's efficiency because the motor shaft does not impact the electromagnetic properties of the motor. Consistent with this view, DOE plans to regulate motors irrespective of the given diameters, lengths, shoulder locations, and special designs in an effort to simplify compliance and to discourage attempts to circumvent the energy conservation standards. This approach would also address efforts to incorporate alterations made to double-shaft motors. DOE requests comment on whether to include motors with the aforementioned alterations in the expanded scope of coverage. Additionally, DOE requests comment on difficulties that may arise from testing motors with non-standard shaft alterations. More specifically, testing a "similar model" to show compliance would likely create difficulties in ensuring the accuracy of claimed efficiency ratings. DOE is interested in information about other methods for testing such motors -- and whether certain changes to the current test procedure are needed to address such situations. If changes are needed, DOE requests comments from interested parties regarding what those changes should be.

*Electric Motors with Brake Components*

Brake motors are motors with a braking mechanism either attached to an exterior shaft or built inside the motor enclosure. The brake mechanism is typically mounted on the end opposite the drive of the motor. The braking system is typically an electrically released, spring-loaded mechanism. The brake component is "energized" during normal operation of the motor. During this normal operation, the brake component is not touching or interfering with the motor operation, but is drawing power from the same source as the electric motor. When an emergency situation arises, power is cut off from the brake component, and the brake then "clamps" down on the motor shaft to quickly stop rotation of the motor.

The Copper Development Association (CDA) commented that brake motors are relatively high unit-shipment volume motors with heavy duty-cycles (even 24/7) that can achieve higher motor efficiencies and that higher efficiencies could provide significant energy savings. (CDA, No. 18 at p. 1) NEMA and ASAP also submitted comment specifically supporting the inclusion of brake motors in an expanded scope of coverage. (ASAP and NEMA, No. 20 at p. 3)

Additionally, NEMA submitted a separate comment advocating the exclusion of integral brake motors as called out in appendix A to subpart B of CFR Part 431. (NEMA, No. 19 at p. 2)

In a 1997 rulemaking, DOE did not cover integral brake motors, described as "integral brake design factory built within the motor," from the scope of coverage because they are "special purpose motors." 62 FR 59978 (November 5, 1997) As mentioned previously, DOE is now considering efficiency standards for "special purpose" and "definite purpose" electric motors, including certain types of motors with brake components.

DOE plans on proposing definitions for two terms to describe motors with brake components: "non-integral brake motors" and "integral brake motors." A "non-integral brake motor" consists of a brake mounted to the motor in such a fashion that the brake component is typically bolted onto the outside of the fan cover of the motor and could be removed from the motor with minimal disassembly, and the motor could operate as a general purpose electric motor. An "integral brake motor" consists of a factory-built unified assembly typically built either inside the endshield of the motor or in between the motor fan and rotor component. With "integral brake motors," the brake component is difficult to remove, and doing so could adversely affect the performance of the motor.

DOE understands that for both motor types, "non-integral brake" and "integral brake," the braking mechanism does not directly interfere with normal operation because it is only engaged when desired or in an emergency. Additionally, both motor types may be tested using current DOE test procedures without modification to the motor. However, the braking mechanism may contribute to friction and windage losses from rotating brake components, or electrical losses as a result of energizing the brake disc. DOE does not know the extent of these losses, and requests comment on any reports or technical papers regarding losses caused by brake components. At this time, DOE is considering setting efficiency standards for both types of brake motors. DOE requests comment on this tentative decision, as well as comment on any other difficulties arising from testing brake motors, especially "integral brake motors," under the approved test methods. DOE requests comment on any specific recommendations related to the manner in which the losses from the brake component should be taken in to account. Based on the information received, DOE may also consider an approach that tests these motors with the braking mechanism removed.

*Customer-Defined Endshields or Flanged Special Motors, Motors with Special Base or Mounting Feet*

Motors may have special or customer-defined endshields, flanges, bases, or mounting feet that do not necessarily conform to NEMA MG1-2011 standards. ASAP and NEMA submitted comment advocating the coverage of flanged special motors and motors with a special base or mounting feet. (ASAP and NEMA, No. 12 at pp. 8-9; ASAP and NEMA, No. 20 at p.4) ASAP and NEMA also recommended that DOE address customer-defined endshields. (ASAP and NEMA, No. 20 at p. 4)

Prior to EISA 2007, only electric motors that were general purpose foot-mounting, which meant being built in standard NEMA T-frame with mounting brackets to make the motor suitable for horizontal operation, were subject to energy conservation standards. Therefore, DOE did not cover motors with special bases or face-mounting configurations because such motors did not fall under the definition of 'electric motor' as defined in EPCA (42 U.S.C. 6311(13)(A), 1992). 62 FR 59978, 59984 (November 5, 1997) However, as a result of the EISA 2007 amendments, DOE believes that such electric motors could be subject to energy conservation standards because DOE is no longer restricted to only covering general purpose electric motors built in a T-frame.

DOE did not cover motors with customer-defined endshields because their special design for a particular application made them "special" or "definite" purpose motors. However, as noted earlier, the EISA 2007 amendments no longer restrict electric motors solely to "general purpose" electric motors. Consequently, DOE is considering setting energy conservation standards for motors with customer-defined endshields consistent with the approach suggested by both industry and energy efficiency advocates.

DOE understands that motors with customer-defined endshields, special flanges, bases, or mounting feet (except for vertical motors, discussed separately) do not affect efficiency because these are external changes to the motor and do not affect the electromechanical properties of the motors. DOE plans to address motors with these types of custom-frame enclosures, but recognizes that some of these motors may be more difficult to attach to a dynamometer for testing. DOE requests comment on its tentative decision to include these motors as part of its efforts to broaden the application of standards to different electric motors and any testing difficulties that may arise from testing such custom motors.

*Partial and Integral Motors*

DOE understands that partial motors, also called "partial ¾ motors" or "¾ motors," are motors missing one or both endshields. Such motors may be closely connected to another piece of equipment, such as a pump or gearbox. When a partial motor is mated to another piece of equipment, it is often referred to as an "integral" motor. For example, an "integral gearmotor" is the combination of a partial motor mated to a gearbox using bolts or some other means of attachment. In this configuration, the gearbox replaces an endshield on the motor and provides a bearing mount for the motor shaft, allowing proper operation.

DOE understands that there is no standard or common industry definition for a partial motor. In one comment, NEMA recommended that DOE continue to exclude partial motors from energy conservation standards because they may not follow NEMA MG1 requirements for thermal, electrical, and/or mechanical performance, but suggested that partial ¾ motors or integrally shafted partial motors should be covered because they are motors missing only a drive-end endshield. (NEMA, No. 19 at p. 3) Subsequently, NEMA and ASAP asserted that partial motors can also be called "partial ¾ motors" and should be categorized with integral shafted partial motors, because they are sold without one or both endshields and could be included in an expanded scope of coverage. (NEMA, No. 20 at p. 3) This apparent contradiction, first grouping partial motors with component sets and then grouping partial motors with partial ¾ motors or integral shafted partial motors, illustrates the need for guidance on how to interpret such terms. Consequently, DOE has created Table 2.4 that outlines its current understanding and interpretation of terms related to partial motors and component sets. (DOE discusses component sets in chapter 3 of the preliminary TSD)

**Table 2.4 Partial Motors and Component Sets**

| Row | Name | Also Called | Description | Example |
|---|---|---|---|---|
| 1 | Partial electric motor | Partial ¾ motor, integral shafted motor, integral shafted partial motor, integral gearmotors | An electric motor necessitating only the addition of one or two endshields with bearings to create an operable motor. | A complete motor with one endshield removed and mated to a gearbox. |
| 2 | Component set | Wound stator/squirrel-cage rotor sets | A combination of motor parts that require more than the addition of one or two endshields with bearings to create an operable motor. These parts may consist of any combination of a stator frame, wound stator, rotor, shaft, or endshields. | A wound stator and squirrel-cage rotor sold independently of any other motor components. End-user must provide shaft, frame, and other components to create a running motor. |

Previously, DOE did not cover "integral gearmotors," from efficiency standards because, at that time, they did not meet the statutory definition of "electric motor." DOE understands integral gearmotors to be a subset of partial motors. An integral gearmotor is an assembly of a motor and a specific gear drive or assembly of gears, such as a gear reducer, as a unified package. DOE did not cover such motors because the motor portion of an integral gearmotor is not necessarily a complete motor, since the end bracket or mounting flange of the motor portion is also part of the gear assembly and cannot be operated when separated from the complete gear assembly. Also, an integral gearmotor is not necessarily manufactured to the standard T-frame dimensions specified in NEMA MG1. DOE found that these characteristics precluded the motor from being used in most general purpose applications without significant modifications and, consequently, integral gearmotors fell outside the scope of the previous statutory definition of ‘‘electric motor.’’ 62 FR 59978, 59982 (November 5, 1997).

Although DOE believes that integral gearmotors are a subset of partial motors, many of the reasons for not including integral gearmotors in the 1997 final rule apply to partial motors as a whole. Partial motors are special purpose motors that are unable to run when operated without one or both endshields. However, with the addition of an endshield, these partial motors can become operational. DOE believes that the absence of one or both endshields does not degrade the efficiency of a motor, rather its ability to operate independently of its driven equipment. When one or two "dummy" endshields are attached to the motor, the motor may have no other characteristics that would otherwise degrade efficiency when compared to a general purpose, subtype I motor designed and built with in a complete frame assembly or housing. DOE is giving serious consideration to including partial motors as part of any effort to expand efficiency standards coverage, particularly in those cases where the motor is operational when paired with at least one end plate. DOE requests feedback on this tentative approach to include partial motors in the expanded scope of standards coverage.

Additionally, DOE is particularly interested in comment concerning how to test a partial motor in a consistent and repeatable manner. The CDA indicated that a new test procedure may be required for partial motors and that the DOE should consider developing a new test standard for these and similar motors. (CDA, No. 18 at p. 2) DOE has received feedback suggesting that manufacturers could show compliance by testing a similar model that could more easily be attached to a dynamometer. (ASAP and NEMA, No. 12 at p. 9) Alternatively, another option would allow a manufacturer to provide one or two "dummy" endshields that could be attached to the motor for the purpose of testing. This approach would enable testing of the motor in question.

*Totally Enclosed, Non-Ventilated Motors*

Unlike totally enclosed, fan-cooled (TEFC) motors, totally enclosed, non-ventilated motors (TENV) are motors that have no external fan blowing air over the outside of the motor. TENV motors may be used in environments where an external fan could clog with dirt or dust. TENV motors are cooled by natural conduction and convection of the motor heat into the surrounding environment, which results in a motor that operates at higher temperatures than a TEFC motor. TENV motors may deal with the higher operating temperatures by adding more frame material to dissipate excess heat or by upgrading stator winding insulation to withstand the higher operating temperatures.

ASAP and NEMA recommended that DOE include TENV motors in an expanded scope of coverage and suggested that manufacturers could demonstrate compliance by testing similar models. (ASAP and NEMA, No. 12 at p. 7) ASAP and NEMA later scaled back its recommendation and supported the coverage of only 140 T- and 180 T-frame size TENV motors. (ASAP and NEMA, No. 20 at p. 3) ASAP and NEMA did not explain their reasoning, but DOE notes that TENV motors are most commonly built in these two frame sizes. DOE requests additional comment regarding the approach suggested by ASAP and NEMA, including the merits of extending standards coverage to other TENV motors as well as reasons in favor of this more limited approach. The CDA also supported the coverage of TENV motors and added that DOE may need to develop new test procedures for these motors. (CDA, No. 18 at p. 2) CDA did not indicate whether the current procedures could be modified to test these motors or what specific steps would need to be included to test these types of motors.

Previously, DOE did not cover TENV motors, believing that they could not be used in most general purpose applications, under the likelihood of a TENV motor being built in a frame size larger than that of a TEFC motor of the same horsepower rating to dissipate the same amount of heat. 62 FR 59978, 59982 (November 5, 1997) Further, TENV motors may have design and construction requirements for extra installation clearances to better dissipate heat in the absence of an external fan. At this time, DOE is considering expanding the scope of standards coverage to include TENV motors in all frame series, rather than to limit this approach solely to 140 T- and 180 T-frame motors. DOE requests comment on this preliminary approach.

Additionally, at this time, DOE does not believe that any special modification to its current test procedures for electric motors would be needed for TENV motors, but requests comment from interested parties about this view.

*Motors with Sleeve Bearings*

A majority of the electric motors currently covered by DOE's standards utilize anti-friction ball bearings. Sleeve bearings are used on larger (generally greater than 400 horsepower) motors as an alternative to anti-friction ball bearings. Sleeve bearings typically have a longer life and the ability to operate at higher speeds than anti-friction ball bearings.

Both ASAP and NEMA asserted that motors with sleeve bearings should be included in the scope of coverage and that testing should be performed on a motor with an equivalent electrical design, but with standard bearings installed. (ASAP and NEMA, No. 20 at p. 4) DOE separately consulted with testing laboratories, subject matter experts, manufacturers and reviewed technical papers to determine that sleeve bearings do not significantly degrade efficiency when compared to anti-friction ball bearings.

DOE did not previously cover electric motors equipped with sleeve bearings, believing that their special mechanical construction categorizes them as special-purpose motors as defined in EPCA. 62 FR 59978 (November 5, 1997) However, as stated, DOE is considering extending efficiency standards coverage to electric motors generally, including special- or definite-purpose motors. Furthermore, DOE does not believe that sleeve bearings significantly affect the efficiency capabilities of an electric motor when compared to anti-friction ball bearings. DOE requests comment on the effect sleeve bearings have on efficiency and its preliminary decision to include such motors in the expanded scope of coverage.

Although DOE does not believe that modifications to its current test procedures are needed for sleeve-bearing motors, it has considered the comment submitted by NEMA and ASAP. DOE notes that in its 1999 final rule on test procedures for electric motors, which covered motors constructed with roller bearings, it allowed manufacturers to substitute standard anti-friction bearings for the roller bearings when testing for energy efficiency. (64 FR 54146) As stated, DOE is not aware of any reasons why a motor with sleeve bearings could not be tested with its sleeve bearings using the current DOE test procedures, but requests additional information on this point. DOE also requests comments from interested parties about the feasibility of testing motors with standard anti-friction bearings temporarily installed rather than the sleeve bearings as originally designed.

*Vertical Hollow-Shaft and Vertical Motors of all Thrust Configurations*

Vertical motors are motors that are designed to operate with the motor mounted in a vertical position, usually with the shaft facing downward. These motors are typically used in pumping applications, such as in wells or pits. Vertical motors can have solid or hollow shafts and those with solid shafts are currently subject to energy conservation standards as a result of EISA 2007. Alternatively, the unregulated hollow shaft vertical motors employ a hollow shaft that allows a pump shaft to be run through the motor shaft. Vertical motors also come in different thrust configurations, such as low, medium, or high. The thrust configuration depends on how much weight the vertical motor's bearings must be able to withstand. The weight on the bearings is a combination of the motor weight, pump shaft weight, and down-thrust created by the pump. The thrust configuration determines which type of bearings the vertical motor may use, either regular anti-friction ball bearings or thrust bearings. Motors with thrust bearings are discussed in more detail in the following section.

ASAP and NEMA were in favor of covering vertical hollow-shaft motors and, more generally, vertical motors of all thrust configurations. (ASAP and NEMA, No. 20 at p. 3) Baldor commented that there is no reason that all vertical motors, including hollow-shaft vertical motors, could not be made in a NEMA Premium® configuration. (Baldor, Public Meeting Transcript, No. 14 at p. 85) Regarding vertical motors, NEMA noted that vertical motors should be tested in a horizontal configuration because test facilities may not be physically able to test them in a vertical arrangement. It added that EISA 2007 recognized this fact when it mandated that a vertical solid-shaft motor be tested in a horizontal configuration. (NEMA, No. 13 at p. 5)

Before EISA 2007 expanded the scope of coverage for motors, vertical motors were not covered equipment because they were not "foot-mounted" ("foot-mounting" was a required construction feature of an "electric motor," as previously defined by statute.) 62 FR 59978 (November 5, 1997) When EISA 2007 expanded the scope of coverage for energy conservation standards for electric motors, it included vertical solid-shaft motors in the definition of general purpose electric motor (subtype II). Vertical hollow-shaft motors were still not covered and vertical motors of different thrust configurations (low, medium, or high) were not addressed.

Based on feedback from manufacturers and discussions with industry experts, DOE does not believe that thrust configuration or shaft type (solid or hollow) affects efficiency levels when vertical motors are tested in a horizontal configuration with anti-friction ball bearings installed. DOE believes that, holding all other variables constant except for shaft type, a vertical, hollow-shaft motor has no electromechanical properties which would cause its efficiency to differ from a vertical solid-shaft motor. Additionally, thrust configuration of a motor should not impact efficiency because any heavy loads that may degrade efficiency when a motor is mounted vertically are not present when the motor is configured in a horizontal position. Therefore, DOE is weighing the possibility of applying energy conservation standards to all hollow-shaft, vertical motors and vertical motors of all thrust configurations with anti-friction ball bearings. Vertical motors of any shaft type or thrust configuration that employ thrust bearings are discussed in the section below. DOE requests comment on the decision to include all permutations of vertical motors in the expanded scope of conservation standards..

Finally, DOE believes the same testing restrictions for solid-shaft vertical motors apply to hollow-shaft vertical motors because they have similar constructions (the only difference being the shaft configuration). Similarly, DOE believes the same testing restrictions for solid-shaft vertical motors of any thrust configuration also apply to hollow-shaft motors of any thrust configuration, for the same reason mentioned above. Additionally, DOE believes it may be necessary to attach a solid-shaft protrusion to the hollow-shaft motor to allow the motor to be attached toa dynamometer for testing. DOE requests comment on attaching a shaft protrusion to a hollow-shaft motor for testing purposes. DOE also requests comment on the preliminary decision to test all vertical motors in a horizontal configuration using anti-friction ball bearings.

*Motors with Thrust Bearings*

Thrust bearings are specialized bearings that are able to withstand operation under heavy axial loads. These bearings are typically used on vertical motors with medium- to high-thrust configurations where a regular, anti-friction ball bearing may deform under the vertical weight.

ASAP and NEMA submitted comment that motors with thrust bearings should be included in the scope of coverage and that they should be tested with an equivalent electrical design with standard bearings. (ASAP and NEMA No. 20 at p. 4) DOE had not previously covered motors with thrust bearings because their special mechanical construction meant they were categorized as special-purpose motors as defined in EPCA. 62 FR 59978 (November 5, 1997) Although DOE understands thrust bearings could potentially degrade efficiency, it agrees with commenters and believes that such motors should be covered. DOE requests additional comments on this potential expansion of scope.

Additionally, EISA 2007 provided that, within the context of subtype II electric motors, vertical motors are to be tested in a horizontal configuration. See 42 U.S.C. § 6311(13)(B)(v) (noting that a subtype II electric motor includes a "vertical solid shaft normal thrust motor (as tested in a horizontal configuration)"). However, DOE understands thrust bearings cannot operate in a horizontal configuration, which means special treatment is necessary for testing these motors in a horizontal configuration. Preliminarily, DOE is evaluating the suggestion made by ASAP and NEMA and considering allowing manufacturers to temporarily swap in grease-lubricated ball bearings for the purposes of testing in a horizontal configuration. Again, this is consistent with the approach that DOE has taken in the past with motors containing roller bearings. DOE requests comment on its understanding of the limitations of thrust bearings with respect to operating in a horizontal configuration for testing, and any additional changes to the test procedure that may be necessary to appropriately test motors with thrust bearings.

*Inverter Capable, Inverter-Only Duty Motors*

An inverter drive is a device used to control the speed or torque characteristics of a motor. Inverter drives are also referred to as variable speed drives, variable frequency drives, adjustable frequency drives, AC drives, or microdrives, which serve as special electronic controllers to help manipulate the power source of a motor. Inverter drives are used to slow a motor down or provide a constant torque output of the motor. Motors that can operate on an inverter may require special hardware or design to withstand the abnormally harsh operating conditions an inverter drive may create, such as increased operating temperatures or harmonic distortion of the motor's power supply. Inverter drives are considered part of an "Advanced Motor System" by DOE and are discussed in more detail in section 2.3.4.

Manufacturer catalogs refer to motors capable of being run on an inverter as "inverter duty." However, DOE understands there are two distinct types of motors that are referred to as "inverter duty" in manufacturer catalogs. The first type is a motor that has the ability to be run on an inverter drive, but can also run continuously when connected directly to a polyphase, sinusoidal power source (i.e., it can be run continuously without an inverter drive). DOE plans to refer to this type of motor as an "inverter capable" motor because it is capable of withstanding inverter duty operation, but the motor design does not necessitate an inverter drive for continuous operation.

The second type of motor that manufacturer catalogs refer to as "inverter duty" is a motor that cannot operate continuously without an inverter drive. This motor may have heavy insulation or other design changes to deal with operating conditions that may result from inverter operation, such as harmonic distortion of the power signal or dielectric stresses resulting from voltage spikes. This motor, unlike an "inverter capable" motor, is specifically built for inverter-fed operation and is generally more expensive to build than an "inverter capable" motor. This second motor type could not be used for continuous duty operation without an inverter drive. DOE plans to refer to this second type of motor as an "inverter-only duty" motor because it is specifically built to only operate continuously on an inverter.

DOE wishes to clarify these two terms because it understands that there is no industry accepted definition that delineates between motors capable of being run on an inverter and motors that can only be run on an inverter. This planned distinction is illustrated in Table 2.5.

