# CHAPTER 3. MARKET AND TECHNOLOGY ASSESSMENT

## TABLE OF CONTENTS

## LIST OF TABLES



## LIST OF FIGURES

# CHAPTER 3. MARKET AND TECHNOLOGY ASSESSMENT

## 3.1 INTRODUCTION

This chapter provides a profile of the electric motor industry in the United States. The U.S. Department of Energy (DOE) developed the preliminary market and technology assessment presented in this chapter primarily from publicly available information. This assessment is helpful in identifying the major manufacturers and their equipment characteristics, which form the basis for the engineering and life-cycle cost (LCC) analyses.

This chapter consists of two sections: the market assessment and the technology assessment. The market assessment provides an overall picture of the market for the equipment concerned, including a scope of the equipment covered, equipment classes, industry structure, manufacturer market shares; regulatory and non-regulatory efficiency improvement programs; and market trends and quantities of equipment sold. The technology assessment identifies a preliminary list of technology options for reducing motor losses to consider in the screening analysis.

The information DOE gathers for the market and technology assessment serves as resource material for use throughout the rulemaking. DOE considers both quantitative and qualitative information from publicly available sources and interested parties.

## 3.2 MARKET ASSESSMENT

This section addresses the scope of the rulemaking, identifies potential equipment classes, estimates national shipments of electric motors, and the market shares of electric motor manufacturers. This section also discusses the application and performance of existing equipment and regulatory and non-regulatory programs that apply to electric motors.

### 3.2.1 Electric Motor Definitions

The Energy Policy and Conservation Act (EPCA), as amended by the Energy Policy Act of 1992 (EPACT 1992), had previously established a definition for "electric motor" as "any motor which is a general purpose T-frame, single-speed, foot-mounting, polyphase squirrel-cage induction motor of the National Electrical Manufacturers Association (NEMA]) Design A and B, continuous rated, operating on 230/460 volts and constant 60 Hertz line power as defined in NEMA Standards Publication MG1–1987." (42 U.S.C. 6311(13)(A) (1992)) Through subsequent amendments to EPCA and, in particular, the Energy Independence and Security Act that was signed into law on December 19, 2007 (EISA 2007), Congress struck the EPACT 1992 definition and replaced it with language that covered a broader scope of general purpose electric motors, (See 42 U.S.C. 6311(13)(A)-(B) (2010)).

Consequently, the new terminology adopted as a result of EISA 2007 generated confusion over the definitions of the terms "electric motor" and "general purpose electric motor." As a result, DOE sought to clarify its interpretations of these definitions in a rulemaking about test procedures for electric motors. On May 4, 2012, DOE published in the *Federal Register* a test procedure final rule for electric motors which clarified the two definitions. 77 FR 26608 A regulatory definition of “electric motor” was promulgated in light of EISA 2007’s removal of the statutory definition of “electric motor.” The definition of “general purpose motor” (now “general purpose electric motor”) was taken directly from the industry standard NEMA MG1-1993 and was intended to specify a broad category of motors that were potentially subject to regulation. The term “electric motor” enumerated specific construction and performance characteristics required for a “general purpose motor” to be covered equipment under Title 10 of the Code of Federal Regulations, Part 431 (10 CFR Part 431).

The test procedure was intended to clear up confusion over the definitions of “electric motor” and “general purpose electric motor.” The test procedure final rule defined the two terms as follows:

*“Electric motor* means a machine that converts electrical power into rotational mechanical power.”

and

*“General purpose electric motor* means any electric motor that is designed in standard ratings with either:

(1) Standard operating characteristics and mechanical construction for use under usual service conditions, such as those specified in NEMA MG1–2009, paragraph 14.2, “Usual Service Conditions,” (incorporated by reference, see § 431.15) and without restriction to a particular application or type of application; or

(2) Standard operating characteristics or standard mechanical construction for use under unusual service conditions, such as those specified in NEMA MG1–2009, paragraph 14.3, “Unusual Service Conditions,” (incorporated by reference, see § 431.15) or for a particular type of application, and which can be used in most general purpose applications.”

EISA 2007 also introduced and established energy conservation standards for several new categories of electric motors. As such, the test procedure final rule sought to clarify DOE’s interpretation of these terms. Ultimately, DOE created new definitions for the terms “general purpose electric motor (subtype I),” “general purpose electric motor (subtype II),” “NEMA Design B motor,” and “fire pump electric motor,” which are shown below.

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.

Further, the recent electric motors test procedure final rule amended 10 CFR 431.12, which now defines 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) but, unlike a general purpose electric motor (subtype I), 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).

Also, as a result of the electric motors test procedure final rule, 10 CFR 431.12 defines a NEMA Design B 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.

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 NFPA 20 (incorporated by reference, see § 431.15).

#### 3.2.1.1 Expanded Scope Definitions

DOE's expanded scope of coverage requires clarifying the terminology related to a number of motor types and, in particular which types of motors would be subject to energy conservation standards and which types would not be subject to minimum standards. NEMA MG1-2011 contains defining language for some of these electric motor types. Where possible, DOE used this language from NEMA MG1–2011 to build potential definitions for some motor types, such as "encapsulated electric motor" as well as NEMA Design A and C electric motors. However, some of the motor types that DOE plans on subjecting to energy conservation standards, such as "partial electric motor" or "air-over electric motor," are not defined in NEMA MG1–2011. Additionally, DOE is not aware of standard, industry-accepted definitions for many of these motor types and will look to create them in a test procedure rulemaking that is being developed in parallel with this motor standards rulemaking. DOE believes the lack of clearly defined, standard motor definitions could cause confusion concerning which motor types are subject to efficiency regulations. Therefore, DOE has worked with industry experts in an effort to create working definitions for various motor types that DOE plans on including in the expansion of energy conservation standards. DOE also looks to create definitions for motor types that are specifically called out from being covered under energy conservation standards. A more in-depth discussion of these motor types, as well as reasons for DOE including or excluding them in the expanded scope of energy conservation standards, are discussed in more detail in chapter 2 of the preliminary technical support document (TSD). Below, DOE presents a short summary of the motor characteristics and the definitions it is considering for each motor type.

*Air-Over Electric Motors*

Air-over electric motors require an external, separate means of cooling to allow continuous duty operation. These motors are subject to over-heating and therefore cannot run continuously without a specified amount of air flowing over the motor housing, which is typically specified by the manufacturer.

DOE may consider proposing to include a definition for "air-over electric motor" based on the MG1–2011 paragraph 1.26.9 definition of a "totally enclosed air-over machine" with modifications to the definition to also include air-over electric motors with an open-frame construction. DOE wishes to make this change in an effort to broaden the scope of the NEMA MG1–2011 definition to include air-over electric motors with both totally enclosed and open-frame constructions. DOE believes both frame constructions of these motor types use the same methods for heat dissipation and therefore looks to define them under the same term. DOE is considering the following definition for "air-over electric motor:"

> *Air-over electric motor* means an electric motor designed for cooling by a ventilating means external to and not supplied with the motor.

*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 "clamps" down on the motor shaft to quickly stop rotation of the motor.

DOE may consider 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 require disassembly of the motor which may adversely affect its performance.

DOE is considering the following definitions for "non-integral brake motor" and "integral brake motor" based on comments and feedback from industry experts and NEMA. DOE is using comments and feedback to define these motor types because there is no definition for these motor types in MG1–2011. DOE plans to adopt the following definitions:

*Integral brake motor* means an electric motor containing a brake mechanism either inside of the motor endshield or between the motor fan and endshield such that removal of the brake component would require extensive disassembly of the motor or motor parts.

*Non-integral brake motor* means an electric motor containing a brake mechanism attached externally in such a manner that it could be readily detached from the motor without extensive disassembly of the motor or motor components.

*Component Sets*

Component sets of electric motors are comprised of a combination of motor parts, such as a stator, rotor, shaft, stator housing, shaft bearings, endshields, or other electric motor parts. DOE delineated between component sets and partial motors in chapter 2 of the preliminary TSD when it called out partial motors as motors only missing one or more endshields. Endshields are the circular, metal plates on each end of the motor that enclose the ends of the motor and house the shaft bearings and possibly other components. Component sets are typically sold to be turned into complete electric motors or installed in equipment by the end-user.