**Table 2.5 Inverter Duty and Inverter Capable Motor Definitions**

| Covered | Not Covered |
|---|---|
| Inverter-Capable Electric Motor – An electric motor that can run continuously when directly connected to a polyphase, sinusoidal bus, but is also capable of handling operation on an inverter drive. | Inverter-Only Duty Electric Motor – An electric motor designed such that it can only be run continuously when operated on an inverter drive. |

NEMA responded to the RFI by suggesting that DOE not cover an inverter duty motor if it is in full compliance with NEMA MG1-2006 Part 31 (titled "Definite-Purpose Inverter-Fed Polyphase Motors"), or if an inverter-duty motor has variable-frequency drive rating information on the nameplate. NEMA also suggested that DOE should use the term "definite purpose inverter-fed motors" for inverter duty motors that are not covered. (NEMA, No. 19 at p. 3) DOE believes this approach opens a possible compliance loophole where a manufacturer may produce and nameplate a continuous-duty motor in full compliance with the applicable provisions under 10 CFR Part 431, but which could also be run continuously without an inverter drive. DOE has presented the terms "inverter-capable" and "inverter-only duty" in an effort to effectively differentiate between the two types of motors and simplify compliance.

DOE discussed inverter-duty motors in previous motor rulemakings. In the 1997 Policy Statement and the 1999 final rule, DOE noted that "NEMA Design A or B motors that are single-speed, meet all other criteria under the definitions in EPCA for covered equipment, and can be used with an inverter in variable speed applications as an additional feature, are covered equipment under EPCA. In other words, being suitable for use on an inverter by itself does not exclude a motor from EPCA requirements". 62 FR 59978 (November 5, 1997) and 64 FR 54114 (October 5, 1999). DOE is continuing with this approach and is considering setting standards for "inverter-capable" motors while not covering "inverter-only duty" motors. DOE is considering the adoption of these terms and the related definitions that would apply to help clarify the scope of coverage and to prevent potential compliance loopholes. DOE requests feedback on this approach, including the presented terms and accompanying definitions.

Finally, at this time, DOE does not believe any specific alterations to its test procedures are necessary for "inverter capable" motors because DOE does not believe these motors have any characteristics that would prevent them from being tested according to 10 CFR 431.16. Nevertheless, DOE requests feedback on this understanding and whether "inverter-capable" motors require any changes to the current DOE test procedure.

*Immersible Electric Motors*

Immersible motors are electric motors capable of being submerged and removed from a liquid without causing damage to the motor. Immersible motors are different than submersible motors because they are not designed to run while submerged in liquid but rather are designed to withstand temporary immersion in liquid. An immersible motor uses special seals to prevent water from getting in to its enclosure.

In response to the framework document, NEMA and ASAP commented that greater clarification was needed by NEMA for this category of product. (ASAP and NEMA, No. 12 at p. 9). DOE is aware of the lack of a definition for immersible motors and seeks to clarify the distinctions between immersible and submersible motor types.

In a 1997 rulemaking, DOE discussed motors with seals and their effect on efficiency. In that rulemaking, DOE found that when a motor with new seals is tested, the efficiency is significantly understated due to the fact that new seals are stiff relative to "broken in" seals and, consequently, loses caused by friction increase. FR 59978, 59980 (November 5, 1997)

In light of the 1997 rulemaking decision and DOE's evaluation of the possible expansion of scope of conservation standards, DOE is considering subjecting immersible electric motors to minimum efficiency standards. Aside from seals, which could possibly be removed during testing, DOE does not believe there are any other characteristics of immersible motors that inhibit improved efficiency. Additionally, DOE does not believe there are any abnormal difficulties with attaching immersible motors to a dynamometer for testing. DOE requests comment on the decision to include immersible electric motors in the expanded scope of conservation standards. DOE also requests comment on the definition of immersible electric motors. Lastly, DOE requests comment on the testing of immersible motors, especially with regards to removing seals before testing or any other characteristics that may affect efficiency or the ability to test these motor types.

### 2.3.3 Motor Types not Covered under Expanded Scope of Coverage

Through its RFI, DOE sought information regarding a wide variety of motors employing fundamentally different designs and technologies. ASAP and NEMA responded by urging DOE to exclude from any potential standards all of the motors listed in Table 2.6 with the exception of Totally Enclosed Air-Over (TEAO) motors. (ASAP and NEMA, No. 20 at p. 4) In subsequent communications with DOE, these parties modified their views in favor of not covering TEAO motors from standards.

**Table 2.6 Electric Motors Excluded from Expanded Scope of Coverage**

| **Electric Motor Description** | |
|---|---|
| Totally-Enclosed Air Over (TEAO) | Direct current |
| Component sets | Single phase |
| Intermittent duty | Liquid cooled |
| Inverter-only duty | Submersible |
| Multispeed | - |

Additionally, the CDA commented that some of the electric motors in Table 2.6, such as inverter-only duty motors and TEAO motors, should be included and new test procedures provided because of their increasing shipment volumes. (CDA, No. 18 at p. 2) However, the CDA did not provide any additional information on what such test procedures might entail.

At this time, DOE is not including any of these types of electric motors in its expanded scope of coverage. DOE understands that some of the motors listed in Table 2.6 would require extensive modifications to the currently accepted test procedures. TEAO, liquid cooled, and submersible motors are all continuous-duty motors, but are required to operate in special environments, such as underwater or in an area with a minimum amount of airflow, to prevent the motors from overheating during continuous duty operation. IEEE 112B and CSA C390 are designed to test motors with self-contained cooling devices, such as a totally enclosed fan-cooled motors, and do not present procedures for the testing of motors in specialized environments.

Other motors, such as intermittent duty and inverter-only duty motors, are not capable of continuous-duty operation and, therefore, never reach a steady-state temperature which IEEE 112B requires for certain calculations. Direct current and single-phase motors do not run on AC, polyphase sinusoidal power, which is also required for IEEE 112B. Additional information on each of these motor types can be found in chapter 3 of the preliminary TSD.

### 2.3.4 Advanced Electric Motor Systems

The motor systems listed in Table 2.7 are systems that DOE tentatively views as "advanced electric motor systems." DOE believes that these systems are advanced motor systems because there are significant differences between these motors or controllers and general purpose motors that run directly on a polyphase, AC sinusoidal bus discussed in section 2.3.2. DOE believes that if it were to include these types of motors as part of its standards analysis, extensive test procedure changes would be required because they have drastically different electromechanical properties relative to squirrel-cage induction motors and they do not run directly off of polyphase, AC sinusoidal power sources, which is required for testing with IEEE

112B. Generally, DOE understands that there are no current test procedures for these "advanced electric motor systems," but seeks comment on the potential for significant energy savings with these motor systems. DOE's preliminary findings on these motors are discussed below.

**Table 2.7 Advanced Electric Motor Systems**

| **Motor Description** |
|---|
| Inverter Drives |
| Permanent magnet motors |
| Electrically commutated motor |
| Switched reluctance motors |

*Inverter Drives*

The current scope of coverage includes motors with a single, constant rotational speed. A motor's rotational speed is determined by the frequency of the power source, as well as the pole configuration of the motor. The equation determining a motor's speed is:

$$Speed\ of\ motor = \frac{120 * (Frequency\ of\ power\ source)}{Number\ of\ Motor\ Poles}$$

Inverter drives, also called variable-frequency drives (VFDs), variable-speed drives, adjustable frequency drives, AC drives, microdrives, or vector drives, work by changing the frequency of the power source fed into an electric motor. The equation above shows that controlling the frequency of the power source of a motor allows the user to control the speed of that motor. One of the biggest advantages of a VFD is the ability to reduce the speed of a motor when the full, nameplate-rated speed is not needed. This practice can save energy over a motor's lifetime. VFDs can also control start-up characteristics of motors, such as locked-rotor current or locked-rotor torque, which allows motors to achieve higher efficiencies when running at rated speed.[i]

DOE is aware of the energy saving potential of motors that run on VFDs[j,k]. However, DOE does not know of any relevant test procedures for testing motors run on a VFD. IEEE 112B requires a motor to be tested at its nameplate-rated speed, but motors only capable of running on an inverter will not have a nameplate rated speed. DOE requests information on whether a test procedure, which accounts for the entire motor system, including the VFD, is being developed.

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[i] Li, Harry. *Impact of VFD, Starting Method and Driven Load on Motor Efficiency*. 2011.Siemens Industry, Inc.
[j] S. Dereyne, K. Stockman, S. Derammelaere, P. Defreyne. *Variable Speed Drive Evaluation Using Iso Efficiency Maps*. 2011. Technical University College of West-Flanders. Department of Electrical Energy, Systems and Automation, Ghent University.
[k] Rajagopalan, Satish, Vairamohan, Baskar Vairamohan, and Samotyj, Marek. *Electric Motors for the Modern World - A Look at New Motor Technologies and New Applications*. 2011. Electric Power Research Institute (EPRI)

*Permanent Magnet Motors*

In both polyphase AC induction motors and permanent magnet motors, the stator is energized by three-phase alternating current, which induces a magnetic field that rotates around the stator. This rotating magnetic flux induces a voltage in the squirrel-cage rotor, which in turn creates a current in the squirrel-cage rotor. These currents then create an opposing magnetic field in the rotor that causes it to rotate at a slower speed than the stator field.[l] In permanent magnet motors, the rotor uses an embedded permanent magnet to create a constant magnetic field that causes the rotor to rotate as the stator magnetic field rotates. Since the rotor is rotating at the same speed as the rotating stator field, the motor can be referred to as a synchronous motor. Permanent magnet motors have several advantages over AC induction motors including a higher efficiency potential, higher power/torque density, lower operating temperature, smaller size and quieter operation.[m] In AC induction motors, some of the stator current is used to induce rotor current in order to produce magnetic flux in the rotor. These additional currents generate heat in the motor, leading to increased losses. Permanent magnet motors, on the other hand, do not require a current in the rotor to produce magnetic flux since the flux is already provided by the permanent magnets. With no current in the rotor there are no rotor losses, which contributes to the high efficiency of permanent magnet motors.

Permanent magnet motors can be classified into two major groups: those with permanent magnets mounted on the surface of the rotor and those with permanent magnets placed in the interior of the rotor core. Surface permanent magnet (SPM) motors employ arc-shaped magnets glued or secured to the outer surface of the rotor core. This arrangement is not as structurally robust as the arrangement used in interior permanent magnet (IPM) motors, which instead have their permanent magnets placed inside of slots made in the interior of the laminated rotor core, thereby increasing retention of the magnet during high-speed operation compared to SPM designs. Different magnet grades are used in permanent magnet motors, with ceramic-ferrites and rare-earth metals being the most common choices. Although rare-earth magnets are more expensive than ceramic-ferrites, they have a higher magnetic energy density which permits increased energy output from a motor. However, the market for rare-earth metals is highly concentrated, with the vast majority of supply coming from China.[n] Wide-spread adoption of permanent magnet motors could be hindered by the inability of suppliers to respond to increased global demand as well supply disruptions caused by Chinese export policy.

Synchronous motors are typically not capable of starting from a fixed frequency AC power source. If the rotor is stationary when the stator field starts rotating at full speed, the rotor will not develop enough starting torque to overcome its own inertia. One popular method for overcoming this constraint is to use a VFD to start the motor. By increasing the frequency of the

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[l] When a motor operates with the rotor rotating at a speed slower than the rotating stator field, it is considered to be "asynchronous."

[m] Rajagopalan, S., B. Vairamohan, and M. Samotyj. *Electric Motors for the Modern World - A Look at New Motor Technologies and Applications.* 2011. Electric Power Research Institute: Palo Alto, CA.

[n] U.S. Department of Energy. *Critical Materials Strategy*. December 2011. Washington, DC.

AC signal from zero to the desired running speed, the rotor is able to operate at synchronous speed with the accelerating stator field. This method of starting has the added benefit of the energy savings associated with adjustable speed control as discussed in section 2.3.2. Alternatively, some designs of interior permanent magnet motors incorporate a squirrel cage in the rotor, allowing the rotor to start across-the-line like an AC induction motor. These types of self-starting motors are called line start permanent magnet (LSPM) motors. During the motor transient start up, the squirrel cage in the rotor contributes to the production of enough torque to start the rotation of the rotor, albeit at an asynchronous speed. When the speed of the rotor approaches synchronous speed, the constant magnetic field of the permanent magnet locks to the rotating stator field, thereby pulling the rotor into synchronous operation. LSPM motors would be suitable in applications where the higher efficiency of permanent magnet motors is desired, but for which the added cost of a VFD remains prohibitive.

DOE is aware of the energy saving potential of permanent magnet motors. DOE does not know of any relevant test procedures for testing these motors. IEEE 112B is specific to polyphase induction motors and does not specify how to segregate losses for permanent magnet motors. The DOE requests comment on the potential energy savings from permanent magnet motors, as well as any relevant test procedures that are used to measure the efficiency of these motors. DOE also seeks information regarding whether already existing test procedures could be modified to test the efficiency of these motors, including specific recommendations as to how to modify those procedures.

*Electronically Commutated Motors*

Electronically commutated motors (ECMs), also called brushless DC motors, are permanent-magnet synchronous motors combined with an on-board electronic controller that can measure and regulate the motor’s performance. The commutator in older, brushless motors previously consisted of a rotary mechanical component that manipulated the power being fed to the stator. In ECMs, an electronic microprocessor controls the rotary mechanical component − and, consequently, the power supply. The use of the microprocessor permits greater customized control over motor performance. Some ECMs run on a DC power supply, while others run on a single phase or polyphase AC power supply which is rectified (i.e., converted) to DC power in the motor’s controllers. The microprocessor in the motor control converts this DC power into a trapezoidal three-phase AC signal (unlike the sinusoidal AC signal used to power the permanent magnet motors discussed in the previous paragraph), inducing a rotating magnetic field in the stator windings. The rotor uses an embedded permanent magnet to create a constant magnetic field that causes the rotor to rotate as the stator magnetic field rotates. The position of the rotor is monitored by a microprocessor, which adjusts the magnetic fields in the stator to achieve the desired operating speed and torque. The motor can also communicate its status to the equipment it is powering, offering instant feedback of the unit’s performance.

Like other types of permanent magnet synchronous motors, ECMs have several advantages over AC induction motors due to their higher efficiency, higher power/torque density, lower operating temperature, smaller size and quieter operation. ECMs also offer adjustable speed control with their programmable electronics, which can save energy in a manner similar to VFDs, which are discussed earlier in this section. However, the inclusion of programmable electronic controls also increases the cost of manufacturing an ECM.

However, DOE does not know of any relevant test procedures for testing electronically commutated motors. IEEE 112B requires that a motor be tested at its nameplate rated speed. However, motors capable of only being run on an electronic commutator will not have a nameplate rated speed because they are variable speed motors and can be run at a range of speeds as specified by the user. Additionally, the electronic commutator has its own electrical losses which are not accounted for in IEEE 112B. These electrical losses are the result of manipulating the power source into the motor. DOE requests comment on the potential energy savings from electronic commutated motors, as well as any relevant test procedures. DOE also seeks information regarding whether already existing test procedures could be modified to test the efficiency of these motors, including specific recommendations as to how to modify those procedures.

*Switched Reluctance Motors*

Switched reluctance (SR) motors are synchronous motors that operate on the principle of magnetic reluctance. Magnetic reluctance is a measure of the permeability of a given material with respect to magnetic flux. Compared to high reluctance materials, low reluctance materials offer lower resistance to the passage of magnetic lines of force. In a magnetic circuit, the presence of a magnetic field causes magnetic flux to follow the path of least magnetic reluctance. When low reluctance materials (such as iron) are in the presence of a magnetic field, flux will tend to concentrate in the low reluctance material, forming strong temporary poles that cause an attractive force toward regions of higher flux. Just as in a DC motor, the stator in a SR motor consists of wound field coils. Unlike induction and permanent-magnet motors, the rotor does not contain any windings or magnets. The rotor in a SR motor consists of a low reluctance material, such as laminated silicon steel, with multiple projections that act as magnetic poles through magnetic reluctance. An electronic controller is used to energize each phase in sequence. As each phase is energized, the poles of the rotor are drawn to the position of least magnetic reluctance, which occurs when the poles of the stator and rotor are aligned. A full rotation of the rotor can be achieved by sequentially energizing each phase.

SR motors have several advantages over AC induction motors, such as higher efficiency and simpler construction. Unlike permanent-magnet motors, they do not rely on rare-earth magnets in their construction. However, they also have several disadvantages including high torque ripple (the difference between the maximum and minimum torque during one revolution) and noise (associated with torque ripple). Additionally, SR motors cannot be run on commercially available drives that can both operate induction and permanent-magnet motors, a fact that could discourage users who have already invested in VFDs from adopting SR motors.

DOE does not know of any relevant test procedures for testing switched reluctance motors. DOE requests comment on the potential energy savings from switched reluctance motors, as well as any relevant test procedures or the potential to modify the current existing test procedures.

### 2.3.5 Equipment Class Groups and Equipment Classes

Within each set of electric motors it addressed, EISA 2007 prescribed separate energy conservation standards by horsepower, enclosure, and pole configuration. The standards correspond to Table 12-12 of NEMA MG 1-2006 (which is equivalent to NEMA Premium efficiency levels) for subtype I electric motors; and Table 12-11 of NEMA MG1-2006 (which is equivalent to EPACT 1992 efficiency levels for motors from 1 to 200 horsepower and 2 to 6 poles) for subtype II, fire pump electric motors, and NEMA Design B electric motors greater than 200 horsepower. [o] (42 U.S.C. 6313(b)(2))

When DOE amends energy conservation standards, it often divides covered equipment into classes. By statute, these classes are based on: (a) the type of energy used; (b) the capacity of the equipment; or (c) any other performance-related feature that justifies different standard levels, such as features affecting consumer utility. (42 U.S.C. 6295(q)) As a result of changes introduced by EISA 2007, particularly with the addition of general purpose electric motors (subtype II) as a subset of motors covered by the term "electric motor," there are a large number of motor design features that DOE must consider in this rulemaking. In the following sections, DOE discusses a variety of design features that DOE is considering for inclusion as part of its analysis.

Due to the large number of characteristics involved in electric motor design (e.g., horsepower rating, pole-configuration, etc.), DOE currently plans to use two constructs to help develop appropriate energy conservation standards for electric motors: "equipment class groups" and "equipment classes." An equipment class group is a collection of electric motors that share a common design type. Equipment class groups include motors over a range of horsepower ratings, enclosure types, and pole-configurations. Essentially, each equipment class group is a collection of a large number of equipment classes with the same design type. An equipment class represents a unique combination of motor characteristics for which DOE will determine an energy efficiency conservation standard. For example, given a combination of motor design type, horsepower rating, pole-configuration, and enclosure type, the motor design type dictates the equipment class group, while the combination of the remaining characteristics dictates the specific equipment class.

The framework document divided those electric motors that are currently covered by standards (but which did not include all of the motors discussed in section 2.3.2) into ten equipment class groups based on combinations of motor design (NEMA Design A or B, NEMA

[o] In NEMA MG1-2011, the latest version of MG1, two tables were added as extensions to tables 12-11 and 12-12. Table 20A was added as an extension to Table 12-11, which includes efficiency ratings for 6- and 8-pole motors from 300 to 500 horsepower. Similarly, Table 20B was added as an extension to Table 12-12, which also includes efficiency ratings for 6- and 8-pole motors from 300 to 500 horsepower. Additionally, Table 12-12 itself was expanded to include efficiency ratings for 8-pole motors below 200 horsepower. Finally, the actual efficiency values found in these tables have not changed over time for a given rating. For example, the 12-12 (or 12-11) efficiency value for an open, 4-pole, 5 horsepower electric motor is the same in MG1-2006, MG1-2009, and MG1-2011.

Design C, vertical solid shaft normal thrust, or fire pump electric motor), frame type (U- or T-frame), and enclosure (open or enclosed). Based on additional analysis and a review of comments, DOE has reduced this number down to three groups based on two main characteristics: the designated NEMA design letter and whether the motor meets the definition of a fire pump electric motor. DOE's resulting equipment class groups are for NEMA Design A and B motors, NEMA Design C motors, and fire pump electric motors. Within each of these three broad groups, DOE uses combinations of other pertinent motor characteristics to enumerate its individual equipment classes. To illustrate the differences between the two terms, consider the following example. A NEMA Design B, 50 horsepower (hp), 2-pole enclosed electric motor and a NEMA Design B, 100 hp, 6-pole open electric motor would be in the same equipment class group (for the preliminary analysis, group 1), but each would represent a unique equipment class that will ultimately have its own efficiency standard. There are 510 potential equipment classes consisting of all permutations of NEMA design type, standard horsepower ratings, pole configurations, and enclosure types. Table 2.8 outlines the relationships between equipment class groups and the characteristics used to define equipment classes. The following sections discuss a variety of these design features in greater detail.

**Table 2.8 Electric Motor Equipment Class Groups**

| Equipment Class Group | Electric Motor Design | Horsepower | Poles | Enclosure |
|---|---|---|---|---|
| 1 | NEMA Design A & B* | 1-500 | 2, 4, 6, 8 | Open |
| | | | | Enclosed |
| 2 | NEMA Design C* | 1-200 | 2, 4, 6, 8 | Open |
| | | | | Enclosed |
| 3 | Fire Pump* | 1-500 | 2, 4, 6, 8 | Open |
| | | | | Enclosed |

*Including IEC equivalents.

In response to the framework document, NEMA suggested that the number of classes be kept to a minimum when establishing efficiency standards in a manner similar to what Congress did when it separated electric motors into general purpose electric motor (subtype I) and (subtype II). (NEMA, No. 13 at p. 7) NEMA also suggested that when looking at any increase in efficiency levels, coverage should be based on a common set of technology options for the electric motors covered. (NEMA, No. 13 at p. 3) Table 2.8 presents a simplified version of the ten equipment class groups presented during the framework stage of the analysis. The technical basis for the simplified groups is described in the following paragraphs. DOE requests comment on these simplified groups.

NEMA also asserted that it did not appear that DOE intends to establish separate equipment class groups for general purpose subtype I and subtype II electric motors. (NEMA, No. 13 at p. 3) NEMA is correct. DOE based its groups in Table 2.8 on the NEMA design types (NEMA Design A, B, or C) rather than the characteristics designating a motor as subtype I or II. Because DOE is considering expanding the scope of coverage to include motors beyond just general purpose electric motors, it decided not to base equipment class groupings on subtype I and subtype II definitions. This approach would allow DOE to simplify its expansion of scope of coverage to include all NEMA Design A, B, or C continuous, polyphase, squirrel cage induction motors. Additionally, DOE understands that certain criteria that were used to delineate subtype I and subtype II motors do not have any effect on motor efficiency, such as a motor being footless.