DOE is considering the following definition of “component sets” of electric motors based on comments gathered from subject matter experts (SME), NEMA, and other industry experts. DOE is taking this approach because there is no definition for these motor types in MG1–2011.

*Component set* means a combination of motor parts that require more than the addition of two endshields to create an operable motor. These parts may consist of any combination of a stator frame, wound stator, rotor, shaft, or endshields.

*Motors with Customer Defined Endshields*

Motors may have special or customer-defined endshields, flanges, bases, or mounting feet that do not conform to NEMA MG1–2011 standards for typical endshields, flanges, bases, or mounting feet dimensions. DOE may consider proposing a definition for motor types with “customer-defined endshields” that are based on comments and feedback from industry experts and NEMA. DOE bases this definition on electric motors that deviate from the standard endshield or flange mounting specifications for Type C face-mounting, Type D flange-mounting, or Type P flange-mounting types specified in NEMA MG1-2011, paragraphs 1.63.1, 1.63.2, and 1.63.3 respectively. DOE is taking this approach because there is no definition for these motor types in MG1–2011. DOE is considering the following definition for electric motors with customer defined endshields:

A motor with *customer defined endshields* means an electric motor with customized flanges which do not conform to NEMA MG1–2011 paragraphs 1.63.1, 1.63.2, or 1.63.3.

*Encapsulated Electric Motors*

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 drip-proof (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 may consider proposing a definition for “encapsulated electric motors” based on the definition of “machine with sealed windings” in paragraph 1.27.2 from NEMA MG1–2011. DOE is considering the following definition for electric motors with encapsulated stator windings:

*Encapsulated electric motor* means an electric motor that has an insulation system which, through the use of materials, processes, or a combination of materials and processes, results in windings and connections that are sealed against contaminants. This type of machine is intended for environmental conditions and shall be capable of passing the conformance test in NEMA MG1–2011 paragraph 12.62.

*IEC Design N Electric Motors*

IEC Design N electric motors are similar to NEMA Design B electric motors with regards to locked-rotor limits and torque performance requirements. While IEC Design N motors are currently subject to energy conservation standards, DOE is looking to add a definition for them in order to clarifying any coverage-ambiguity.

DOE may consider proposing to set a definition for "IEC Design N electric motor" that would incorporate language from IEC Standard 60034-12 (2007 Ed. 2.1) with some modifications that would make the definition more comprehensive. The IEC Standard 60034-12 (2007 Ed. 2.1) defines IEC Design N motors as "normal starting torque three-phase cage induction motors intended for direct-on-line starting, having 2, 4, 6 or 8 poles and rated from 0,4 kW to 1,600 kW," with torque characteristics and locked-rotor characteristics described in later tables. DOE looks to modify this definition to include all references to tables for torque characteristics and locked-rotor characteristics tables to clarify the performance requirements of IEC Design N electric motors in the definition. DOE is considering the following definition for IEC Design N motors:

> *IEC design N electric motor* means an electric motor with a three-phase cage induction motor intended for direct-on-line starting, having 2, 4, 6, or 8 poles, rated from 0.4 kW to 1,600 kW and conforming to the IEC 60034-12 edition 2.1 torque characteristics found in section 6.1, locked rotor apparent power in section 6.2, and starting requirements in section 6.3.

*Immersible Electric Motors*

Immersible motors are motors capable of being submerged and removed from liquid without damaging or destroying the motor. Immersible motors are different than submersible motors because they are not designed to run while submerged in liquid. DOE understands that immersible motors do not rely on the cooling provided by submersion in liquid to operate continuously. DOE is also aware that industry sometimes interchanges the use of the two terms "immersible" and "submersible." Because of the potential confusion of the two terms, DOE believes it may be appropriate to provide definitions for both immersible and submersible electric motor types.

The definition DOE is considering for "immersible electric motor" is based on comments and feedback from industry experts and NEMA. DOE may consider proposing a definition for this motor type in an effort to provide clarification concerning electric motor types that may be subject to efficiency regulation and those that are exempt. The definition DOE is considering for this motor type is:

> *Immersible electric motor* means an electric motor designed to withstand complete immersion in liquid for a limited amount of time.