#### 2.3.5.1 Electric Motor Design

The NEMA Standards Publication MG1-2011, "Motors and Generators," defines a series of standard electric motor designs that are differentiated by variations in performance requirements (See NEMA MG1-2011, paragraph 1.19.1). NEMA MG1 defines Designs A, B, and C electric motors, which constitute all NEMA defined electric motors covered by this preliminary analysis. These designs are categorized based on performance requirements for full-voltage starting and developing locked-rotor torque, breakdown torque, and locked-rotor current, all of which affect an electric motor's utility and efficiency.

NEMA Design A and NEMA Design B electric motors have different locked-rotor current requirements. Whereas NEMA Design A electric motors have no locked-rotor current limits, NEMA Design B electric motors are required to stay below maximum levels specified in NEMA MG1-2011 paragraph 12.35.1. This tolerance for excess current will allow NEMA Design A motors to reach the same efficiency levels as NEMA Design B with fewer design changes and constraints. Therefore, DOE has preliminarily concluded that the potential efficiency differences between NEMA Design A and B electric motors are not significant enough to warrant a separate equipment class group for these two NEMA Design types.

DOE also notes that Congress held NEMA Design A and NEMA Design B motors to the same energy conservation standards in both EPACT 1992 (Pub. L. No. 102–486) and EISA 2007 (Pub. L. No. 110–140).[p] However, DOE believes that the different torque requirements for NEMA Design C electric motors represent a change in utility that can affect efficiency performance. The difference in torque requirements will restrict which applications can use which NEMA Design types. As a result, NEMA Design C motors cannot always be replaceable with NEMA Design A or B motors, or vice versa. For the framework document, DOE had taken an approach similar to the approach in EPACT 1992 and EISA 2007. DOE considered NEMA Design A and B motors in a group together, while placing NEMA Design C motors in their own equipment class group.

Comments from Baldor and NEMA suggested that by grouping NEMA Design A and B electric motors together, DOE should be aware that increasing locked-rotor current requires other design changes, such as the inclusion of protective devices into a given motor design, so potential efficiency increases should be based on the more restricted motors − i.e. NEMA Design B electric motors. (Baldor, Public Meeting Transcript, No. 14 at p. 77; NEMA, No. 13 at p. 4)

[p] EPACT 1992 defined "electric motor" to include both NEMA Design A and Design B motors and established standards for such motors. Similarly, EISA 2007 included NEMA Design A and Design B motors in the definition of "general purpose electric motor (subtype I)" and established standards for such motors.

Per NEMA MG1, Design B electric motors are designed with more stringent design constraints than NEMA Design A electric motors. As mentioned, NEMA Design B motors have limits on locked-rotor current whereas NEMA Design A motors do not. This design requirement constrains the potential energy efficiency improvements that can be made for NEMA Design B motors relative to NEMA Design A motors. Because of these design constraints, and as discussed further in the engineering analysis section of this preliminary TSD, DOE conducted its analysis using NEMA Design B electric motors as the representative unit for equipment class group 1. By doing so, DOE ensured that all electric motors within equipment class group 1 (i.e., NEMA Design A and B motors) would be capable of reaching all of the efficiency levels analyzed.

The CDA supported this approach and cited the low shipment volumes of NEMA Design A electric motors as another reason for analyzing NEMA Design A and B motors together. (CDA, No. 18 at p. 2) DOE agrees and, as is demonstrated in its shipments analysis (preliminary TSD chapter 9), NEMA Design B electric motors constitute an overwhelming majority of electric motor shipments. Because of this fact, DOE projects that minimal energy savings would be likely to result from separating NEMA Design A motors into another equipment class group.

Finally, NEMA asserted that there are no performance standards – minimum locked-rotor torque, breakdown torque, or pull-up torque – that define a NEMA Design C electric motor either in a 2-pole configuration or greater than 200 hp in NEMA MG1-2009. (NEMA No. 13 at p. 4) In other words, in its view, because NEMA itself has not prescribed the particular operating performance characteristics and standards for Design C motors in either a 2-pole configuration or with a rating greater than 200 horsepower, there can be no motor with either of these configurations that can be considered a NEMA Design C motor.

In spite of NEMA's claim, DOE has found numerous instances where manufacturers offer for sale electric motors with a horsepower rating greater than 200 advertised as NEMA Design C electric motors. For this stage of the analysis, DOE has not examined efficiency levels for NEMA Design C electric motors over 200 hp or in a 2-pole configuration. However, DOE requests public comment on whether electric motors that are labeled as NEMA Design C electric motors, but that are outside the defined performance standards for NEMA Design C electric motors in NEMA MG1-2009 (now NEMA MG1-2011), can be considered Design C motors. The metric for including these NEMA Design C motors may be comparing performance characteristics to other industry standards, using a relative deviation from the corresponding performance requirements for high horsepower NEMA Design A or B motors, or some other metric.

#### 2.3.5.2 Horsepower Rating

Horsepower is a critical performance attribute of an electric motor that is directly related to the capacity of an electric motor to perform useful work. Additionally, efficiency generally scales with horsepower. In other words, with all else equal, a 50 hp electric motor is usually more efficient than a 10 hp electric motor. Because there is a direct correlation between horsepower and efficiency, DOE preliminarily used horsepower rating as a criterion for distinguishing equipment classes in the framework document and continues with that approach for the preliminary analysis.

DOE received public comments advocating that NEMA Design A and B electric motors from 1 horsepower through 500 horsepower meet the same efficiency level rather than continuing to use the 200 horsepower mark set forth in EISA 2007. (ACEEE, Public Meeting Transcript, No. 14 at p. 18; Baldor, No. 8 at p. 2) DOE agrees with this approach and has preliminarily adopted a simplified approach that does not separate the NEMA Design A and B motors at any particular horsepower rating.

#### 2.3.5.3 Pole Configuration

The number of poles in an induction motor determines the synchronous speed (i.e., revolutions per minute) of that motor. There is an inverse relationship between the number of poles and a motor's speed. As the number of poles increases from two to four to six to eight, the synchronous speed drops from 3,600 to 1,800 to 1,200 to 900 revolutions per minute, respectively. In addition, manufacturer feedback and independent analysis indicated that the number of poles has a direct impact on the electric motor's performance and achievable efficiency because some pole configurations utilize the space inside of an electric motor enclosure more efficiently than other pole configurations. DOE used the number of poles as a means of differentiating equipment classes in the framework document and has maintained this approach in the preliminary analysis.

Baldor commented that there are currently no standardized NEMA efficiency values for 8-pole motors in NEMA MG1-2009 Table 12-12, which equates to the NEMA Premium efficiency level. (Baldor, Public Meeting Transcript, No. 14 at p. 140) Baldor added that NEMA is developing efficiency levels for these motors and hopes to have them completed before DOE's final rule is published (Baldor, Public Meeting Transcript, No. 14 at p. 140). At this time, NEMA MG1-2011 has been updated to include efficiency ratings for 8-pole motors in Table 12-12. DOE has used these updated efficiency values for its analysis.

#### 2.3.5.4 Enclosure Type

EISA 2007 prescribes separate energy conservation standards for open and enclosed electric motors. (42 U.S.C. 6313(b)(1)) Electric motors manufactured with open construction allow a free interchange of air between the electric motor's interior and exterior. Electric motors with enclosed construction have no direct air interchange between the motor's interior and exterior (but are not necessarily air-tight) and may be equipped with an internal fan for cooling (see NEMA MG1-2011, paragraph 1.26). Whether an electric motor is open or enclosed affects its utility in that open motors are generally not used in harsh operating environments, whereas totally enclosed electric motors often are. The enclosure type also affects an electric motor's ability to dissipate heat (the open motors' free air exchange allows for better thermal dissipation), which enables open motors to achieve higher efficiency levels than their enclosed counterparts. DOE used an electric motor's enclosure type (open or enclosed) as an equipment class setting criterion in the framework document and, having received no comments regarding this approach, it continued to use this criterion in the preliminary analysis.

As discussed previously, DOE plans to include TENV motors in its expanded scope of coverage. DOE understands that TENV motors may have characteristics that may affect efficiency, namely the higher operating temperature of the motor. However, at this time, DOE does not believe that these higher operating temperatures will prevent the motors from being able to meet the same efficiency standards as typical enclosed motors and, thus, warrant a separate equipment class group. This preliminary decision is based on a review of catalog data and the range of efficiencies offered for TENV motors, as well as manufacturer feedback advocating the inclusion of TENV motors in the expanded scope of coverage. DOE requests comments regarding this preliminary decision to not establish a separate equipment class group for TENV motors.

#### 2.3.5.5 Frame Type

EISA 2007 prescribed energy conservation standards for electric motors built with a U-frame, whereas previously only electric motors built with a T-frame were covered.[q] (Compare 42 U.S.C. § 6311(13)(A)(1992) with 42 U.S.C. §6311(13)(B)(2011) In general, for the same combination of horsepower rating and pole configuration, an electric motor built in a U-frame is built with a larger "D" dimension than an electric motor built in a T-frame. The "D" dimension is a measurement of the distance from the centerline of the shaft to the bottom of the mounting feet. In the framework document, DOE separated T-frame and U-frame electric motors into separate equipment class groups because U-frame motors have a larger frame size than T-frame motors of the same rating. DOE believed that this frame size increase for U-frame electric motors could lead to higher efficiencies relative to T-frame motors.

Baldor commented that it manufactures only a low volume of U-frame electric motors. Baldor and NEMA noted that most U-frame electric motor customers, who are in the automotive industry, purchase these motors to replace current U-frame motors in existing applications − not for new installations. (Baldor, No. 8 at p. 4; NEMA, No. 19 at p. 6) Baldor added that these automotive companies previously specified that all U-frame electric motors used in their plants meet certain efficiency levels that were lower than those set in EISA 2007. However, as EISA 2007 expanded coverage to include these motors, that trend is changing and Baldor noted that U-frame motors, because of their larger frame size, could be designed to meet the same efficiency levels as T-frame motors. Baldor also stated that, despite the possibility of being redesigned and made more efficient, U-frame electric motors were viewed as outdated and being phased out. (Baldor, Public Meeting Transcript, No. 14 at pp. 126-127, 132-133) Finally, NEMA concluded that efficiency differences between U-frame and T-frame electric motors are negligible. (NEMA, No. 19 at p. 6)

While DOE recognizes that automotive manufacturers may set their own specifications for the U-frame motors used in their plants, DOE's standards set the minimum efficiency levels that a given covered motor would be required to meet. As a result, any standards that DOE may set for U-frame motors are likely to have a substantially broader and more significant impact

[q] The terms "U-frame" and "T-frame" refer to lines of frame size dimensions, with a T-frame motor having a smaller frame size for the same horsepower rating as a comparable U-frame motor. In general, "T" frame became the preferred motor design around 1964 because it provided more horsepower output in a smaller package.

than the internal requirements of a particular industry. DOE also notes that those requirements may vary by manufacturer or plant, a factor that could reduce the impact of any projected benefits of these manufacturer requirements. Regarding the phasing out of U-frame motors, DOE largely agrees with this assessment based on the limited amount of information it has reviewed. That fact notwithstanding, DOE believes that, due to their larger frame size, a U-frame electric motor should be able to achieve any efficiency that identically or similarly-rated T-frame electric motor can. (Larger sized motors are capable of being more efficient because they can use more electrical steel which, in turn, can help lower core losses).

DOE also received feedback during manufacturer interviews indicating that increased efficiency levels for U-frame electric motors may cause them to exit the market rather than invest the money to design a more efficient U-frame electric motor. Manufacturers cite a lack of profit in this sector as a reason for exiting it rather than spending more money on research and development to increase U-frame motor efficiency. DOE is aware of such limiting factors.

Based on comments received during the framework meeting and manufacturer interviews, DOE is combining U-frame and T-frame electric motors in the same equipment class for the following reasons:

1) U-frame electric motors have a very small and shrinking market share of less than 3 percent, as they are being phased-out of production. Because of this trend toward T-frame electric motors, NEMA has removed any discussion of U-frame electric motors in MG1 in favor of T-frame electric motors.

2) A U-frame design electric motor does not have unique utility when compared to its smaller equivalent in a T-frame design. In general, a T-frame design could replace an equivalent U-frame design with minor modification of the mounting configuration for the driven equipment. By comparison, a U-frame design that is equivalent to a T-frame design would require substantial modification to the mounting configuration for the same piece of driven equipment.

3) Available market data indicate that for the range of horsepower ratings that are covered by the scope of motors examined in preparation of this preliminary analysis, T-frame electric motors are already being manufactured with higher efficiencies than their U-frame counterparts.

#### 2.3.5.6 Vertical Electric Motors

EISA 2007 also prescribed energy conservation standards for vertical solid shaft normal thrust electric motors as tested in a horizontal configuration. (42 U.S.C. § 6311(13)(B)(v)) Additionally, DOE is contemplating expanding its scope to include vertical motors of all configurations and shaft types (solid or hollow). These electric motors are most often found as NEMA Design A and NEMA Design B electric motors in a wide range of horsepower ratings and in all four pole configurations currently covered by subpart B of 10 CFR Part 431. One of the major differences between these vertical-mounting electric motors and typical horizontal-mounting general purpose electric motors is the P-base mounting.[r] Additionally, as its name suggests, these electric motors operate while mounted vertically, but are tested while mounted horizontally (as mandated by EISA 2007). In the framework document, DOE considered using this design characteristic to disaggregate equipment class groups.

In response to the framework document, NEMA asserted that any efficiency standard for vertical solid shaft normal thrust electric motors should be based on the efficiency level measured when the motor is tested in the horizontal position. (NEMA, No. 13 at p. 5) According to NEMA, test facilities may not be capable of testing in a vertical position, and testing in a horizontal configuration negates the vertical thrust loads on the bearings, which may affect efficiency levels. (NEMA, No. 13 at p. 5) Baldor commented that not only should vertical electric motors be included in the scope, but added that the efficiency level that can be obtained by vertical solid shaft normal thrust electric motors when tested in a horizontal configuration is the same as that for a normal (horizontal) mounted electric motor. (Baldor, Public Meeting Transcript, No. 14 at pp. 85, 127; Baldor, No. 8 at p. 4) Baldor stated that vertical electric motors use the same stator and rotor parts as horizontal configuration motors, but they have a different bearing support system that enables the motor to run in a vertical position. Therefore, Baldor believes there is no reason that these motors cannot achieve the same efficiencies as their horizontal counterparts (Baldor, No. 8 at p. 4)

As mandated by EISA 2007, all vertical solid shaft normal thrust motors are to be tested in a horizontal configuration (42 U.S.C. § 6311(13)(B)(v)). Although DOE believes a change in utility affecting performance, including efficiency, occurs when these electric motors are operated while mounted vertically, the horizontal testing requirement will allow these electric motors to be required to meet the same efficiency standards as normal, horizontal, electric motors tested in a horizontal position. DOE does not believe that there is any electromechanical difference between vertical-mounting and horizontal-mounting electric motors − instead, the difference is based solely on how these motors are operated in the field. Therefore, because EISA 2007 requires that these motors be tested horizontally and these electric motors are electromechanically equivalent to typical, horizontal electric motors, DOE has tentatively decided to eliminate the vertical position as an equipment class setting criterion in the preliminary analysis.

As previously mentioned, DOE is planning to expand the scope of coverage to include all vertical-mounting electric motors, including hollow shaft, solid shaft, and other vertical motors of any thrust configuration. However, DOE still plans to eliminate the vertical configuration as a class setting criterion in the preliminary analysis. DOE does not believe there are any electromechanical differences between hollow shaft and vertical shaft motors or vertical motors with different thrust configurations when horizontally mounted using antifriction bearings for

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[r] A P-base mounting configuration is the typical mounting configuration for vertically mounted motors. The P-base mounting configuration generally takes the place of the horizontal foot-mounting configuration for vertical motors.

testing. Therefore, DOE maintains that these characteristics are not necessary as equipment class setting criteria in the preliminary analysis. DOE requests feedback on the decision not to use the vertical motor configuration (whether hollow shaft, vertical solid shaft, or thrust configuration variations) as equipment class setting criteria.

### 2.3.5.7 Thrust or Sleeve Bearings

DOE's planned expansion of coverage includes motors with thrust or sleeve bearings. DOE understands that thrust bearings are primarily used on vertical motors, but may also be used on horizontal motors in the form of angular bearings. DOE does acknowledge that thrust bearings may degrade efficiency. However, by statute, vertical motors are to be tested in a horizontal configuration. Thrust bearings cannot properly operate in a horizontal position, and for this reason, motors that are tested in a horizontal configuration will likely have its thrust bearings replaced with regular, anti-friction ball bearings for testing purposes. The absence of thrust bearings during testing drives DOE's decision not to use thrust bearings as a class setting criterion in the preliminary analysis.

DOE also plans on expanding the scope to cover motors with sleeve bearings. Sleeve bearings are typically used on fractional horsepower motors or motors over 400 horsepower. Sleeve bearings are used as an alternative to ball bearings due to their longer life and suitability for direct-connect applications. DOE consulted with testing laboratories, subject matter experts, technical papers, and manufacturers and determined that sleeve bearings do not significantly affect efficiency and therefore DOE has not established a separate equipment class group for these motors.[s]

DOE requests feedback on the decision not to use thrust bearings or sleeve bearings as equipment class setting criteria.

### 2.3.5.8 Close-Coupled Pump Electric Motor

EISA 2007 prescribed energy conservation standards for close-coupled pump electric motors. (42 U.S.C. § 6311(13)(B)) These electric motors can be purchased as NEMA Design A, Design B, or Design C electric motors, and are usually in two- or four-pole configurations. Close-coupled pump electric motors are frequently built with different shafts than a typical general purpose electric motor. Although these shafts may represent a separate utility, such as allowing the motor to be coupled to a pump, DOE does not believe that this change significantly affects the efficiency of the electric motors because shaft geometry does not affect the electromechanical functions of an electric motor. Therefore, DOE preliminarily decided not to use this motor characteristic as an equipment class setting criterion in the framework document.

[s] William R. Finley and Mark. M Hodowanec. Sleeve Vs. Anti-Friction Bearings: Selection of the Optimal Bearing for Induction Motors. 2001. IEEE. USA.

Interested parties indicated that close-coupled pump electric motors generally have long running times and are similar to other general purpose electric motors (subtype II). Because of these factors, these commenters asserted that close-coupled pump motors should be required to meet the NEMA Premium efficiency levels that subtype II motors must currently meet. (Baldor, Public Meeting Transcript, No. 14 at p. 83; NEMA, No. 13 at p. 4) DOE is unaware of any specific design constraints that would prevent close-coupled pump electric motors from reaching NEMA Premium efficiency levels. Therefore, DOE is not using this characteristic as an equipment class setting criterion for the preliminary analysis and DOE has not performed a separate engineering analysis on close-coupled pump electric motors.

DOE requests feedback on the decision not to use this characteristic as equipment class setting criteria.

#### 2.3.5.9 Fire Pump Electric Motors

EISA 2007 prescribed energy conservation standards for fire pump electric motors. (42 U.S.C. § 6313(b)(2)(B)) As stated previously, DOE adopted a definition of "fire pump electric motor," which incorporated portions of National Fire Protection Association Standard (NFPA) 20, "Standard for the Installation of Stationary Pumps for Fire Protection" (2010). Pursuant to NFPA 20, these electric motors must comply with NEMA Design B performance standards. In addition to meeting the performance requirements for NEMA Design B electric motors, fire pump electric motors must continue running even if the electric motor is overheating or may be damaged due to continued operation. These additional requirements for fire pump electric motors constitute a change in utility that DOE believes could also affect their performance and efficiency. Therefore, DOE contemplated examining fire pump electric motors in their own equipment class group in the framework document.

Interested parties indicated that fire pump electric motors run for very few hours each year and do not present a significant opportunity to reduce energy consumption. (Baldor, No. 8 at p. 4) Regardless, interested parties expressed concern that they may be exploited as a means to circumvent efficiency standards. (ASAP and NEMA, No. 12 at p. 4) While DOE seeks to simplify equipment class groups, it recognizes that fire pump electric motors are defined, in part, by the NFPA 20, Standard for the Installation of Stationary Pumps for Fire Protection, 2010 Edition, and have a unique utility that differentiates them from other NEMA Design B electric motors. As such, DOE is also aware of the unique safety and operating requirements for fire pump motors, as defined under chapter 9 of NFPA 20, Electric Drive for Pumps, and the relatively low operating time for a fire pump electric motor. In view of the foregoing, DOE is considering the possibility of setting efficiency levels for fire pump electric motors at a level that would help close potential loopholes in the efficiency standards. Therefore, the preliminary analysis includes polyphase, single speed continuous fire pump electric motors as a separate equipment class group.

### 2.3.5.10 Voltage

EISA 2007 also expanded the range of voltages under which polyphase electric motors operate and are required to meet energy conservation standards. (42 U.S.C. § 6311(13)(B)) In addition to the currently regulated polyphase electric motors that operate at 230 and 460 volts, EISA 2007 added all other polyphase electric motors operating at voltages less than 600 volts. Currently, electric motors designed to run on 230 volts or 460 volts are required to meet the same efficiency standards. DOE understands that this is the case because design voltage does not have a bearing on an electric motor's efficiency capability. This is not to say that DOE believes that an electric motor specifically designed to run on 460 volts will perform as well, in terms of efficiency, if run on 575 volts. Rather, DOE believes that an electric motor designed to run on 575 volts can perform as well (in terms of efficiency) as an otherwise equivalent electric motor designed to run on 460 volts. This is corroborated by the fact that NEMA and ASAP recommended that all motors with a voltage of 600 or less should be set to the same efficiency levels. (ASAP and NEMA, No. 12 at p. 7) Since DOE does not believe that a motor's voltage impacts its efficiency, DOE does not plan to use it as an equipment class setting criterion in the preliminary analysis.

Baldor urged DOE to exclude non-standard voltage levels that, in its view, were never meant to be regulated. (Baldor, Public Meeting Transcript, No. 14 at p. 78) It noted that including a wide range of voltages may inadvertently cover variable-frequency motors used with variable-speed controls, which often have non-standard voltage ratings. (Baldor, Public Meeting Transcript, No. 14 at pp. 78-79) Baldor also commented that voltages such as 575 volts are already covered at NEMA Premium levels. (Baldor, Public Meeting Transcript, No. 14 at p. 83) DOE clarifies that, based on materials it has reviewed, an electric motor designed for a non-standard voltage or that is used with a variable-speed controller does not preclude that electric motor from current standards coverage as either a general purpose electric motor (subtype I) or a general purpose electric motor (subtype II), so long as such voltage rating or controller does not signify that such a motor is a special or definite purpose electric motor. (Should DOE decide to apply standards to special or definite purposes electric motors, this standards coverage gap would be closed.) Baldor's comment reinforces this view − i.e., that voltage changes do not affect efficiency levels of the electric motors discussed in this scope. To aid in its understanding of the industry's classification process, DOE requests additional information on variable-frequency motors and how the electric motor industry classifies such motors.

Finally, NEMA commented on the expanded scope of coverage to all voltages not more than 600 volts that resulted from EISA 2007's amendments. NEMA recommended that DOE should consider the standard voltages for U.S. power systems in developing equipment classes or as a criterion applicable to all equipment classes and that should be included in the definition of "electric motor" in 10 CFR 431.12. (NEMA, No. 13 at p. 5) But because voltage ratings have no bearing on the efficiency potential for an electric motor, DOE does not believe it is necessary to establish different equipment classes and accompanying standards for electric motors designed for different voltages. Since this standard, if adopted, would only apply to those electric motors sold or imported into the United States, DOE believes that the standard voltages for U.S. power systems will be inherent to the electric motors. Therefore, DOE decided not to use operating voltage as an equipment class setting criterion in the preliminary analysis.

#### 2.3.5.11 Mounting Feet

Mounting feet refer to external attachments on the electric motor housing that secure the electric motor to a mounting base. They are external to the electric motor housing and play no role in how an electric motor operates and therefore DOE did not use this characteristic as an equipment class setting criterion in the framework document.

NEMA commented that Congress distinguished between footed and footless electric motors, such as C-face mounting or D-flange mounting, when it created a specific classification for footless motors under the subtype II motor designation. NEMA agreed that mounting feet have no effect on efficiency and therefore do not require a separate analysis from general purpose electric motors. (NEMA, No. 13 at p. 6) While mounting feet will have no impact on the efficiency of a given motor, in NEMA's view, this feature can impact the installation cost of footless electric motors because consumers will have to find alternate means to secure the electric motor to a base and DOE should account for this factor in its analysis. (NEMA, No. 13 at p. 6) Baldor also commented that footless electric motors are currently at a separate efficiency level than their footed counterparts and it may be difficult determining at which efficiency level to start when grouping footed and footless electric motors together. (Baldor, Public Meeting Transcript, No. 14 at pp. 79-80)

DOE believes that a footless electric motor has no electromechanical differences from its footed counterparts. The only difference between these motors would be the mounting configuration, which affects a motor's overall utility to the end user. In DOE's view, the presence of that feature alone is insufficient to warrant a separate equipment class because it has no effect on the electromechanical workings of the electric motor and therefore will not affect efficiency. Consequently, in DOE's view, there should be no added difficulty in designing a footless motor to meet the same efficiency level as a motor equipped with feet. In the life-cycle cost analysis, DOE estimates life-cycle cost savings between baseline efficiency motors and higher efficiency motors of the same configuration and footless and footed motors are not compared against each other. Further, DOE found no evidence that installation costs would increase with higher electric motor energy efficiency (see section 2.8.4). Therefore, DOE did not incorporate changes in installation costs for electric motors that are more efficient than baseline equipment. However, because footless electric motors (subtype II) are at a lower efficiency level than subtype I motors, DOE will account for this distribution of efficiencies currently available in the market when it conducts the national impact analysis. Please refer to preliminary TSD chapter 10 for additional details on how DOE accounts for this condition.

### 2.3.6 Market Assessment

For the market assessment, DOE researches manufacturers, trade associations, and the quantities and types of equipment sold and offered for sale. Issues addressed in this market assessment included: (1) national electric motor shipments, (2) identification of the largest companies in the electric motor industry, (3) existing non-regulatory efficiency improvement initiatives, (4) developments around standards in States and neighboring countries, and (5) trends in equipment characteristics and retail markets. The information collected serves as resource material that DOE uses throughout the rulemaking. Detailed information can be found in chapter 3 of the preliminary TSD.

#### 2.3.6.1 National Shipments Estimate

DOE estimates the annual electric motor shipments to prepare an estimate of the national impact of energy conservation standards for electric motors. Unit shipments are calculated for each horsepower rating within each equipment class. The foundation for DOE's shipment estimate comes from market research reports, interested parties' responses to the Request for Information (RFI) published in the Federal Register (76 FR 17577 (March 30, 2011)), and stakeholder input.[t]

Table 2.9 shows a summary of the 2011 shipments of motors in scope DOE estimated. For more information on annual and historical shipments please refer to the "Shipments Analysis" chapter of this preliminary TSD (Chapter 9) and section 2.9.

**Table 2.9 Estimated 2011 Shipment Data**

| **2011 Units Shipment by Category** | | | |
|---|---|---|---|
| Design A | Design B | Design C | Fire Pump |
| 46,512 | 4,498,896 | 9,120 | 5,472 |

### 2.3.7 Technology Assessment

The technology assessment provides information about existing technology options and designs to construct more energy-efficient electric motors. There are four main types of losses in electric motors: losses due to the resistance of conductive materials ($I^2R$ losses), core losses, friction and windage losses, and stray load losses. Measures taken to reduce one type of loss typically increase the other type of losses. Some examples of design options to improve efficiency include: (1) higher-grade electrical core steels, (2) use of different conductor types and materials, and (3) increasing the amount of copper wire in the stator (also called slot fill).

In consultation with interested parties, DOE identified several technology options and designs for consideration. These technology options are presented in Table 2.10. Additional detail on these technology options can be found in chapter 3 of the preliminary TSD.

[t] DOE based its shipments estimates on the following sources of data: market research report (IMS Research (February 2012), The World Market for Low Voltage Motors, 2012 Edition, Austin), stakeholder responses to the Request for Information (RFI) published in the Federal Register (76 FR 17577 (March 30, 2011)), and stakeholder input.

**Table 2.10 Options to Increase Electric Motor Efficiency**

| Type of Loss to Reduce | Design Options Considered |
|---|---|
| $I^2R$ Losses | Use copper die-cast rotor cage |
| | Decrease the length of coil extensions |
| | Increase cross-sectional area of rotor conductor bars |
| | Increase end ring size |
| | Increase the amount of copper wire in stator slots |
| | Increase the number of stator slots |
| Core Losses | Improve grades of electrical steel |
| | Use thinner steel laminations |
| | Add stack length (*i.e.*, add electrical steel laminations) |
| | Increase flux density in air gap |
| Friction and Windage Losses | Use bearings and lubricant with lower losses |
| | Install a more efficient cooling system |
| Stray Load Losses | Remove skew on conductor cage |
| | Improve rotor bar insulation |

DOE received comment on the validity of the Epstein test results it used to help select higher-efficiency electrical steels for reducing core loss. Epstein test results are used to determine the watts of loss per pound of electric steel and help benchmark the loss properties of various grades of electrical steel. Commenters noted that Epstein test results do not directly correlate to the efficiencies of electric motors and there are other variables to take into account when determining what efficiency gains can be produced from improved electrical steels. (Advanced Energy, Public Meeting Transcript, No. 14 at p. 109; Baldor, Public Meeting Transcript, No. 14 at p. 107; Baldor, No. 8 at p. 5) NEMA added that the only proven way to evaluate the use of a new type of electrical steel for use in an electric motor is to build several prototype electric motors using the new type of steel and compare the results to electric motors of the same designs built using other types of electrical steel. (NEMA, No. 13 at p. 9)

While Epstein test results may not be entirely indicative of potential efficiency gains achievable in an electric motor design, they are helpful in estimating the relative efficiency performance of multiple electrical steels. Because they are capable of providing this type of data, DOE may continue to use Epstein test results as part of its analysis to help determine the potential efficiency levels that may be achievable when modeling its max-tech units. If DOE chooses to use Epstein test results as part of its analysis, DOE will also consider additional testing on prototypes in accordance with 10 CFR 431.17 to confirm the Epstein testing results.

DOE also received feedback concerning efficiency increases by increasing the amount of copper wire in the stator slots, or slot fill. NEMA commented that increasing slot fill to more than 80 percent of the area of the stator slots cannot be achieved by machine winding, and the resulting hand winding methods cause a huge increase in labor content that companies typically offset by shifting production to lower cost countries, resulting in a loss of U.S. jobs. (NEMA, No. 13 at p. 11) Nidec also indicated that an increase in slot fill will force manufacturers to move from machine winding to hand winding which will entail moving those operations off-shore for cheaper labor. (Nidec, Public Meeting Transcript, No. 14 at p. 111) Finally, Baldor added that increasing slot fill to levels requiring hand winding will make them non-competitive in a global market. (Baldor, No. 8 at p. 6)

DOE is aware of the cost increases caused by hand winding motors and considers that factor in its engineering analysis. As is discussed in Chapter 5 of the preliminary TSD, DOE analyzed the winding of each motor that it tore down. Any motor which was found to be hand wound, DOE assigned a larger amount of labor hours in an effort to capture the increased costs. DOE also assigned more labor time for most software modeled designs due to the higher slot fill percentages than the torn down motors. DOE requests additional interested party feedback on the validity of its approach and any industry data on the percentage of motors that are hand wound and the impact of hand winding on manufacturers.

#### 2.3.7.1 Copper Rotor Designs

DOE understands that several companies worldwide are commercially producing polyphase electric motors with copper rotor bars and a select few manufacturers are producing copper die-cast rotors. Copper, due to its lower resistivity relative to aluminum (the most common rotor conductor material), reduces $I^2R$ losses and therefore increases electric motor efficiency. Motor modeling, performed on DOE's behalf, of copper rotor designs indicated that copper rotors increased efficiency levels in the range of 1-2 NEMA bands. A single NEMA band represents a 10 percent reduction in losses from the previous nominal efficiency. For example, increasing an electric motor's efficiency from a NEMA nominal efficiency of 93.6 percent to the next NEMA nominal efficiency band of 94.1 percent would entail reducing the losses by 10 percent.

Responding to the framework document, Baldor argued that efficiency gains with copper rotors are minimal and that copper die-cast rotors are expensive to produce, with copper die casting presses costing in excess of $2 million each and the number of required presses being significantly greater than the number needed for aluminum casting. (Baldor, No. 8 at p. 5) While DOE recognizes the potential costs involved with this technology shift, DOE is aware of at least one major manufacturer who produces copper die-cast rotors. As noted earlier, technology options are not automatically eliminated due to cost concerns but are weighed as part of the manufacturer impact analysis.

NEMA also voiced concerns about the ability to mount fan blades on the rotor when casting a copper squirrel-cage rotor. Fan blades are typically welded or casted onto the ends of the rotor to help sink heat away from the core of the rotor and to circulate air inside of the electric motor. According to NEMA, the ability to mount fan blades on a die-cast copper rotor has not yet been proven and therefore removing heat from the cast copper bars is more difficult than for aluminum cast rotor bars. (NEMA, No. 13 at p. 10) It suggested that any analysis utilizing cast copper rotors in subtype I or subtype II electric motors must include a detailed thermal analysis in order to properly evaluate the feasibility of the technology and the effect on the level of efficiency that can actually be obtained. (NEMA, No. 13 at p. 10) DOE will take into account technology constraints and any problems that may arise in increasing efficiency levels. DOE may conduct extensive thermal analyses of its software modeled electric motors in the next phase of the analysis, which includes thermal analyses of the copper rotor designs. However, DOE notes that working models of die-cast copper rotors exist and are sold in the electric motor market, demonstrating that copper die-cast rotors are feasible for manufacturers to employ.

## 2.4 SCREENING ANALYSIS

After DOE identified the technologies that might improve the energy efficiency of electric motors, DOE conducted a screening analysis. The purpose of the screening analysis is to determine which options to consider further and which to screen out. DOE consulted with industry, technical experts, and other interested parties in developing a list of design options. DOE then applied the following set of screening criteria, under sections 4(a)(4) and 5(b) of appendix A to subpart C of 10 CFR Part 430, to determine which design options are unsuitable for further consideration in the rulemaking:

- *Technological Feasibility:* DOE will consider only those technologies incorporated in commercial equipment or in working prototypes to be technologically feasible.

- *Practicability to Manufacture, Install, and Service:* If mass production of a technology in commercial equipment and reliable installation and servicing of the technology could be achieved on the scale necessary to serve the relevant market at the time of the effective date of the standard, then DOE will consider that technology practicable to manufacture, install, and service.

- *Adverse Impacts on Equipment Utility or Equipment Availability:* DOE will not further consider a technology if DOE determines it will have a significant adverse impact on the utility of the equipment to significant subgroups of customers. DOE will also not further consider a technology that will result in the unavailability of any covered equipment type with performance characteristics (including reliability), features, sizes, capacities, and volumes that are substantially the same as equipment generally available in the United States at the time.

- *Adverse Impacts on Health or Safety:* DOE will not further consider a technology if DOE determines that the technology will have significant adverse impacts on health or safety.

For a complete discussion of the screening analysis, refer to chapter 4 of the preliminary TSD.

NEMA commented on DOE's "Technological Feasibility" screening criterion and stressed that a prototype that incorporates a particular type of technology should not be misconstrued as demonstrating that it is commercially viable. (NEMA, No. 13 at p. 11) DOE clarifies that the "Technological Feasibility" criterion is only used to determine whether a technology option is possible from a technical perspective. Therefore, a "working prototype" is all that is needed to pass this criterion.

However, this element constitutes only one of DOE's four screening criteria. DOE also determines commercial viability by examining the practicability to manufacture, install, and service equipment with that considered technology, the adverse impacts on equipment utility or equipment availability, and the adverse impacts on health or safety.

NEMA commented that the "Technological Feasibility" screening criterion would rule out all the technology options that are not presently in use. (NEMA, No. 13 at p. 11) Baldor submitted a similar comment, stating that it is unclear how technological feasibility applies to the technology options because it seems to rule out all the tech options that are not presently in use. (Baldor, Public Meeting Transcript, No. 14 at p. 115) However, Baldor also commented that all the listed technology options are things that are done or have been tried and that DOE should keep in mind cost and payback periods of these technology options. (Baldor, Public Meeting Transcript, No. 14 at p. 121) DOE believes that all technologies listed in Table 2.10 are either currently used or have been used in the past to increase efficiency. Therefore, DOE does not believe that its "Technological Feasibility" screening criterion would eliminate any of these design options. DOE notes that although it does not consider cost and payback periods in the screening analysis, it does do so in downstream analyses, such as in the LCC.

DOE received comment on its "Practicability to Manufacture, Install, and Service" screening criterion as well. Nidec suggested that if manufacturers shift to more efficient motors, the motors will likely become larger to reduce core losses. This increase in size could impact retrofitting efforts because the replacement motor may no longer fit into the original motor's application. (Nidec, Public Meeting Transcript, No. 14 at p. 116) DOE understands these concerns and as efficiency levels increase DOE will ensure that utility, which includes frame size considerations, is maintained. Additionally, increased costs due to space-constrained installation and increased shipping costs are taken into account in the national impact analysis (NIA) and the life-cycle cost (LCC) analysis portions of DOE's analytical procedures.

Additionally, DOE received comment on the feasibility of the various core steel materials it plans to examine in setting standards that would help improve electric motor efficiency. Specifically, interested parties recommended that DOE incorporate into its analysis the use of materials that are readily available or could be produced in significant volume for the entire industry. (NEMA, No. 13 at p. 9) Specifically, manufacturers mentioned that there is a very limited supply of U.S.-made fully-processed Type 6 steel that can be used to reduce core losses and that a particular steel grade may be available only from one mill with insufficient production capacity to supply electric motor manufacturers. (Baldor, No. 8 at p. 4; Baldor, Public Meeting Transcript, No. 14 at p. 103) Additionally, Baldor voiced concern that the general quality of steel has worsened in the past few years due to an increase in recycled content. Baldor notes that the losses in this recycled steel are greater, which makes it impossible to achieve the same efficiency for an electric motor without the addition of more steel, copper, and aluminum. (Baldor, No. 8 at p. 4) Under its *Practicability to Manufacture, Install, and Service* screening criterion, DOE intends to screen out any materials that would not be readily available or could not be produced in significant volume for the entire industry. For the preliminary analysis, DOE has used M47, M36, M19, and M15 grade electrical steels. DOE requests comment from industry on the commercial availability of these electrical steel grades and whether DOE should consider others.

Baldor commented on the *Adverse Impacts on Equipment Utility or Equipment Availability* and submitted comment that, in its view, Appendix A to subpart B of 10 CFR Part

431 (now removed from the CFR and to be amended and placed onto DOE's electric motors webpage in the future as guidance) provides that "any rating electric motor built in a NEMA frame larger than the standard NEMA frame series number for that horsepower rating is not considered a 'general purpose electric motor' and consequently is not required to meet the efficiency standards in EPCA." (Baldor, No. 8 at p. 7) Baldor believes that this creates a confusing situation as manufacturers may be required to change frame number series in order to meet a standard level, but then that electric motor would no longer be covered by energy efficiency standards because it would no longer be considered a general purpose electric motor. (Baldor, No. 8 at p. 7) DOE understands that NEMA MG1-2011 Part 13, "Frame Assignments for Alternating Current Integral Horsepower Induction Motors," provides frame assignments for standard horsepower ratings of NEMA Design A and B motors. DOE agrees with Baldor that where a motor designed for use on a particular type of application which is in a frame size that is built in a frame one or more *series* larger than the frame size assigned to that rating by NEMA Standards Publication MG1, it is no longer considered general purpose. However, as will be discussed in the engineering analysis portions of this preliminary TSD, DOE strives to maintain utility (including the baseline frame series) as higher efficiency levels are examined. This step is taken to avoid setting energy conservation standards so high that consumers lose certain utilities.

DOE also received comment on the safety hazards that copper rotors impose upon workers handling molten copper. Due to the higher melting temperature of copper, (almost 2000°F , as opposed to aluminum's 1220°F) working with molten copper is more dangerous than working with aluminum. NEMA asserted that any electric motor designs requiring the use of cast copper rotors also require personnel to work daily in close proximity to hot molten material which will increase workplace injuries. (NEMA, No. 13 at p. 12) (NEMA provided no supporting data for this claim.) Baldor states that cast copper rotors may create several problems that are larger than any advantages it may present, especially in terms of production safety and extra needed energy. (Baldor, No. 8 at p. 5) DOE acknowledges manufacturer concerns over the potential for increased hazards associated with copper die-cast rotors but notes that Baldor provided no data in support of its claim. Accordingly, DOE has not ruled out copper die-cast rotors as an option, particularly in light of the absence of any supporting data regarding the potential risks and the fact that manufacturers are already producing such equipment, which suggests that such equipment can be safely produced in mass quantities. DOE invites manufacturers and others to provide information pointing to the additional risks posed by the manufacture of these types of rotors.

### 2.4.1 Technology Options Screened Out

DOE developed an initial list of design options from the technologies identified in the technology assessment. DOE reviewed the list to determine if the design options are practicable to manufacture, install, and service; would adversely affect equipment utility or equipment availability; or would have adverse impacts on health and safety. In the engineering analysis, DOE considered those design options that satisfied the four screening criteria. It did not consider those options that failed to satisfy one or more of the screening criterion. The design options screened out are summarized in Table 2.11.

**Table 2.11 Design Options Screened Out of the Analysis**

| Design Option Excluded | Eliminating Screening Criterion |
|---|---|
| Plastic Bonded Iron Powder (PBIP) | Technological Feasibility |
| Amorphous Steels | Technological Feasibility |

Chapter 4 of this preliminary TSD discusses each of these screened out design options in more detail, as well as the design options that DOE considered in the electric motor engineering analysis. The chapter also includes a list of emerging technologies that could impact future electric motor manufacturing costs.

#### 2.4.1.1 Plastic Bonded Iron Powder

DOE has previously considered plastic bonded iron powder (PBIP) as a replacement for electrical steel in its rulemaking for small electric motors, at 74 FR 32059 (July 7, 2009). PBIP is based on an iron powder alloy that is suspended in plastic, and is used in certain electric motor applications such as fans, pumps, and household appliances. The compound is then shaped into electric motor components using a centrifugal mold, reducing the number of manufacturing steps.[u] Potential advantages of this technique include lower core losses, a reduced number of production steps, and increased efficiency.

NEMA commented that PBIP has not been incorporated into a working prototype and lacks structural integrity. For these reasons, it suggested that DOE not treat this option as a feasible design option. (NEMA, No. 13 at p. 10) DOE is not aware of any polyphase induction electric motors that have been prototyped using PBIP. Therefore, DOE does not consider this option to be technologically feasible and has screened it out of this rulemaking.

Additionally, DOE remains uncertain whether PBIP is practicable to manufacture, install, and service as insufficient information is available to make a judgment on the ability to manufacture this technology. DOE is also uncertain whether the material has the structural integrity to form into the necessary shape of an electric motor steel frame. Consistent with the approach DOE took in the small electric motors standards rulemaking, DOE believes the lack of a working prototype and the uncertainty regarding the structural integrity of PBIP are sufficient reasons to screen out this technology option.