*Inverter-Capable Electric Motors*

An inverter is a device used to control the speed or torque characteristics of a motor. Inverters may also be referred to as inverter drives, drives, variable speed drives, variable frequency drives, adjustable frequency drives, alternating current (AC) drives, or microdrives. Inverters serve as special electronic controllers to help manipulate the power source of a motor. Inverters are used to slow the rotation of a motor or provide a constant torque output of the motor. Motors that can operate on an inverter may require special construction or design changes to withstand the abnormally harsh operating conditions an inverter may subject a motor to, such as increased operating temperatures or increased harmonic distortion of the motor's power supply. Inverters are considered by DOE as part of an "advanced motor system" and are discussed in more detail in chapter 2 of the preliminary TSD.

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 may be referred to as "inverter duty" in the motor industry. 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 line power source (i.e., it can be run continuously without an inverter). 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 does not necessitate an inverter for continuous-duty operation. The second type of motor that the motor industry may refer to as "inverter duty" is a motor that cannot operate continuously without the use of an inverter. This motor type is discussed under the title "inverter-only electric motor" section below.

DOE wishes to create a clear understanding of each of these two motor types because it understands that there is no industry accepted definitions delineating between motors capable of running continuously on an inverter and motors that can only be run continuously on an inverter. DOE is considering creating a clear, succinct definition for this motor type in an effort to clarify which motor types may be subject to energy conservation standards. The definition DOE is considering for "inverter-capable electric motor" is based on feedback and comments from industry experts, SMEs, and NEMA and reads:

> *Inverter-capable electric motor* means an electric motor that can run continuously when directly connected to polyphase, sinusoidal line power, but is also capable of handling continuous operation on an inverter drive.

*Inverter-Only Electric Motors*

The section above mentions the two types of electric motors capable of being run on an inverter. The first type DOE refers to as an 'inverter-capable' electric motor. The second type of motor often referred 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 resulting from inverter operation, such as harmonic distortion of the power signal, dielectric stresses resulting from voltage spikes, or hotter-than-typical operating temperatures resulting from insufficient air cooling. This motor, unlike an "inverter capable" motor, is specifically built for the conditions resulting from inverter-fed operation, and are therefore generally more expensive to build than an “inverter capable” motor. This second motor type cannot be used for continuous duty operation on line power without an inverter. DOE plans to refer to this second type of motor as an “inverter-only electric motor” because it is specifically built to only operate continuously when operated on an inverter.

The definition DOE is considering for “inverter-only electric motor” is based on feedback and comments from industry experts, SMEs, and NEMA. As discussed above, DOE looks to create a clear, succinct definition for this motor type in an effort to clarify which electric motor types may be subject to energy conservation standards. The definition DOE plans on proposing for “inverter-only electric motor” is:

> *Inverter-only electric motor* means an electric motor designed such that it can only be run continuously when operated through an inverter drive.

*Liquid-Cooled Electric Motors*

Liquid-cooled electric motors rely on a special cooling apparatus that pumps liquid into and around the motor frame. The liquid is circulated around the motor to dissipate heat and prevent the motor from overheating during continuous duty operation. The user of a liquid-cooled motor may employ different liquids or liquid temperatures which could affect the measured efficiency of a motor.

DOE is considering defining “liquid-cooled electric motor” based on the definition of “totally enclosed water-cooled machine” in paragraph 1.26.5 of MG1–2011, with some changes. DOE is proposing to remove “totally enclosed” from the definition so that open-frame motors that are liquid-cooled would also be included in this definition. DOE also plans on replacing the term “water” with “liquid” to include motor types that may use other types of liquids, not just water, as a coolant. DOE is considering the following definition for “liquid-cooled electric motor”:

> *Liquid-cooled electric motor* means an electric motor that is cooled by circulating liquid, with the liquid or liquid conductors coming in direct contact with the machine parts.

*NEMA Design A Electric Motors*

NEMA MG1–2011 defines four types of polyphase, AC induction motors, NEMA design types A, B, C, and D. As stated above, DOE has already adopted a definition for NEMA Design B electric motors. NEMA MG1–2011 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 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.