#### 2.4.1.2 Amorphous Steels

Amorphous core material has been in existence for more than 35 years. Amorphous magnetic steels are non-crystal alloys characterized by extremely low losses, high magnetic permeability and high fracture toughness. Amorphous magnetic steels have low hysteresis losses and high electrical resistance that both help to minimize eddy current loss. They are also thin and

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[u] Horrdin, H., and E. Olsson. *Technology Shifts in Power Electronics and Electric motors for Hybrid Electric Vehicles: A Study of Silicon Carbide and Iron Powder Materials.* 2007. Chalmers University of Technology. Göteborg, Sweden.

brittle, making it difficult to cut and machine the material into shapes suitable for electric motor cores.[v] Additional barriers to the use of amorphous steels include higher production costs and the existence of few electric motors utilizing the technology.[w] While some prototypes have been developed using amorphous core material, DOE is not aware of any polyphase induction motors that use amorphous core technology. Therefore, based on available information, DOE does not believe that this option is likely to be technologically feasible at this time.

## 2.5 ENGINEERING ANALYSIS

The engineering analysis (Chapter 5) develops cost-efficiency relationships for equipment types that are the subject of a rulemaking, estimating manufacturer selling price (MSP) as it relates to increased levels of efficiency. The relationship between the MSP and energy efficiency serves as the basis of the cost-benefit calculations performed during the LCC phase of the analysis. This section provides an overview of the engineering analysis methodology, including a discussion of the representative equipment classes and units, the development of candidate standard levels, a preliminary scaling methodology, price derivations and analysis, and other key issues or regulatory impacts.

### 2.5.1 Methodology

In general, the engineering analysis estimates the efficiency improvement potential of individual design options or combinations of design options that pass the four criteria in the screening analysis. DOE uses this cost-efficiency relationship, developed in the engineering analysis, in the LCC analysis.

In general, DOE can use three methodologies to generate the manufacturing costs needed for the engineering analysis. These methods are:

1. the design-option approach – reporting the incremental costs of adding design options to a baseline model;

2. the efficiency-level approach – reporting relative costs of achieving improvements in energy efficiency; and

3. the reverse engineering or cost assessment approach – involving a "bottom up" manufacturing cost assessment based on a detailed bill of materials derived from electric motor teardowns.

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[v] Research Centre of China, Bejing, China. Amorphous and Nanocrystalline products branch, Advanced Technology and Materials Co., Ltd., Central Iron and Steel research Institute, Bejing, China. *Application of Amorphous Alloy in the New Energy-Efficient Electrical Electric Motor (2011).*
[w] School of Mechanics and Engineer, ShanDong University, Weihai 264209, China. *Review on Applications of Low Loss Amorphous Metals in Electric motors (2010).*

DOE's analysis for the electric motor rulemaking is based on a combination of the efficiency-level approach and the reverse engineering approach. Due to limited manufacturer feedback concerning cost data and production costs, DOE derived its production costs by tearing down electric motors and recording detailed information regarding individual components as a means to derive material and labor costs. The process was performed on the representative units illustrated below in Table 2.12. DOE used the cost derived from the engineering teardown and the corresponding nameplate nominal efficiency of the torn down motor to report the relative costs of achieving improvements in energy efficiency. DOE derived material prices from current, publicly available data. DOE supplemented the findings from its tests and teardowns through: (1) a review of data collected from manufacturers about prices, efficiencies, and other features of various models of electric motors; and (2) interviews with manufacturers about the techniques and associated costs used to improve efficiency. DOE then aggregated the cost numbers by weighing individual data points by company-level sales volumes for each equipment class. In addition, DOE will use the cost data generated by the engineering analysis in the manufacturer impact analysis (see section 12).

To develop levels with the highest efficiency and that are technologically feasible (*i.e.*, the "max-tech" levels) for each representative unit analyzed, DOE used a combination of electric motor software design programs, manufacturer feedback, and manufacturer supplied data from interviews. DOE's engineering analysis documents the design changes and associated costs when improving electric motor efficiency from a baseline level up to a max-tech level. This analysis includes considering improved electrical steel for the stator and rotor, improved electrical conductors, and any other applicable design options remaining after the screening analysis. As each of these design options are added, the manufacturer's cost generally increases and the electric motor's efficiency improves.

DOE received comment on the use of software products as a method of simulating its max-tech electric motors. Baldor stated it was unaware of any software that will model the most advanced technologies. Baldor continued, suggesting that results need to be accurate and verified, and recommended consulting with Dr. James Kirtley at the Massachusetts Institute of Technology, an expert in motor modeling software who could provide guidance on selecting and using such software. (Baldor, Public Meeting Transcript, No. 14 at pp. 157, 162) NEMA reaffirmed Baldor's concern and commented that it was unaware of any commercially available software that can properly model all of the technology options that DOE indicated that it would study for electric motors. (NEMA, No. 13 at p. 12) NEMA added that it knew of no software that includes an analysis of the thermal characteristics of an electric motor that would enable one to properly evaluate the temperature rise at rated load and its effect on the calculated efficiency. This last element, according to NEMA, is especially important in evaluating the possibility of using a change in materials, such as copper rotors. (NEMA, No. 13 at p. 13) Lastly, WEG commented that there are several key parameters, such as locked-rotor current and torque, pull-up torque, breakdown torque, and frame size that must be considered when modeling new electric motor designs to ensure they are compatible with existing applications, protection systems, and codes. (WEG, No. 5 at p. 1)

DOE is aware of the difficulties in accurately modeling electric motors using design software and the need to consult with knowledgeable experts. Additionally, DOE understands the possibility that software-modeled electric motors may not perform the same way when built and operated in the real world if the software models are not applied properly by an experienced engineer. In response to these concerns, DOE has located an industry expert to work in conjunction with DOE's software modeling expert to potentially design and build software modeled prototypes to verify their performance ratings. Prototyping software modeled electric motors will be a way of validating software modeled designs to ensure DOE bases its maximum technology efficiencies on achievable design parameters.

Additionally, manufacturers stressed that DOE should be aware of the design constraints of fire pump electric motors listed in NFPA 20 and 70 as well as the National Electrical Code (NEC), the Occupational Safety and Health Administration (OSHA), and the Environmental Protection Agency (EPA) when designing fire pump electric motors. (Baldor, Public Meeting Transcript, No. 14 at p. 175; NEMA, No. 13 at p. 19) While DOE does not plan on modeling fire pump electric motors it requests comment on which particular NFPA, NEC, OSHA, and EPA design constraints it should consider and whether the costs associated with these constraints increase as efficiency increases.

### 2.5.2 Representative Units

As discussed in section 2.3, DOE placed electric motors into three separate equipment class groups. Due to the high number of equipment classes within these groups, DOE selected and analyzed only a few representative units from each equipment class group and based its overall analysis for all equipment classes (within that equipment class group) on these representative units. Table 2.12 lists the design criteria that enumerate all electric motor equipment classes. During the preliminary analysis, DOE selected three units to represent equipment class group 1 and two units to represent equipment class group 2. DOE based the analysis of equipment class group 3 on the representative units for equipment class group 1 because of the low shipment volume and run time of fire pump electric motors.

**Table 2.12 Variable Motor Design Criteria**

| Design Criteria | Notes |
|---|---|
| Design type | Dictates equipment class group |
| Horsepower rating | Given a design type, and therefore equipment class group, the combination of these three criteria determines an electric motor's equipment class within said equipment class group. |
| Pole-configuration | |
| Enclosure type | |

*Design Type*

For equipment class group 1, which includes NEMA Design A and B electric motors, DOE only selected NEMA Design B motors as representative units to analyze in the engineering analysis. DOE chose NEMA Design B electric motors because NEMA Design A electric motors can generally meet NEMA Design B efficiency levels due to their less stringent locked-rotor current limits. Additionally, NEMA Design B units have much higher shipment volumes than NEMA Design A motors. As mentioned, for equipment class group 2, DOE selected two representative units to analyze. Because Design C is the only NEMA design type covered by this equipment class group, DOE only selected NEMA Design C motors for analysis as its representative units. Equipment class group 3 consists of fire pump electric motors. For equipment class group 3, DOE plans on developing any potential amended energy conservation standards based off of its analysis of equipment class group 1 because fire pump electric motors are required to meet National Electrical Manufacturers Association (NEMA) Design B performance standards.

*Horsepower Rating*

Horsepower rating is an important equipment class setting criterion. DOE received comments about this issue with respect to representative unit selections. Baldor asserted that when DOE selects representative units, the entire range of horsepower ratings needs to be examined and multiple models need to be tested. (Baldor, Public Meeting Transcript, No. 14 at p. 137) NEMA emphasized its belief that DOE must select at least three or four separate electric motor ratings to adequately cover the NEMA frame number series used for electric motors rated from 1 to 500 horsepower and suggested the following configurations: (1) NEMA Design B, 5 horsepower, 4-pole, enclosed; (2) NEMA Design B, 50-hp, 6-pole open; (3) NEMA Design B, 250-hp, 4-pole open; (4) NEMA Design C, 10-hp, 4-pole, open; (5) NEMA Design C, 40-hp, 6-pole, open; and (6) NEMA Design C, 200-hp, 4-pole, enclosed. (NEMA, No. 13 at p. 14)

When DOE selected its preliminary analysis representative units, DOE chose those horsepower ratings that constitute a high volume of shipments in the market and provide a sufficiently wide range upon which DOE could reasonably base a scaling methodology. For NEMA Design B motors, for example, DOE chose 5-, 30-, and 75-hp rated electric motors to analyze as representative units. DOE selected the 5-hp rating because it is the rating with the highest shipment volume of all motors. DOE selected the 30-hp rating as an intermediary between the small and large frame number series electric motors. Although 75 horsepower is not as high a horsepower rating as recommended by NEMA, DOE believes that this rating can be used to model the highest horsepower ratings. This is because there is less variation in efficiency for horsepower ratings above 75 and therefore DOE determined it was not necessary to analyze a 250 horsepower motor. For NEMA Design C electric motors, DOE again selected the 5-hp rating as well as a 50-hp rating. DOE only selected two horsepower ratings for these electric motors because of the low shipment volumes. For more information on how DOE selected these horsepower ratings see chapter 5 of the preliminary TSD.

*Pole-Configuration*

Pole-configuration is another important equipment class setting criterion which DOE had to consider when selecting its representative units. For the preliminary analysis, DOE selected 4-pole motors for all of its representative units. DOE chose 4-pole motors because they represent the highest shipment volume of motors compared to other pole configurations. DOE chose not to alternate between pole configurations for its representative units, as recommended by NEMA, because it wanted to keep as many design characteristics constant as possible. By doing so, it would allow DOE to more accurately identify how design changes affect efficiency across horsepower ratings. For example, if DOE compared a 5-hp, 4-pole electric motor and a 50-hp, 6-pole electric motor at the NEMA Premium efficiency level it would be difficult to determine how much of the efficiency change occurred because of the change in horsepower rating and how much occurred because of the pole-configuration change. Additionally, DOE believes that the horsepower rating-versus-efficiency relationship is the most important (rather than pole-configuration and enclosure type versus efficiency) because there are significantly more horsepower ratings to consider.

*Enclosure Type*

The final equipment class setting criterion that DOE had to consider when selecting its representative units was enclosure type. For the preliminary analysis, DOE elected to only analyze electric motors with enclosed designs rather than open designs for all of its representative units. DOE selected enclosed motors because, as with pole-configurations, these motors have higher shipments than open motors. Again, DOE did not alternate between the two design possibilities for its representative units because it sought to keep design characteristics as constant as possible in an attempt to more accurately identify the reasons for efficiency improvements.

*Frame Type*

The last criterion that DOE considered when selecting its representative units was frame type (i.e. U- or T-frame). DOE selected T-frame motors because they represent the highest volume of shipments. As discussed in section 2.3, the scope of coverage set by EISA 2007 included both NEMA U-frame and T-frame designs. However, NEMA indicated that the low volume of U-frame electric motors makes it unnecessary to select a U-frame electric motor as a representative unit. NEMA added that the energy savings and cost analyses pertinent to U-frame electric motors can be incorporated into the analysis of the overall set of general purpose electric motors (subtype II). (NEMA, No. 13 at p. 13) For these reasons and those discussed above in 2.3.5.5, DOE did not select any U-frame motors as representative units and at this time does not plan to do so in the latter stages of this rulemaking. This approach may change depending on the data and comments DOE receives in response to this preliminary analysis.

Finally, Table 2.13 illustrates the representative units that DOE selected for the preliminary analysis. DOE requests comment on the appropriateness of these representative units.

**Table 2.13 Representative Units for Preliminary Analysis**

| Representative Unit | Specifications | |
|---|---|---|
| 1 | NEMA Design B, T-frame, Enclosed, 4-pole | 5 Horsepower |
| 2 | | 30 Horsepower |
| 3 | | 75 Horsepower |
| 4 | NEMA Design C, T-frame, Enclosed, 4-pole | 5 Horsepower |
| 5 | | 50 Horsepower |

### 2.5.3 Candidate Standard Levels Analyzed

For each representative unit, DOE selected a baseline model as a reference point against which to measure changes that may result from energy conservation standards. For each equipment class directly analyzed, DOE looked at manufacturer catalogs to determine the minimum efficiencies of motors currently available. This search included motors previously not covered by conservation standards, but would be covered in the planned expansion of scope. DOE used these minimum efficiency levels as the baseline efficiencies for each equipment class directly analyzed. Then, the energy savings and price of the baseline model is compared to the energy savings and price of each higher energy efficiency level. Energy efficiency levels are termed "candidate standard levels" (CSLs) and are meant to characterize the cost-efficiency relationship.

In the framework document, DOE used the MotorMaster+ database in developing potential CSLs for electric motors.[x] Baldor expressed concern with this approach and stated that the MotorMaster+ database needs updating. (Baldor, Public Meeting Transcript, No. 14 at p. 152) DOE confirmed this claim after comparing the MotorMaster+ database with current manufacturer catalog data. As a result, DOE created its own electric motor database built from up-to-date manufacturer catalog data and used the manufacturer catalog database it created as a reference point when developing potential CSLs. This information was supplemented with data collected at manufacturer interviews as well as by contacting electric motor manufacturers and distribution channels to gather the most current catalog data available.

#### 2.5.3.1 Baseline Candidate Standard Level

In the framework document, DOE laid out an approach it was considering for selecting its baseline models, or baseline efficiency levels. Baseline models serve as reference points for each equipment class against which DOE can measure changes in efficiency and costs resulting from potential energy conservation standards. In the framework document, DOE stated that the baseline models it would select would correspond to the least efficient, most typical electric motor sold in a given equipment class. At the time, DOE had not yet considered expanding the scope of conservation standards, and therefore specified that the baseline models would be equivalent to the minimum applicable energy conservation standards set by EISA 2007. However, for the preliminary analysis, DOE has revised the baseline efficiency levels to accommodate motors now included in the expanded scope of coverage. None of the motors in the planned scope expansion are currently held to any conservation standards, therefore, the baseline efficiencies of some representative units are below the current required EISA 2007 standards. DOE used manufacturer catalogs to select the baseline efficiency levels for its representative units. These levels were the minimum observed catalog efficiencies for all NEMA Design A and B motors (equipment class group 1) for which DOE plans on establishing or

[x] MotorMaster+ is an energy-efficient motor selection and management tool, which includes a database of over 20,000 electric motors. For more information about MotorMaster+, visit *www1.eere.energy.gov/industry/bestpractices/software.html#mm*

amending energy conservation standards. Table 2.14 shows the nameplate efficiencies of the baseline representative units for this equipment class group.

For the NEMA Design C equipment class group (equipment class group 2) DOE did not find any NEMA Design C motors (equipment class group 2) below EISA 2007 efficiency levels, and therefore is using the EISA 2007 conservation standards as the baseline for equipment class group 2.

Should DOE not find any economic justification for amended energy conservation standards above the baseline efficiency level, subtype I and subtype II motors would remain subject to the same efficiency levels (i.e., different from each other) mandated by EISA 2007. Additionally, DOE notes that although the efficiencies in Table 2.14 represent the baseline, DOE's efficiency distribution for this equipment class group shows a significant portion of motors already above the baseline efficiency level.

**Table 2.14 Representative Unit Baseline Efficiency Level versus Current Lowest Energy Conservation Standards**

| Motor | Nameplate Baseline Efficiency | NEMA MG1-2011 Table 12-11 (EPACT 1992) Efficiency |
|---|---|---|
| 5 horsepower, 4-pole enclosed frame NEMA Design B motor | 82.5% | 87.5% |
| 30 horsepower, 4-pole enclosed frame NEMA Design B motor | 89.5% | 92.4% |
| 75 horsepower, 4-pole enclosed frame NEMA Design B motor | 93.0% | 94.1% |

#### 2.5.3.2 Improved Candidate Standard Level

As previously discussed, DOE had considered using EISA 2007 efficiency levels for the baseline CSL efficiencies in the framework public meeting, but changed its decision in light of the planned expansion of scope. Since DOE plans on using the lowest-observed catalog efficiencies to characterize the new baseline efficiency level, DOE plans on basing the improved CSLs on efficiencies levels equivalent to the applicable energy conservation standards that were set by EISA 2007 (previously the basis for the baseline CSL).

NEMA suggested that DOE develop its baseline efficiency levels for electric motors based on the EISA 2007 regulations. (NEMA, No. 13 at p. 13) DOE agrees with establishing a CSL based on the EISA 2007 regulations, however, because of the planned scope of conservation standards expansion, it will not correspond to the baseline efficiency, but rather the first and second incremental CSLs. DOE selected the NEMA MG1-2011, Table 12-11 efficiency values as the first incremental CSL over the baseline level for the NEMA Design A and B equipment class group (equipment class group 1). NEMA MG1-2011, Table 12-11 is equivalent to the EPACT 1992 levels for 1 to 200 horsepower electric motors and the EISA 2007 levels for NEMA Design B electric motors with a horsepower rating greater than 200. EISA 2007 also mandated that general purpose electric motors (subtype I) from 1 to 200 horsepower and 2 to 6 poles meet efficiency levels that correspond to NEMA MG1-2011, Table 12-12[y] (i.e., equivalent to NEMA Premium levels). Therefore, DOE selected NEMA MG1-2011, Table 12-12 (including the new NEMA Premium ratings for 8-pole motors) as its second incremental CSL. Because equipment class group 1 includes motors that are considered general purpose electric motors (subtype II) and EISA 2007 mandated efficiency standards equivalent to Table 12-11 for these motors, DOE believes Table 12-11 is the appropriate first incremental efficiency level to represent equipment class group 1.

Baldor commented that although fire pump electric motors are used very intermittently, if they were deregulated or were prescribed lower efficiency standards than general purpose motors, manufacturers could sell them cheaply for general purpose applications as a means of skirting efficiency laws. Baldor stated that manufacturers could potentially do this because there are no regulations limiting the applications in which a fire pump motor may be used. (Baldor, Public Meeting Transcript, No. 14 at pp. 129, 130) Baldor did not address the additional costs manufacturers must expend when producing a motor that satisfies the NFPA requirements and whether sufficient incentives exist for this potential circumvention path. Nevertheless, DOE notes that it will assess the feasibility of raising fire pump electric motors to higher efficiency levels, which could have the added benefit of discouraging their use as a compliance loophole. NEMA added that because of their low quantity, the sparse potential energy savings, and the projected life cycle costs of fire pump electric motors, DOE should incorporate the analysis of these motors into the overall class of general purpose subtype II electric motors (NEMA, No. 13 at p. 13).

Additionally, NEMA cited NFPA 20, which states that polyphase fire pump electric motors must comply with NEMA Design B standards. However, NEMA emphasized that fire pump motors have additional requirements that distinguish them from typical, general purpose, NEMA Design B electric motors. (NEMA, No. 13 at p. 13) As mentioned previously, DOE is aware of the low volume and run-time of fire pump electric motors as well as the design restrictions placed on fire pump electric motors. Therefore, DOE has created a separate equipment class group for fire pump motors which it will use to analyze these motors. However, as fire pump motors have to meet the performance criteria for NEMA Design B motors and DOE is directly analyzing NEMA Design B motors for equipment class group 1, DOE will partially base its fire pump motor analysis on the results of the equipment class group 1 analysis.

When selecting incremental CSLs for equipment class group 1, DOE based its second incremental CSL (CSL 2) on the NEMA MG1-2011, Table 12-12 (i.e., NEMA Premium)

[y] EISA 2007 actually referred to the 2006 version of NEMA MG1, but as the industry document has been updated and the efficiency values for the pertinent ratings (i.e. combination of horsepower, pole-configuration, and enclosure type) have not changed, DOE has referenced the most up to date version of MG1, NEMA MG1-2011. Another benefit of using the most recent version of this industry document is that tables 12-11 and 12-12 have been expanded to include additional motor ratings.

efficiency levels. This level is generally one or two NEMA "bands" more than the NEMA MG1-2011 Table 12-11 (i.e. EPACT 1992) values, which constitute DOE's first incremental CSL (CSL 1). As mentioned earlier, NEMA defines a "band" as a 10 percent reduction in losses from the lower level of efficiency. Actual efficiency numbers in the NEMA MG1-2011 efficiency tables are based on this "band" rule as well as a NEMA survey on achievable efficiencies by individual manufacturers. The standardized NEMA nominal efficiency values can be found at NEMA MG1-2011 Table 12-10.

The third incremental CSL (CSL 3) for equipment class group 1 is based on the most efficient levels DOE found in its electric motor database. This level represents the best or near best efficiency level at which current manufacturers are producing electric motors and generally exceeds the NEMA Premium level by one NEMA band of efficiency. DOE also created a fourth incremental CSL (CSL 4) that is an incremental efficiency level one NEMA band above CSL 3 that DOE developed using computer software modeling.

The final CSL (CSL 5) is based on the theoretical maximum efficiency possible using design options that were not screened out in DOE's screening analysis. DOE based its efficiency value on computer software modeling and manufacturer feedback. Table 2.15 shows DOE's preliminary CSLs for equipment class group 1 electric motors.

**Table 2.15 Candidate Standard Levels for Equipment Class Group 1 Motors**

| CSL Number | CSL Name | NEMA MG1-2011 Tables | Note |
|---|---|---|---|
| 0 | Baseline | -- | Lowest observed efficiency in catalogs |
| 1 | EPACT 1992 | 12-11 (and 20A[z]) | Minimum EISA 2007 |
| 2 | NEMA Premium | 12-12 (and 20B[aa]) | Maximum EISA 2007 |
| 3 | Best-in-Market | -- | -- |
| 4 | Incremental Level | -- | -- |
| 5 | Maximum Technologically Feasible | -- | -- |

Because fewer NEMA Design C motors are available on the market, DOE used a slightly different method for developing its CSLs for equipment class group 2. For more information see Chapter 5 (Engineering Analysis) of the preliminary TSD.

DOE received feedback on increasing efficiency levels beyond NEMA Premium levels. ACEEE and Baldor commented that DOE should not try to exceed the NEMA Premium levels. (ACEEE and Baldor, Public Meeting Transcript, No. 14 at pp. 88-89) Baldor added that technology constraints can make the market much more difficult because replacing a NEMA

[z] Table 20A was added in NEMA MG1-2011 as an extension to Table 12-11, which includes efficiency ratings for 6- and 8-pole motors from 300 to 500 horsepower.
[aa] Table 20B was added in NEMA MG1-2011 as an extension to Table 12-12, which includes efficiency ratings for 6- and 8-pole motors from 300 to 500 horsepower.

Design B electric motor with a NEMA Design A electric motor (which can be more efficient) could cause problems when starting an application. Because NEMA Design A motors allow a larger locked-rotor current (also known as starting current) than NEMA Design B motors, the replacement motor may cause circuits to trip because of the larger current used at startup. (Baldor, Public Meeting Transcript, No. 14 at p. 89)

Although ACEEE, speaking on behalf of ASAP and NEMA, advocated expanding the scope of coverage and moving all electric motors to NEMA MG1-2009, Table 12-12 efficiency levels in this rulemaking, they also stated that moving to or beyond these levels would be in the best interest of consumers, manufacturers, and the economy. (ACEEE, NEMA, and ASAP, Public Meeting Transcript, No. 14 at p. 22) The CDA submitted similar comments, suggesting that even higher minimum efficiencies are cost-effective, especially for the larger 200-500 horsepower electric motors that are usually heavy-duty-cycle electric motors. The CDA also suggested that for these motors, payback of the increased costs because of higher efficiency standards could be achieved in months or one year of operation. (CDA, No. 18 at p. 3) ASAP and NEMA later tempered its position somewhat in its written comments, noting that they do not support DOE creating standards more efficient than the Table 12-12 levels. (ASAP and NEMA, No. 12 at p. 2) ASAP and NEMA reiterated this position in response to the RFI that DOE published in March 2011. (ASAP and NEMA, No. 20 at p. 5) NEMA emphasized the “strategic value” of current NEMA Premium efficiency level standards and suggested that DOE should be careful not to inadvertently ignore the risks to electric motor users of being non-competitive if they are raised. (NEMA, No. 13 at p. 11)

DOE appreciates the comments from all interested parties on its candidate standard levels. DOE is aware of the design changes required to meet efficiencies up to and beyond the Table 12-12 levels. However, DOE plans to run a full analysis on the market and on cost increases as efficiency increases beyond the Table 12-12 levels. DOE will characterize the relationship between cost and efficiency to such levels and will consider how consumers, utilities, manufacturers, and the Nation as a whole will be affected.

Additionally, NEMA suggested that when DOE determines efficiency levels based on test results, it should use the provisions outlined in 10 CFR 431.17. NEMA asserted that “based on the experience with the testing of baseline small electric motors and the improper conclusions arrived at when testing too small a sample size, then DOE should follow the requirements of the procedure in 10 CFR 431.17 when the efficiency is determined by testing.” (NEMA, No. 13 at p. 15) Baldor added that any efficiency values of modeled electric motors that fall between NEMA nominal efficiency levels should be rounded down. (Baldor, Public Meetings Transcript at p. 172)

DOE notes that 10 CFR 431.17 provides the provisions that manufacturers must follow in order to demonstrate compliance with an electric motor energy conservation standard and, thus, it includes stipulations for sample sizes. But because NEMA has provisions in place that guarantee to customers the minimum energy efficiency performance of electric motors with labeled nominal full-load efficiencies, DOE believes that repetitive testing of the same model was unnecessary. All motors tested and torn down by DOE were manufactured by NEMA members. As a result, the preliminary analysis ultimately relies on the manufacturer’s nominal nameplate efficiency, so long as the results from testing in accordance with 10 CFR 431.16 yielded results that fell within the allowable variance as provided in NEMA MG1-2011. DOE uses the nameplate nominal efficiency of tested electric motors to represent its CSLs, except for some of the highest CSLs, which are based on the efficiencies of computer modeled designs rounded to the next lowest NEMA nominal efficiency level. For each CSL based on the data gleaned from a tested and torn-down motor, DOE tested one unit (11 total).

Finally, Baldor urged DOE to consider NEMA MG1-2009's requirements − e.g., specific torque or current requirements − when developing potential efficiency levels. (Baldor, Public Meeting Transcript, No. 14 at p. 99) NEMA added that DOE should review the NEMA MG1-2009 standards in their entirety to understand all of the performance requirements for general purpose electric motors such that designs developed by DOE meet all of those requirements. (NEMA, No. 13 at p. 8) DOE recognizes these concerns and the importance of maintaining utility within the context of improving efficiency levels. Therefore, for a given representative unit, DOE sought to ensure that all of the electric motors tested and modeled contained comparable performance characteristics − i.e., within the specifications laid out in NEMA MG1-2011 (which is equivalent to those provided in MG1-2009 as requested by interested parties)).

### 2.5.4 Material Price Analysis

DOE conducted the engineering analysis using material prices based on manufacturer feedback, industry experts, and publicly available data. Most material prices were based on the 2010 price of the material. However, cast copper and copper wire pricing were based on prices tracked over a five-year time period from 2007 through 2011. DOE used a five-year average price for copper materials because of the high volatility of copper prices relative to other electric motor materials such as electrical steel or aluminum, prices of which experience relatively little yearly fluctuation.

DOE received very limited feedback concerning material prices for any of the previous five-year span. Manufacturers suggested using the London Metal Exchange (LME) as a starting point for raw metal prices and applying a markup to compensate for wire processing or steel extruding. For the preliminary analysis, DOE did use the LME material prices as well as Producer Price Indices to derive previous year's prices.

DOE requests comment on its tentative decision on its reference case material price scenario, which is to use 2010 prices for all of its material prices other than copper. DOE also requests comment on its preliminary decision to use a five-year average for its material prices for cast copper and copper wiring.

### 2.5.5 Cost Model and Markups

DOE derived the manufacturer's selling price for each design in the engineering analysis by considering the full range of production costs and non-production costs. The full production cost is a combination of direct labor, direct materials, and overhead. The overhead contributing to full production cost includes indirect labor, indirect material, maintenance, depreciation, taxes, and insurance related to company assets. Non-production cost includes the cost of selling, general and administrative items (market research, advertising, sales representatives, logistics), research and development (R&D), interest payments, warranty and risk provisions, shipping, and profit factor. Because profit factor is included in the non-production cost, the sum of production and non-production costs is an estimate of the manufacturer's selling price (MSP). DOE utilized various markups to arrive at the total cost for each component of the electric motor. These markups are outlined in detail in Chapter 5 of the preliminary TSD. Figure 2.5.1 presents the components of the MSP.

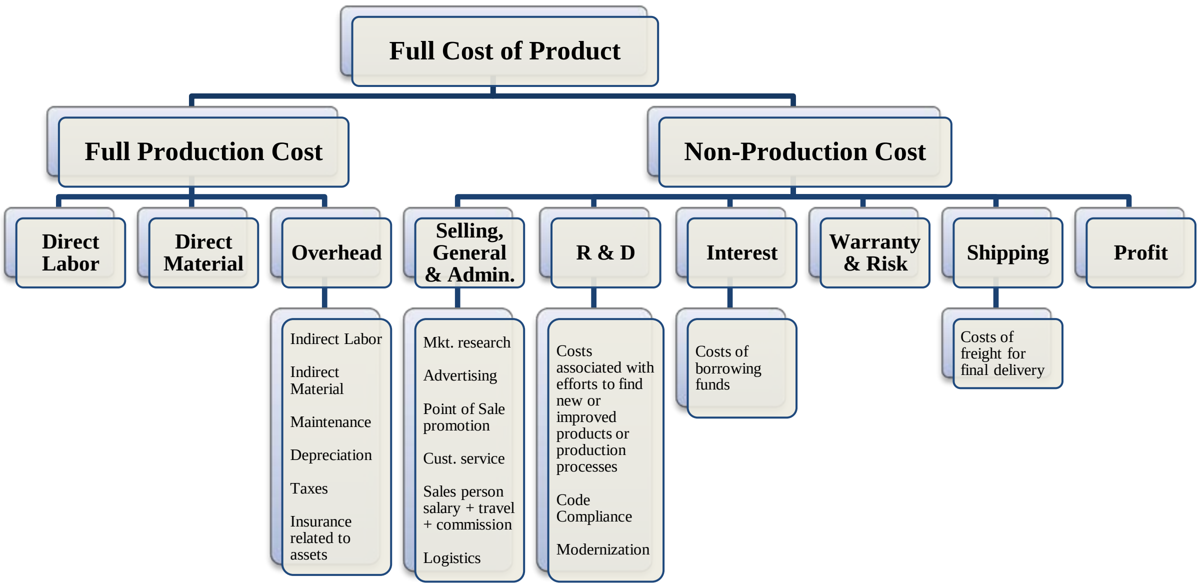


**Figure 2.5.1 Method of Cost Accounting for Electric Motors Rulemaking**

In response to the framework document, Baldor suggested that DOE consider differentiating the costs for a hand-wound electric motor design from a machine-wound one when determining prices for its electric motor. Baldor specifically noted that during tear-downs, DOE should note this fact because it signifies a large change in labor costs. (Baldor, No. 8 at p. 6) To account for this factor, the preliminary analysis includes an aggregate labor rate of foreign and domestic labor. DOE looked at the percentage of electric motors imported to the U.S. and the percentage of electric motors built domestically and based the balance of foreign and domestic labor rates on these percentages. During tear-downs, DOE examined stator construction to determine if it was machine-wound or hand-wound. DOE found none of its physically torn down motors were hand wound. However, DOE increased labor hours to compensate for hand winding for software modeled motors with reported slot fill over 80 percent. Additional details regarding these assumptions can be found in Chapter 5 (Engineering Analysis) of the preliminary TSD.

Baldor commented that the cost and selling price are not directly related, and that some high-volume original equipment manufacturers (OEMs) demand lower prices. This, in turn, causes margins to shrink between cost and selling price. (Baldor, No. 8 at p. 6) DOE is aware that advertised or negotiated prices are not always indicative of production costs for manufacturers. Accordingly, DOE plans to derive its own cost basis for electric motor production. Price determination begins with electric motor tear-down and pricing of raw material to which various markups are applied as illustrated in figure 2.5.2.

Baldor asserted that low-volume electric motors often mean less automation and therefore higher labor cost to manufacture. (Baldor, No. 8 at p. 7) DOE will consider the possibility of higher labor costs for low-volume electric motors and seeks manufacturer feedback on specific electric motors which may fall into a “low-volume” category and what variations in labor costs may be associated with these motors.

Finally, NEMA suggested that DOE clarify how it plans to resolve any differences between the costs it derives and the actual costs the manufacturer incurs. NEMA also stated that DOE should account for manufacturing techniques that may vary among different manufacturers. (NEMA, No. 13 at p. 15) NEMA also commented that they are not able to qualify a relationship between cost and efficiency, but in general terms higher efficiency levels require more raw material and therefore higher costs. (NEMA, No. 19 at p. 4) DOE is aware of the difficulty of determining accurate costs for electric motor designs and production. While DOE does not generate a different set of costs for individual manufacturers, it has spoken to individual manufacturers and examined publicly available information, such as SEC 10-Ks, in effort to understand subtle differences among manufacturers. Consequently, DOE has one set of markups that it applies to its bills of materials, which is designed to be a typical markup scheme for an electric motor manufacturer. Refer to chapter 5 of the preliminary TSD for more detail on DOE’s cost model

### 2.5.6 Scaling Methodology

Once DOE has identified cost-efficiency relationships for the representative units that it has selected, it must appropriately scale the engineering analysis results of these representative units to the other equipment classes not directly analyzed. To scale the findings from one equipment class to another, DOE identifies relationships between the equipment classes through a characterization of the current market. To do this, DOE considered two methodologies, which are described in detail in Chapter 5 of the preliminary TSD. In response to the framework document, DOE received several interested party comments on scaling the results of the engineering analysis.

NEMA suggested that any standards that DOE develops from any scaling method should also yield values corresponding to the values for nominal efficiency in table 12-10 of NEMA MG1-2009. (NEMA, No. 13 at p. 17)

As discussed previously, DOE based the first three of its CSLs for equipment class group 1 on torn down motors. As these motors were marketed and sold with NEMA nominal efficiencies, DOE used those values to denote each of those CSLs. Consequently, the efficiency levels that DOE scaled to for the non-representative units were also selected from the NEMA nominal efficiency levels. For the two CSLs that were achieved for the representative units using software modeling, DOE used the NEMA nominal efficiency values.

With regards to the scaling methodology, Baldor commented that it would be very difficult to scale between (1) different enclosure types and pole configurations and (2) horsepower ratings (the latter because frame sizes change which could limit stack length increases). (Baldor, Public Meeting Transcript, No. 14 at pp. 166 and 170) It added that when scaling from open to enclosed motors, comparisons should be based on the same frame size and number of poles. (Baldor, No. 8 at p. 7) Baldor also mentioned that NEMA does not have Premium efficiency levels for 8-pole electric motors, but these levels may be published in the near future before DOE completes its standards rulemaking. (Baldor, Public Meeting Transcript, No. 14 at pp. 140-41) NEMA also expressed concern over scaling between different pole configurations and indicated that it was unclear how DOE intended to do this. (NEMA, No. 13 at p. 17) NEMA voiced concerns about scaling efficiency relative to horsepower rating as well and suggested that scaling can only be performed on electric motors of the same frame number series because it is not necessarily true that all technologies will translate to increased efficiencies in other ratings. (NEMA, No. 13 at p. 18) NEMA added that a scaling relationship cannot consistently be used because of many variables, such as frame size, power density, and cooling. (NEMA, No. 19 at p. 4) Finally, NEMA suggested that the designs for various horsepower and efficiency ratings should be modeled and checked against the results to obtain confidence in the scaling method. (NEMA, No. 13 at p. 18) DOE invites comments from interested parties on potential scaling methodologies based motor losses and corresponding levels of energy efficiency.

DOE recognizes that scaling motor efficiencies is a complicated proposition that has the potential to result in efficiency standards that are not evenly stringent across all equipment classes. However, between DOE's three equipment class groups, there are several hundred combinations of horsepower rating, pole configuration, and enclosure. Within these combinations there are still a large number of standardized frame number series. Given this sizable number of frame number series, DOE cannot feasibly analyze all of these variants -- hence, the need for scaling. Scaling across horsepower ratings, pole configurations, enclosures, and frame number series is a necessity. For the preliminary analysis, DOE considered two methods to scaling, one that develops a set of power law equations based on the relationships found in the EPACT 1992 and NEMA Premium tables of efficiency and one based on the incremental improvement of motor losses. Ultimately, DOE did not find a large discrepancy between the two methods and elected to use the, simpler, incremental improvement of motor losses approach.

The baseline efficiency (CSL 0) is based on the lowest efficiency levels for each horsepower rating, pole configuration, and enclosure type observed in motor catalog data for the motors that DOE plans on including in the expanded scope of conservation standards. For CSL 1 (NEMA MG1-2011 Table 12-11) and CSL 2 (NEMA MG1-2011 Table 12-12), DOE did not have to do any scaling and simply used the efficiency values found in those newly expanded tables.

For the higher CSLs, namely 3, 4, and 5, DOE's conservation of motor losses approach relies on NEMA MG1-2011 Table 12-10 of nominal efficiencies and the relative improvement in motor losses of the representative units. As has been discussed, each incremental improvement in NEMA nominal efficiency (or NEMA band) corresponds to roughly a 10 percent reduction in motor losses. After CSLs 3, 4, and 5 were developed for each representative unit, DOE applied the same reduction in motor losses (or the same number of NEMA band improvements) to various segments of the market based on the representative units. DOE assigned a segment of the electric motors market, based on horsepower ratings, to each representative unit analyzed. DOE's assignments of these segments of the markets were in part based on the standardized NEMA frame number series that NEMA MG1-2011 assigns to horsepower and pole combinations. In the end, each CSL above CSL 2 was one NEMA band above the previous CSL for each representative unit -- i.e. CSL 3 exceeded Table 12-12 by one band, CSL 4 by two, and CSL 5 by three. The second scaling approach that DOE considered is described in detail in Chapter 5 of the preliminary TSD.

### 2.5.7 Other Regulatory Impacts on the Engineering Analysis

In conducting an engineering analysis, DOE recognizes that regulatory changes occurring outside of the standards-setting process can affect equipment manufacturing. Some of these changes can also affect the efficiency of the equipment. DOE attempts to identify all "outside" issues that can impact the engineering analysis.

## 2.6 MARKUPS ANALYSIS

Chapter 6 describes how DOE determined the installed price of electric motors. DOE derived the installed price by applying markups to the manufacturer selling price it determined in the engineering analysis (chapter 5). Markups, sales tax, and installation costs are the costs associated with bringing a manufactured electric motor into service as an installed piece of electrical equipment.

For electric motors, DOE defined six distribution channels and estimated their respective shares of shipments. The six channels are:

(1) from manufacturers to original equipment manufacturers (OEMs) and then to end-users (50 percent of shipments);
(2) from manufacturers to distributors and then to end-users (24 percent of shipments);
(3) from manufacturers to distributors to OEMs and then to end-users (23 percent of shipments);
(4) from manufacturers to end-users through contractors (less than 1 percent of shipments);
(5) from manufacturers to distributors to contractors and then to end-users (less than 1 percent of shipments); and
(6) directly to the end-user (less than 2 percent of shipments). [bb]

Weighting the markups in all six channels by each channel's share of shipments yields an average overall baseline markup of 1.63 and an overall incremental markup of 1.50. DOE used those markups for each equipment class. DOE also analyzed shipping costs as one of the costs that determine installed equipment price.

[bb] Total does not add up to 100 percent due to rounding

Several of the interested parties commented on the distribution channels for electric motors. Nidec, NEMA, and Baldor stated that about half of the electric motors they sold were sold to OEMs, and the other half to distributors. (Nidec, Public Meeting Transcript, No. 14 at pp. 187-188; NEMA, No. 13 at p. 20; Baldor, No. 8 at p. 8) Nidec and NEMA both commented that less than one or two percent of electric motors were sold directly to end-users and contractors. (Nidec, Public Meeting Transcript, No. 14 at pp. 187-188; NEMA, No. 13 at p. 20) Baldor agreed with this comment and further suggested that the contractors category should be removed from the distribution channels. (Baldor, Public Meeting Transcript, No. 14 at pp. 188-189)

NEMA commented that electric motor distributors sell 60 percent of their units to end-users for replacement of failed electric motors or capital projects, while the remaining 40 percent units goes to smaller OEMs. (NEMA, No. 13 at p. 20) Baldor commented similarly that electric motor distributors sell half their electric motors to EASA repair shops and half to national distributors. (Baldor, No. 8 at p. 8, Public Meeting Transcript, No. 14 at pp. 188-189)

GE suggested that importers should be included as part of the distribution chain and commented that electric motors can be sold from OEMs to distributors and from distributors to OEMs. (GE, Public Meeting Transcript, No. 14 at p. 192)

DOE based the description of the distribution channels on a literature review, expert inputs and stakeholder comments received during the public meeting. More details on the description of the distribution channels are available in chapter 6. DOE welcomes stakeholder feedback on the different shares of shipments being sold through each channel.

Two of the interested parties commented that electric motor prices are highly variable and determined mostly at the project level. Nidec commented that the margin on an individual electric motor can vary greatly, based on availability and market opportunities, and there is no average margin or average selling price. (Nidec, Public Meeting Transcript, No. 14 at pp.186-187, 190-191) NEMA commented that there is no linear relationship between cost and selling price. It noted that while margins are important, they are managed at the customer or project level, not at the individual stock-keeping unit level. NEMA further suggested that DOE should include detailed variable and fixed labor and burden rates as well as country of manufacture variances and freight costs. (NEMA, No. 13 at p. 15)

DOE acknowledges that its approach is a simplification of real-world practices, but DOE is unaware of a tractable method for incorporating the practices mentioned in the comments, or for including detailed variable and fixed labor and burden rates as well as country of manufacture variances. Therefore, in the preliminary analysis DOE estimated the equipment price using the markup approach it has used in other energy conservation standards rulemakings. DOE also estimated shipping costs and integrated these in the LCC analysis. DOE requests input from interested parties regarding any viable alternative approach and source of information that could be used to develop equipment prices.

## 2.7 ENERGY USE CHARACTERIZATION

The energy use characterization (chapter 7) estimates the energy use by electric motors. The energy use by electric motors equals the end-use load plus any energy losses associated with electric motor operation. The energy use is derived from three components: useful mechanical shaft power, electric motor losses, and reactive power.[cc] Electric motor losses consist of $I^2R$ (resistance heat) losses, core losses, stray-load losses, and friction and windage losses.

The annual energy consumption of an electric motor that has a given nominal full-load efficiency depends on the electric motor's sector (industry, agriculture, or commercial) and application (compressor, fans, pumps, material handling and processing, fire pumps, and others), which in turn determine the electric motor's annual operating hours and loading.

To calculate the annual kilowatt-hours (kWh) consumed at each efficiency level in each equipment class, DOE used the nominal efficiencies at various loads from the engineering analysis, along with estimates of operating hours and electric motor loading for electric motors in various sectors and applications.

To determine the variation in field energy use in the industry sector, DOE used statistical information on annual electric motor operating hours and loading derived from a database of more than 15,000 field measurements obtained through the Washington State University and the New York State Energy Research and Development Authority. For agriculture and the commercial sector, DOE relied on data found in the literature.

Chapter 7 provides greater detail on the methods, data, and assumptions used for the energy use characterization.

### 2.7.1 Variability in Field Operating Conditions

Two of the interested parties commented on the variability of electric motor usage and energy costs across different types of industry. NEMA commented that process industries and commercial buildings often run electric motors continuously, while many equipment manufacturers operate one or two shifts with a 5-day work week. (NEMA, No. 13 at p. 21) WEG commented that energy costs should be weighted by the hours of operation per industry to ensure that the industries with the highest usage hours and lowest energy costs are properly accounted for. (WEG, No. 5 at p. 1)

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[cc] In an alternating current power system, the reactive power is the root mean square (RMS) voltage multiplied by the RMS current, multiplied by the sine of the phase difference between the voltage and the current. Reactive power occurs when the inductance or capacitance of the load shifts the phase of the voltage relative to the phase of the current. Although reactive power does not consume energy, it can increase losses and costs for the electricity distribution system. Electric motors tend to create reactive power because the windings in the electric motor coils have high inductance.

In the preliminary analysis, DOE characterized the electric motor usage (i.e. load and annual operating hours) by sector and application and developed statistical distributions to represent variability in the field.

### 2.7.2 Impact of Repair on Efficiency

The Electrical Apparatus Service Association (EASA) commented that a comprehensive study has been done by EASA and the Association of Electrical and Mechanical Trades to investigate the effect of repair and rewind on electric motor efficiency. EASA commented that the study showed that electric motor efficiency could be maintained by following the good practices identified in the study. (EASA, No.7 at pp. 1-2)[dd]

In the preliminary analysis, DOE assumed that one-third of repairs are done following good practice as defined by EASA and do not impact the efficiency of the electric motor (i.e., no degradation of efficiency after repair). DOE assumed that two-thirds of repairs do not follow good practice and that a slight decrease in efficiency occurs once the electric motor is repaired. DOE assumed the efficiency decreases by 1 percent in the case of electric motors less than 40 horsepower, and by 0.5 percent in the case of larger electric motors. DOE request comments on this approach.

### 2.7.3 Electric Motor Efficiency and Slip

Baldor commented that the installation of a more efficient electric motor could lead to less energy savings than anticipated. Baldor pointed out that, because a more efficient electric motor usually has less slip than a less efficient one does, this attribute can result in a higher operating speed and a potential overloading of the electric motor. Baldor recommended that DOE include the consequence of a more efficient electric motor operating at an increased speed in any determination of energy savings. (Baldor, No. 8 at pp. 7-8)

DOE acknowledges that the arithmetic cubic relation between speed and power requirement in many variable torque applications can affect the benefits gained by efficient electric motors, which have a lower slip. However, DOE does not have robust data to incorporate this effect in the main analysis. Instead, DOE developed assumptions where no solid data were available and estimated the effects of higher operating speeds as a sensitivity analysis in the LCC spreadsheet. For the eight representative units analyzed in the LCC analysis, the LCC spreadsheet allows one to consider this effect as a sensitivity analysis according to a scenario described in appendix 7A of the TSD.

DOE seeks stakeholder inputs on the methodology and the assumptions that might be used to quantify the impact of higher speeds in energy savings calculations where appropriate and on how to extend this analysis in the NIA. DOE also requests stakeholder input on a possible

[dd] Both EASA Standard AR100-2010 and the EASA/AEMT Rewind Study are available at http://www.easa.com

increase in installation costs when replacing a baseline efficiency electric motor with a more efficient electric motor with a lower slip, due to the necessary speed adjustments required.

## 2.8 LIFE-CYCLE COST AND PAYBACK PERIOD ANALYSIS

In determining whether new or amended energy conservation standards would be economically justified, DOE must consider a number of factors, including the economic impact of potential standards on end-users. (42 U.S.C. § 6295(o)(2)(B)(i)) Chapter 8 describes the LCC analysis, which calculates the discounted savings in operating costs throughout the estimated average life of the covered equipment compared to any increase in the equipment's installed cost likely to result directly from the imposition of a standard. The effect of standards on individual customers includes a change in operating expense (usually a decrease) and a change in purchase price (usually an increase). DOE analyzed the net effect by calculating the change in LCC compared to the base case. Inputs to the LCC calculation include the installed customer cost (purchase price plus shipping, sales tax, and installation cost); operating expenses (energy and maintenance costs); lifetime of the equipment; and a discount rate.

In considering the economic impacts of standards, DOE calculates a PBP as well as changes in LCC that are likely to result from each CSL. Chapter 8 describes the PBP analysis, which calculates the amount of time needed to recover the additional cost that customers pay for increased efficiency. Numerically, the simple PBP is the ratio of the increase in purchase price to the decrease in annual energy costs.

### 2.8.1 Approach

In calculating both the LCC and the PBP, DOE used Monte Carlo simulation and probability distributions (described in appendix 8B) to model both the uncertainty and variability in inputs. Results are represented by distributions. Inputs to the LCC and PBP analysis are:

- electric motor application and sector,
- annual energy use,
- electric motor efficiency,
- electricity prices and price trends,
- operating hours,
- electric motor lifetime, and
- a discount rate.

These variables, and the interactions among them, are discussed further below.

In each Monte Carlo simulation, one application is identified by sampling a distribution of applications for each equipment class. The selected application determines the number of operating hours per year as well as the electric motor loading. DOE used the operating hours and electric motor loading for each application to estimate electric motor energy use. Because of the wide range of applications and electric motor use characteristics considered in the LCC and PBP analysis, the range in annual energy use is quite broad.

There is also a distribution of sectors (i.e., industry, agriculture, and commercial) associated with each application. The sector to which an application belongs determines the energy price and discount rate DOE used to calculate the LCC in each simulation.

Using a baseline distribution of equipment efficiencies for each representative unit, DOE assigned specific equipment efficiency to each unit. If an electric motor was assigned an equipment efficiency that was greater than or equal to the efficiency of the standard level under consideration, the LCC calculation showed that the electric motor unit would not be impacted by that standard level.

DOE collected technical data (e.g., technical specifications, efficiency level, weight) and price information on electric motors currently available for purchase by compiling major manufacturers and distributors' equipment catalogs in a single database and reviewing electric motor data available from MotorMaster+ 4.01.01 (an online NEMA Premium efficiency motor selection and management tool which includes a catalog of more than 20,000 low-voltage induction motors).[ee] The data collected corresponds to the latest catalog data available at the time when the information was collected (between March and May 2012).

DOE welcomes any inputs on alternative sources of information that DOE should consider to improve its knowledge of the current market and technical characteristics of electric motors, and efficiency distributions.

### 2.8.2 Electricity Prices

DOE derived sector-specific average electricity prices for four different U.S. Bureau of the Census (Census) regions (Northeast, Midwest, South, and West) using data from the Energy Information Administration (EIA Form 861). For each sector, DOE assigned electricity prices using a Monte Carlo approach that incorporated weightings based on the estimated share of electric motors in each region. The regional shares were derived based on indicators specific to each sector (e.g., for industry, the value of shipments by Census region from the Manufacturing Energy Consumption Survey [MECS]). To estimate future trends in energy prices, DOE used projections from the EIA's *Annual Energy Outlook 2011* (*AEO 2011*).

Baldor commented that DOE should account for electricity price variations and the distribution of electric motors across the United States. (Baldor, Public Meeting Transcript, No. 14 at pp. 195-196) In the LCC analysis, DOE accounted for the variability in electricity prices as

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[ee] MotorMaster+ is a free online National Electrical Manufacturers Association (NEMA) Premium® efficiency motor selection and management tool that supports motor and motor systems planning by identifying the most efficient action for a given repair or motor purchase decision. The tool includes a catalog of more than 20,000 low-voltage induction motors and features motor inventory management tools, maintenance log tracking, efficiency analysis, savings evaluation, energy accounting, and environmental reporting capabilities. See http://www1.eere.energy.gov/industry/bestpractices/software_motormaster.html.

follows. DOE first derived an average electricity price for four different Census regions (Northeast, Midwest, South and West). For each end use sector, DOE assigned electricity prices using a Monte Carlo approach with weightings according to the estimated share of electric motors in each region. The regional shares were derived based on indicators specific to each sector (e.g., for the electric motor industry, DOE relied on the shipment values by Census region from the MECS).

### 2.8.3 Electric Motor Lifetime

DOE estimated the mechanical lifetime of electric motors in hours (i.e., the total number of hours an electric motor operates throughout its lifetime, including repairs, and routine maintenance) depending on its horsepower size. DOE then developed Weibull distributions of mechanical lifetimes. The lifetime in years for a sampled electric motor was then calculated by dividing the sampled mechanical lifetime by the sampled annual operating hours of the electric motor. This model produces a negative correlation between annual hours of operation and electric motor lifetime: electric motors operated many hours per year are likely to be retired sooner than electric motors that are used for only a few hundred hours per year. DOE considered that electric motors of less than 75 horsepower are most likely to be embedded in a piece of equipment (i.e., an application). For such applications DOE developed Weibull distributions of application lifetimes expressed in years, then compared the sampled motor mechanical lifetime (in years) with the sampled application lifetime. DOE assumed that the electric motor would be retired at the younger of the two ages.

### 2.8.4 Installation Costs

DOE found no evidence that installation costs would increase with higher electric motor energy efficiency. Thus, DOE did not incorporate changes in installation costs for electric motors that are more efficient than baseline equipment.

Several of the interested parties commented that DOE should consider that increasing the efficiency of an electric motor would change its mechanical configuration, specifically its diameter or length. (Nidec, Public Meeting Transcript, No. 14 at pp. 200-201; NEMA, No. 13 at p. 20) Nidec further commented that a change in the mechanical configuration would increase installation costs, compared to installing a baseline electric motor. (Nidec, Public Meeting Transcript, No. 14 at pp. 200-201) Baldor commented similarly, asserting that improving the efficiency of its electric motors would require an increase in stack length. In the case of steel band electric motors, additional stack length will increase frame length and the overall size of the electric motor. Baldor stated that, in the case of cast-iron frame electric motors, there is a fixed length of casting, and adding more stack to increase the electric motor’s efficiency would require the electric motor to be built with a larger diameter frame. (Baldor, Public Meeting Transcript, No. 14 at pp. 202-203; Baldor, No. 8 at p. 7) WEG commented that the installation cost will remain the same, because the electric motors consist of the same mechanical package unless an incentive was made to the manufacturer to change that package. (WEG, No. 5 at p. 1)

In the engineering analysis, when the efficiency of the electric motors was increased, the electric motor frame remains in the same NEMA frame size requirements as the baseline electric motor. In addition, electric motor installation cost data from RS Means Electrical Cost Data

2010 show a variation in installation costs by horsepower (for three-phase electric motors), but not by efficiency. Therefore, in the preliminary analysis, DOE assumed there is no variation in installation costs between a baseline efficiency electric motor and a higher efficiency electric motor. DOE welcomes comments from interested parties on this issue.

### 2.8.5 Repair and Maintenance Costs

Nidec commented that repair and maintenance costs could increase with increasing electric motor efficiency, because of a more active material and the difficulty associated with filling the slot pieces to maintain the efficiency. (Nidec, Public Meeting Transcript, No. 14 at p. 201) For the preliminary analysis, DOE accounted for the differences in repair costs of a higher efficiency electric motor compared to a baseline efficiency electric motor, based on data from a price guide for electric motor repair published by the Vaughen's Price Publishing Company. For maintenance costs, DOE did not find data indicating a variation between a baseline efficiency and higher efficiency electric motor. According to Vaughen's, the price of replacing bearings, which is the most common maintenance practice, is the same at all efficiency levels.

### 2.8.6 Rebates and Incentives

One interested party, Baldor, commented that rebates and incentives from utilities should be included in the LCC calculation. (Baldor, Public Meeting Transcript, No. 14 at pp. 196-197) DOE did not include rebates and incentives in its LCC analysis, because the future prevalence and magnitude of such incentives is highly uncertain. DOE's analysis seeks to evaluate the cost-effectiveness of standards for customers, independent of any other programs that may affect the cost to customers.

## 2.9 SHIPMENTS ANALYSIS

An important component of any estimate of future impacts from energy conservation standards is equipment shipments (chapter 9). DOE uses projections of shipments for the base case and each potential standards case as inputs to the calculation of national energy savings (NES).

In order to develop shipment estimates for electric motors in the expanded scope by horsepower, DOE used data from a market research report[ff], inputs from interested parties, and interested parties' responses to the Request for Information (RFI) published in the Federal Register. 76 FR 17577 (March 30, 2011). DOE estimates total shipments in scope were 4.56 million units in 2011. DOE then used estimates of market distributions to redistribute the shipments across pole configurations and enclosures to provide shipment values for each electric motor equipment class and sector.

Nidec commented that imported equipment with an embedded electric motor should be

[ff] IMS Research (February 2012), The World Market for Low Voltage Motors, 2012 Edition, Austin, TX.

counted in the shipments analysis. (Nidec, Public Meeting Transcript, No. 14 at p. 211). DOE's shipments data represent the sum of U.S. production and imports minus exports and include motors imported as part of larger equipment.

DOE's shipments projection assumes that electric motor sales are driven by machinery production growth for equipment including motors. DOE assumed that growth rates for motor shipments correlate to growth rates in fixed investment in equipment and structures[gg] including motors, as provided by the U.S. Bureau of Economic Analysis's (BEA)[hh]. Additional data on "real gross domestic product" (GDP) from *AEO 2011* for 2015–2035 was used to project fixed investments in the selected equipment and.

### 2.9.1 Repair Versus Replacement

Several of the interested parties commented that higher efficiency levels would increase the rate of repair and rewind, because the significant increase in new electric motor costs prompts users to delay the purchase of new, more efficient electric motors. These commenters added that changes in the physical or electrical characteristics of more efficient electric motors also contribute to an increase in rewind rates. (NEMA, No. 12 at pp. 1-3; NEMA, No. 13 at p. 22; ACEEE, Public Meeting Transcript, No. 14 at p. 95; Baldor, No. 8 at p. 7; UL, Public Meeting Transcript, No. 14 at p. 120)

DOE acknowledges that increased electric motor prices could affect the "repair vs. replace" decision and could lead to increasing the longevity of less efficient electric motors and decreased shipments. However, DOE did not find sufficient data to quantitatively estimate the impact of potential standard levels on shipments and therefore used a price elasticity equal to zero as a default. DOE welcomes recommendations on data sources to help better estimate the impacts of increased efficiency levels on shipments as well as inputs on how to quantitatively estimate these impacts.

Chapter 9 provides greater detail on the methods, data, and assumptions used for the shipments analysis.

## 2.10 NATIONAL IMPACT ANALYSIS

The national impact analysis (NIA; TSD chapter 10) assesses the aggregate impacts of potential efficiency standards at the national level. DOE determined the NES and NPV for the CSLs considered for the equipment classes analyzed. The NES and NPV impacts are the cumulative energy and economic effects of a standard for electric motor energy use. DOE

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[gg] Heating, ventilation, and air conditioning (HVAC) equipment which incorporates motors is typically included in "structures" and not in equipment.

[hh] Bureau of Economic Analysis (March 01, 2012), Private *Fixed Investment in Equipment and Software and structure by Type*. http://www.bea.gov/iTable/iTable.cfm?ReqID=12&step=1

projected impacts from shipments in the 30-year projection period. The NIA includes impacts until all products shipped in the period are retired.

DOE analyzed energy savings, energy cost savings, equipment costs, and NPV of savings (or costs) for each CSL compared to a base case that reflects no amended or new standards. The national energy and cost savings (or increases) that would result from energy conservation standards depend on the projected energy savings per electric motor and the anticipated numbers of electric motors sold. DOE created projections of electric motor shipments in the base case that include the mix of efficiencies being sold at the time the standard would become effective. DOE then derived energy savings for various CSLs for all equipment classes using scaled cost-efficiency relationships from the engineering analysis.

DOE estimated the cumulative national energy consumption of motors shipped during the analysis period, 2015–2044. DOE calculated cumulative NES as the difference between cumulative national energy consumption in the base case (without new or amended energy conservation standards) and under each CSL. DOE estimated energy consumption and savings based on site energy (kilowatt-hours [kWh] of electricity), then converted those values to primary (source) energy using factors that account for losses in transmission, distribution, and electricity generation.

DOE has historically presented NES in terms of primary energy savings. DOE has recently published a Statement of Policy regarding its intent to incorporate full-fuel-cycle (FFC) metrics into its analyses, and outlining a proposed approach. DOE stated that it intends to calculate FFC energy and emission impacts by applying conversion factors generated by the Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) model to the NEMS-based results currently used by DOE. 76 FR 51282 (Aug. 18, 2011). Additionally, DOE will review alternative approaches to estimating these factors and may decide to use a model other than GREET to estimate the FFC energy and emission impacts in any particular future appliance efficiency standards rulemaking. It also stated that DOE will review alternative approaches to estimating these factors and may decide to use a model other than GREET to estimate the FFC energy and emission impacts in any particular future appliance efficiency standards rulemaking. During this review process, DOE examined an approach to developing FFC multipliers using NEMS-BT. This approach is based on AEO projections of future fuel supply and other data that affect the calculations. The GREET model uses a different representation of the energy production system to develop its own internal forecasts, which differ from those in the Annual Energy Outlook. By using the FFC multipliers derived from NEMS-BT, DOE is able to ensure that the multipliers are consistent with the approach used to estimate primary energy savings and emissions impacts.

For this preliminary analysis, DOE calculated FFC energy savings using a NEMS-based methodology described in appendix 10-C. Chapter 10 of this TSD presents both the primary energy savings and the FFC energy savings for the considered candidate standard levels (CSLs).

## 2.11 CUSTOMER SUBGROUP ANALYSIS

In the NOPR phase of the rulemaking, DOE will evaluate the potential impacts of standards on customer subgroups, such as small businesses, to see whether potential energy conservation standards affect them differentially in a significant manner.

The analysis of subgroups of electric motor owners depends on identifying characteristics related to electric motor use or economics that sets a subgroup apart from other electric motor owners. DOE will analyze the effects on those groups by comparing the electric motor owners' capital and operating costs with and without an energy conservation standard. DOE will use LCC analysis methods for subgroup analysis by modifying cost assumptions to reflect the situations of each subgroup. Factors that could result in differential impacts to subgroups include differences in energy prices and electric motor usage.

## 2.12 PRELIMINARY MANUFACTURER IMPACT ANALYSIS

The purpose of the MIA is to identify the likely impacts of higher energy conservation standards on manufacturers. The Process Rule provides guidance for conducting this analysis with input from manufacturers and other interested parties.[ii] DOE will apply this methodology to its evaluation of amended standards for electric motors. The Process Rule gives guidelines for considering financial impacts and a wide range of quantitative and qualitative industry impacts that might occur after adoption of a standard. For example, a particular standard level could require changes to manufacturing practices of electric motors. DOE will identify and discuss these impacts in interviews with manufacturers and other interested parties during the NOPR stage of the analysis.

DOE will conduct the MIA in three phases, and will further tailor the analytical framework based on the comments it receives. In Phase I, DOE creates an industry profile to characterize the industry and identify important issues that require consideration. In Phase II, DOE prepares an industry cash-flow model and an interview questionnaire to guide subsequent discussions. In Phase III, DOE interviews manufacturers and assesses the impacts of amended standards both quantitatively and qualitatively. DOE assesses industry and subgroup cash flow and NPV using the Government Regulatory Impact Model (GRIM). DOE then assesses impacts on competition, manufacturing capacity, employment, and regulatory burden based on manufacturer interview feedback and discussions.

In the past, DOE reported MIA results in its standards rulemakings only in the NOPR phase of the rulemaking. However, DOE is now evaluating and reporting preliminary MIA information at this preliminary analytical phase. DOE gathered the information for the analysis

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[ii] See appendix A to subpart C of 10 CFR Part 430--Procedures, Interpretations and Policies for Consideration of New or Revised Energy Conservation Standards for Consumer Products.

during the manufacturer interviews conducted after the engineering analysis. See Chapter 12 of the preliminary TSD for more detail on the MIA.

ASAP and NEMA stated that the technical parameters to manufacture electric motors for higher efficiency levels can be very difficult or even impossible to implement. For example, the physical size of the electric motor housing cannot be increased in many applications. Also, mandating higher efficiency levels for Design B electric motors may cause the in-rush current to exceed the limits specified in NEMA MG1-2011 paragraph 12.35.1. ASAP and NEMA also commented that manufacturers would be required to use expensive materials in order to meet higher efficiency levels, resulting in increased costs to consumers. (ASAP and NEMA, No. 12 at pp. 2-3) DOE will take these design constraints into consideration when developing equipment and capital conversion costs at each efficiency level for the NOPR phase. DOE will also include the additional material costs at each efficiency level in its manufacturer production cost (MPC) calculations. Both of these costs are integral inputs to the Government Regulatory Impact Model (GRIM) that will be developed during the NOPR phase.

Baldor recommended that DOE attempt to interview and visit both domestic and non-domestic electric motor manufacturers, including some of the smaller foreign electric motor manufacturers, because a large number of electric motors are imported into the U.S. as stand-alone electric motors or included in other equipment. (Baldor, No. 8 at p. 6) DOE seeks to interview a representative cross-section of the electric motors industry and intends to contact manufacturers, including domestic, non-domestic, large, and small manufacturers that can provide a representative picture of the industry.

ASAP and NEMA also commented that forcing manufacturers to invest in small increases in electric motor efficiency above NEMA Premium levels would divert research and development resources from advanced electric motor technologies with better potential for energy savings. (ASAP and NEMA, No. 12 at p. 3) DOE recognizes that there is an opportunity cost associated with any investment and agrees that manufacturers would need to spend capital to meet any efficiency levels above the base case. As a result, manufacturers must determine the extent to which they will balance the investment in upgrading existing electric motors with the decision to invest in new equipment development. DOE will include the equipment and capital conversion costs necessary to meet potential standards in its NOPR analysis.

### 2.12.1 Sources of Information for the Manufacturer Impact Analysis

Several analyses provide important information applicable to the MIA. Such information includes manufacturing costs from the engineering analysis, shipment forecasts, and efficiency distributions. DOE will supplement this information with company financial data and other information gathered during interviews with manufacturers.

The interview process plays a key role in the MIA. DOE aggregates information across manufacturers, creating a combined opinion or estimate for DOE. DOE conducts detailed interviews with manufacturers to gain insight into the range of potential impacts of standards.

Typically, DOE solicits both quantitative and qualitative information during the interviews on the potential impacts of efficiency levels on sales, direct employment, capital assets, and industry competitiveness. DOE prefers an interactive interview process, rather than a written response to a questionnaire, because it helps clarify responses and identify additional issues. Before the interviews, DOE will circulate a draft document showing estimates of the financial parameters based on publicly available information. DOE will solicit comment on these estimates during the interviews. See chapter 12 of the preliminary TSD for more detail on the methodology used in the MIA.

#### 2.12.1.1 Industry Cash-Flow Analysis

The industry cash-flow analysis relies primarily on the GRIM. DOE uses the GRIM to analyze the financial impacts of more stringent energy conservation standards on the industry.

The GRIM analysis uses several factors to determine annual cash flows from an amended energy conservation standard: annual expected revenues; manufacturer costs (including cost of goods sold, depreciation, research and development, selling, and general and administrative expenses); taxes; and conversion capital expenditures. DOE compares the results against base-case projections that involve no amended energy conservation standards. The financial impact of amended energy conservation standards is the difference between the two sets of discounted annual cash flows. Other performance metrics, such as return on invested capital, also are available from the GRIM. See chapter 12 of the preliminary TSD for more information on the industry cash-flow analysis.

### 2.12.2 Manufacturer Subgroup Analysis

Industry cost estimates are inadequate to assess differential impacts among subgroups of manufacturers because these subgroups may have different cost structures or regulatory frameworks that affect their respective business models. For example, small and niche manufacturers, or manufacturers whose cost structure differs significantly from the industry average, could experience a more negative impact. Ideally, DOE would consider the impact on every firm individually; however, because this usually is not possible, DOE typically uses the results of the industry characterization to group manufacturers exhibiting similar characteristics.

During the interview process, DOE will discuss the potential subgroups and subgroup members it has identified for the analysis. DOE will encourage manufacturers to recommend subgroups or characteristics that are appropriate for the subgroup analysis. See chapter 12 of the preliminary TSD for more detail on the manufacturer subgroup analysis.

### 2.12.3 Competitive Impacts Assessment

EPCA directs DOE to consider any lessening of competition likely to result from the imposition of standards. (42 U.S.C. § 6295(o)(2)(B)(i)(V)) It further directs the Attorney General to determine in writing the impacts, if any, of any lessening of competition. (42 U.S.C. § 6295(o)(2)(B)(ii))

DOE will make a determined effort to gather firm-specific financial information and impacts and report the aggregated impact of the amended standard on manufacturers. The competitive impacts analysis will focus on assessing the impacts on smaller manufacturers. DOE will base the assessment on manufacturing cost data and information collected from interviews with manufacturers. The manufacturer interviews will focus on gathering information that would help in assessing asymmetrical cost increases to some manufacturers, an increase in the proportion of fixed costs (with the potential to elevate business risk), and potential barriers to market entry (e.g., proprietary technologies). DOE will provide the Attorney General with a copy of the NOPR for consideration in his evaluation of the impact of standards on the lessening of competition. DOE will publish the Attorney General's letter and address any related comments in the final rule.

### 2.12.4 Cumulative Regulatory Burden

DOE recognizes and seeks to mitigate the overlapping effects on manufacturers of new or amended DOE standards and other regulatory actions affecting the same equipment. DOE will analyze and consider the impact on manufacturers of multiple, equipment-specific regulatory actions.

### 2.12.5 Preliminary Results for the Manufacturer Impact Analysis

One important aspect of the preliminary MIA is the opportunity it creates for DOE to identify key manufacturer issues early in the development of amended energy conservation standards. During preliminary interviews, manufacturers identified five major areas of concern: (1) core steel availability, (2) equipment conversion costs, (3) die cast copper rotors, (4) impacts on competition and domestic production, and (5) increase in equipment repair.

DOE requests comment on its identification of key issues and requests data and information from interested parties that can assist in evaluating the potential impact of amended standards on manufacturers.

#### 2.12.5.1 Core Steel Availability

Manufacturers commented that there is a limited global supply for the types of core steel necessary to build higher efficiency electric motors, particularly high-grade lamination steel. This shortage of higher grade steel could be exacerbated if efficiency standards for other equipment require more widespread use of this steel, causing a sudden increase in demand.

DOE welcomes comment on the supply of core steels used in its designs. In particular, DOE seeks comment on the global and domestic supply of lower loss electrical steels such as M36, M19, and M15 as compared to the projected consumption based on candidate standard levels.

#### 2.12.5.2 Equipment Conversion Costs

Some manufacturers publicly commented that certain technology options required to meet higher efficiency levels may require large capital investments. NEMA stated that a change in materials can have a significant impact on the manufacturing of electric motors, such as the safe handling of the materials, incoming material testing, new tooling, development of new manufacturing processes, and quality control procedures. (NEMA, No. 13 at p. 23) Baldor similarly stated that if high efficiency standards are set, extensive changes in tooling and manufacturing will be required before any energy savings can be realized. (Baldor, No. 8 at p. 2) DOE intends to include all relevant conversion costs driven by standards during the NOPR phase.

During interviews, manufacturers voiced concern about the potential for assets to be stranded due to higher energy conservation standards. For every new capital investment made by manufacturers, some portion of the manufacturers' existing equipment for core production would be stranded. Additionally, manufacturers indicated that there are often very long lead times for obtaining advanced machinery. Specifically, manufacturers estimated that it would take two years for installation of new machinery to be completed after the purchase request is made for some of these capital investments.

#### 2.12.5.3 Copper Die-cast rotors

Manufacturers commented on the impracticability of die-casting copper rotors. Namely, they were concerned with the rising cost of copper, the health hazards of die casting copper, and the difficulty of purchasing copper die casting equipment. Several manufacturers noted that copper die-casting equipment cannot be purchased; instead, copper die-casting companies require manufacturers to contract out this procedure.

Additionally, Baldor commented that they are concerned about the increased level of carbon emissions and energy consumption at their manufacturing facilities due to die-cast copper rotors as well as the increased cost of medical liability under the upcoming health insurance laws. (Baldor, No. 8 at p. 7) DOE is aware of the higher cost of die-cast copper rotors and seeks data showing the relative increase in energy and carbon emissions from die-casting copper. Additionally, DOE seeks data showing potential health insurance cost increases resulting from the use of copper die-casting equipment.

#### 2.12.5.4 Impacts on Competition and Domestic Production

Some manufacturers commented that their competitive ability would decrease with the implementation of amended energy conservation standards. Baldor stated that hand-winding of electric motors will decrease their competitiveness in the global market due to increased labor costs. (Baldor, No. 8 at p. 8) During interviews, manufacturers stated that companies with domestic production already face difficulty competing with companies who manufacture in lower-labor-cost countries, and any standard that requires additional labor will be detrimental to American manufacturing plants. ASAP and NEMA stated that some domestic electric motor manufacturers may elect to exit portions of the market rather than make the necessary investments to meet higher efficiency levels. (ASAP and NEMA, No. 12 at p. 3) Baldor similarly commented that increasing efficiency standards has the potential to drive some manufacturers out of the market for low-volume electric motor designs or to shift manufacturing to locations outside the U.S. (Baldor, No. 8 at p. 2)

DOE will analyze the potential impacts of standards on competition and domestic employment during the NOPR phase and will take these concerns into account.

#### 2.12.5.5 Increase in Equipment Repair

ASAP and NEMA stated that if standards were implemented at high efficiency levels, the increased cost of obtaining compliant electric motors or the change in physical or electrical characteristics could cause customers to rebuild or repair existing electric motors that are less efficient rather than replace them with new efficient electric motors. This could result in a significant lost opportunity for energy savings, particularly because repairing or rewinding an electric motor may not return that electric motor to its previous efficiency. (ASAP and NEMA, No. 12 at p. 3)

Notwithstanding, DOE understands that current repair and rewind practices set forth in the American National Standards Institute/Electrical Apparatus Service Association (ANSI/EASA) publication AR100-2010: "Recommended Practice for the Repair of Rotating Electrical Apparatus," September 2010, and the EASA/Association of Electrical and Mechanical Trades publication "The Effect of Repair/Rewinding on Motor Efficiency," have greatly improved the rewind and repair process for electric motors, and provide the potential for no loss of efficiency after a motor is rewound or repaired.

DOE will take both of the above into consideration as it conducts its analyses for the NOPR, including the shipment projections.

## 2.13 UTILITY IMPACT ANALYSIS

The utility impact analysis estimates specific effects of new or amended energy conservation standards on the electric utility industry. For this analysis, DOE adapted the National Energy Modeling System (NEMS), which is a large, multi-sectoral, partial-equilibrium model of the U.S. energy sector that the EIA has developed throughout the past decade, primarily for preparing EIA's *Annual Energy Outlook* (*AEO*). NEMS, which is available in the public domain, produces a widely recognized baseline energy forecast for the United States through 2035.The typical NEMS outputs include forecasts of electricity sales, prices, and electric generating capacity. In previous rulemakings, a variant of NEMS (currently termed NEMS-BT, BT referring to DOE's Building Technologies Program), was developed to better address the specific impacts of an energy conservation standard.

DOE typically conducts the utility impact analysis as a scenario that departs from the latest *AEO* reference case. In other words, the energy savings impacts from amended energy conservation standards are modeled using NEMS-BT to generate projections that deviate from the *AEO* reference case.

## 2.14 EMPLOYMENT IMPACT ANALYSIS

Standards can affect employment both directly and indirectly. Direct employment impacts are changes in the number of employees at plants that produce the covered equipment and at affiliated distribution and service companies as a result of the new standards. DOE evaluates direct employment impacts in the manufacturer impact analysis. Indirect employment impacts that occur because of the imposition of standards may result from customers shifting expenditures between goods (the substitution effect) and from changes in income and overall expenditure levels (the income effect).

DOE plans to utilize Pacific Northwest National Laboratory's impact of sector energy technologies (ImSET) model to investigate the indirect employment impacts of potential standards. The ImSET model, which was developed for DOE's Office of Planning, Budget, and Analysis, estimates the employment and income effects energy-saving technologies produce in buildings, industry, and transportation. Compared with simple economic multiplier approaches, ImSET allows for a more complete and automated analysis of the economic impacts of energy conservation investments.

## 2.15 EMISSIONS ANALYSIS

In the emissions analysis, DOE will estimate the reduction in power sector emissions of carbon dioxide ($CO_2$), nitrogen oxides ($NO_x$), and mercury (Hg) using the NEMS-BT computer model. In the emissions analysis, NEMS-BT is run similarly to the *AEO* NEMS, except that electric motors energy use is reduced by the amount of energy saved (by fuel type) due to each standard level considered. The inputs of national energy savings come from the NIA spreadsheet model, while the output is the forecasted physical emissions. The net benefit of each considered standard level is the difference between the forecasted emissions estimated by NEMS-BT at that level and the latest *AEO* Reference Case.

### 2.15.1 Carbon Dioxide

In the absence of any Federal emissions control regulation of power plant emissions of $CO_2$, a DOE standard is likely to result in reductions of these emissions. The $CO_2$ emission reductions likely to result from a standard will be estimated using NEMS-BT and national energy savings estimates drawn from the NIA spreadsheet model. The net benefit of the standard is the difference between emissions estimated by NEMS-BT at each standard level considered and the *AEO* Reference Case. NEMS-BT tracks $CO_2$ emissions using a detailed module that provides results with broad coverage of all sectors and inclusion of interactive effects.

### 2.15.2 Sulfur Dioxide

$SO_2$ emissions from affected electric generating units (EGUs) are subject to nationwide and regional emissions cap and trading programs, and DOE has preliminarily determined that these programs create uncertainty about the potential standards' impact on $SO_2$ emissions. Title IV of the Clean Air Act sets an annual emissions cap on $SO_2$ for affected EGUs in the 48 contiguous states and the District of Columbia (D.C.). $SO_2$ emissions from 28 eastern states and D.C. are also limited under the Clean Air Interstate Rule (CAIR, 70 Fed. Reg. 25162 (May 12, 2005)), which created an allowance-based trading program. Although CAIR has been remanded to EPA by the U.S. Court of Appeals for the District of Columbia Circuit (D.C. Circuit), see *North Carolina v. EPA*, 550 F.3d 1176 (D.C. Cir. 2008), it remains in effect temporarily, consistent with the D.C. Circuit's earlier opinion in *North Carolina v. EPA*, 531 F.3d 896 (D.C. Cir. 2008). On July 6, 2011 EPA issued a replacement for CAIR, the Cross-State Air Pollution

Rule. 76 FR 48208 (August 8, 2011). (See http://www.epa.gov/crossstaterule/). On December 30, 2011, however, the D.C. Circuit stayed the new rules while a panel of judges reviews them, and told EPA to continue enforcing CAIR (see *EME Homer City Generation v. EPA*, No. 11-1302, Order at *2 (D.C. Cir. Dec. 30, 2011)).

The attainment of emissions caps is typically flexible among EGUs and is enforced through the use of emissions allowances and tradable permits. Under existing EPA regulations, any excess $SO_2$ emissions allowances resulting from the lower electricity demand caused by the imposition of an efficiency standard could be used to permit offsetting increases in $SO_2$ emissions by any regulated EGU. However, if the standard resulted in a permanent increase in the quantity of unused emissions allowances, there would be an overall reduction in $SO_2$ emissions from the standards. While there remains some uncertainty about the ultimate effects of efficiency standards on $SO_2$ emissions covered by the existing cap and trade system, the NEMS-BT modeling system that DOE uses to forecast emissions reductions currently indicates that no physical reductions in power sector emissions would occur for $SO_2$. DOE acknowledges, however, that even though there is a cap on $SO_2$ emissions and uncertainty whether efficiency standards would reduce $SO_2$ emissions, it is possible that standards could reduce the compliance cost by reducing demand for $SO_2$ allowances.

### 2.15.3 Nitrogen Oxides

Under CAIR, there is a cap on $NO_x$ emissions in 28 eastern states and the District of Columbia. All these States and the District of Columbia (DC) have elected to reduce their NOx emissions by participating in cap-and-trade programs for EGUs. Therefore, energy conservation standards for electric motors may have little or no physical effect on these emissions in the 28 eastern states and the DC for the same reasons that they may have little or no physical effect on $NO_X$ emissions. DOE will use the NEMS-BT to estimate $NO_x$ emissions reductions from possible standards in the States where emissions are not capped.

### 2.15.4 Mercury

On February 16, 2012, EPA announced national emissions standards for hazardous air pollutants (NESHAPs) for mercury and certain other pollutants emitted from coal and oil-fired EGUs. 76 FR 24976. The NESHAPs do not include a trading program and, as such, DOE's energy conservation standards would likely reduce Hg emissions. For the emissions analysis for this rulemaking, DOE plans to estimate mercury emissions reductions using NEMS-BT based on *AEO*, which does not incorporate the NESHAPs. DOE expects that future versions of the NEMS-BT model will reflect the implementation of the NESHAPs.

### 2.15.5 Particulate Matter

DOE acknowledges that particulate matter (PM) exposure can impact human health. Power plant emissions can have either direct or indirect impacts on PM. A portion of the pollutants emitted by a power plant are in the form of particulates as they leave the smokestack. These are direct, or primary, PM emissions. However, the great majority of PM emissions associated with power plants are in the form of secondary sulfates, which are produced at a significant distance from power plants by complex atmospheric chemical reactions that often involve the gaseous (non-particulate) emissions of power plants, mainly $SO_2$ and $NO_x$. The quantity of the secondary sulfates produced is determined by a very complex set of factors including the atmospheric quantities of $SO_2$ and $NO_x$, and other atmospheric constituents and conditions. Because these highly complex chemical reactions produce PM comprised of different constituents from different sources, EPA does not distinguish direct PM emissions from power plants from the secondary sulfate particulates in its ambient air quality requirements, PM monitoring of ambient air quality, or PM emissions inventories. For these reasons, it is not currently possible to determine how the amended standard impacts either direct or indirect PM emissions. Therefore, DOE is not planning to assess the impact of these standards on PM emissions. Further, as described previously, it is uncertain whether efficiency standards will result in a net decrease in power plant emissions of $SO_2$, which are now largely regulated by cap and trade systems.

One stakeholder, Baldor, commented that the change in electric motor manufacturing equipment associated with increasing efficiency—specifically the use of copper rotors, retooling, and a higher level of steel—would cause extra processing to be performed and would increase energy use, potentially increasing air emissions. (Baldor, Public Meeting Transcript, No. 14 at pp. 232-233) In response, DOE notes that EPCA directs DOE to consider the total projected amount of energy, or as applicable, water, savings likely to result directly from the imposition of the standard when determining whether a standard is economically justified. (42 U.S.C. 6295(o)(2)(B)(i)(III)) DOE interprets this to include energy used in the generation, transmission, and distribution of fuels used by appliances or equipment. In addition, DOE is evaluating the full-fuel-cycle measure, which includes the energy consumed in extracting, processing, and transporting primary fuels. DOE's current accounting of primary energy savings and the full-fuel-cycle measure are directly linked to the energy used by appliances or equipment. DOE believes that energy used in manufacturing of appliances or equipment falls outside the boundaries of "directly" as intended by EPCA. Thus, DOE did not consider such energy use and air emissions in the NIA and in the emissions analysis.

## 2.16 MONETIZATION OF EMISSIONS REDUCTION BENEFITS

DOE will consider the estimated monetary benefits likely to result from the reduced emissions of $CO_2$ and $NO_X$ that are expected to result from each of the standard levels considered.

In order to estimate the monetary value of benefits resulting from reduced emissions of $CO_2$, DOE plans to use the most current Social Cost of Carbon (SCC) values developed and/or agreed to by an interagency process. The SCC is intended to be a monetary measure of the incremental damage resulting from greenhouse gas (GHG) emissions, including, but not limited to, net agricultural productivity loss, human health effects, property damage from sea level rise, and changes in ecosystem services. Any effort to quantify and to monetize the harms associated with climate change will raise serious questions of science, economics, and ethics. But with full regard for the limits of both quantification and monetization, the SCC can be used to provide estimates of the social benefits of reductions in GHG emissions.

At the time of this notice, the most recent interagency estimates of the potential global benefits resulting from reduced $CO_2$ emissions in 2011, expressed in 2011$, were $5.0, $22.5, $37.0, and $68.4 per metric ton avoided. For emissions reductions that occur in later years, these values grow in real terms over time. Additionally, the interagency group determined that a range of values from 7 percent to 23 percent should be used to adjust the global SCC to calculate domestic effects, although DOE will give preference to consideration of the global benefits of reducing $CO_2$ emissions. To calculate a present value of the stream of monetary values, DOE will discount the values in each of the four cases using the discount rates that had been used to obtain the SCC values in each case.

DOE recognizes that scientific and economic knowledge continues to evolve rapidly as to the contribution of $CO_2$ and other GHG to changes in the future global climate and the potential resulting damages to the world economy. Thus, these values are subject to change.

DOE also intends to estimate the potential monetary benefit of reduced $NO_X$ emissions resulting from the standard levels it considers. For $NO_x$ emissions, available estimates suggest a very wide range of monetary values for $NO_X$ emissions, ranging from $455 to $4,679 per ton in 2011$).[jj] In accordance with U.S. Office of Management and Budget (OMB) guidance, DOE will conduct two calculations of the monetary benefits derived using each of the economic values used for $NO_x$, one using a real discount rate of 3 percent and another using a real discount rate of 7 percent.[kk]

DOE does not plan to monetize estimates of Hg in this rulemaking. DOE is aware of multiple agency efforts to determine the appropriate range of values used in evaluating the potential economic benefits of reduced Hg emissions. DOE has decided to await further guidance regarding consistent valuation and reporting of Hg emissions before it once again monetizes Hg in its rulemakings.

## 2.17 REGULATORY IMPACT ANALYSIS

In the NOPR stage, DOE will prepare a regulatory impact analysis (RIA) pursuant to Executive Order 12866, Regulatory Planning and Review, 58 FR 51735, October 4, 1993, which is subject to review under the Executive Order by the Office of Information and Regulatory Affairs at the OMB. The RIA addresses the potential for nonregulatory approaches to supplant or augment energy conservation standards in order to improve the energy efficiency or reduce the energy consumption of the equipment covered under this proposed rulemaking.

DOE recognizes that voluntary or other nonregulatory efforts by manufacturers, utilities, and other interested parties can substantially affect energy efficiency or reduce energy

[jj] For additional information, refer to U.S. Office of Management and Budget, Office of Information and Regulatory Affairs, 2006 Report to Congress on the Costs and Benefits of Federal Regulations and Unfunded Mandates on State, Local, and Tribal Entities, Washington, DC.

[kk] OMB, Circular A-4: Regulatory Analysis (Sept. 17, 2003).

consumption. DOE plans to base its regulatory impact assessment on the actual impacts of any such initiatives to date, but also will consider, to the extent possible, information presented by interested parties regarding the impacts current initiatives might have in the future. (See chapter 17 of the preliminary TSD)

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