DOE is considering defining "NEMA Design A electric motor" based on the definition found in NEMA MG1–2011 paragraph 1.19.1.1. DOE believes that the MG1–2011 definition of "NEMA Design A" electric motor is clear and concise and may consider proposing to define this term as:

> *NEMA design A electric motor* means a squirrel-cage motor designed to withstand full-voltage starting and developing locked-rotor torque as shown in NEMA MG1–2011 paragraph 12.38, pull-up torque as shown in NEMA MG1–2011 paragraph 12.40, breakdown torque as shown in NEMA MG1–2011 paragraph 12.39, with locked-rotor current higher than the values shown in paragraph 12.35.1 for 60 hertz and paragraph 12.35.2 for 50 hertz and having a slip at rated load of less than 5 percent for motors fewer than 10 poles.

*NEMA Design C Electric Motors*

Similarly, NEMA MG1-2011also establishes different torque requirements for NEMA Design C electric motors relative to NEMA Design A and B motors. NEMA Design C motors are typically used for applications that require high starting-torque applications, such as rock crushers or other crushing applications. DOE has placed NEMA Design C motors in their own equipment class group for the preliminary analysis. Therefore, DOE believes adopting a formal definition would be consistent with its potential adoption of NEMA Design B and NEMA Design A electric motor definitions.

DOE is considering a definition of "NEMA Design C electric motor" based on the definition found in NEMA MG1–2011 paragraph 1.19.1.3. DOE believes that the MG1–2011 definition of "NEMA Design C" electric motor is clear and concise and plans to propose to define this term as:

> *NEMA Design C electric motor* means a squirrel-cage motor designed to withstand full-voltage starting, developing locked-rotor torque for high-torque applications up to the values shown in NEMA MG1–2011 paragraph 12.38, pull-up torque as shown in NEMA MG1–2011 paragraph 12.40, breakdown torque up to the values shown in NEMA MG1–2011 paragraph 12.39, with locked-rotor current not to exceed the values shown in paragraph 12.35.1 for 60 hertz and paragraph 12.35.2 for 50 hertz, and having a slip at rated load of less than 5.

*Partial Electric Motors*

DOE understands partial motors, also called "partial ¾ motors" or "¾ motors," as motors that are missing one or both endshields. These motors may have an endshield removed to allow the motor to be directly 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.

DOE is considering creating a standard, industry-accepted definition of the term "partial electric motor" in order to clarify its understanding of a potential expansion of scope of energy conservation standards. Additionally, DOE believes it is currently used inconsistently as an "umbrella" term to describe a wide range of electric motor types, including motor types that DOE believes should fall under the definition of "component sets" of electric motors. DOE is considering a definition of "partial electric motor" based on discussions with industry experts, SMEs, and comments from NEMA and other motor-industry groups. DOE hopes to clarify energy conservation standards coverage for this rulemaking by setting clear definitions for "partial motors." The definition DOE is considering for "partial electric motor" is:

> *Partial electric motor* means an electric motor necessitating only the addition of one or two endshields with bearings to create an operable motor. Included under this definition are integral motors and partial ¾ motors.

*Submersible Electric Motors*

DOE understands submersible electric motors are only capable of continuous duty operation while completely submerged in liquid. Submersible motors are similar to liquid-cooled motors because they use liquid to dissipate the heat produced during this continuous duty operation. However, submersible motors are typically submerged in a liquid as opposed to liquid-cooled electric motors that use a separate hose and pump apparatus connected to the motor. DOE believes a motor designed to operate while submerged in open water and a motor that utilizes a hose and pump apparatus could create significant design changes which would warrant separate definitions. Therefore, DOE is considering separate definitions for these two motor types to avoid any potential ambiguity between the two motor types.

DOE is considering defining "submersible electric motor" based on the description of "submersible motors for deep well pumps" in NEMA MG1–2011 part 18, page 52. The definition DOE is considering is:

> *Submersible electric motor* means an electric motor designed for continuous operation while submerged in a liquid. Such a motor is unable to operate continuously if not submerged in liquid.

*Totally Enclosed Non-Ventilated Electric Motors*

A majority of the medium-size electric motors shipped in the U.S. are TEFC. These motors have a fan on the outside of the end opposite the drive-end which blows air over the surface of the motor (typically the fan is enclosed by a metal fan cover). This airflow over the surface of the motor helps dissipate heat during the motor's operation. Unlike 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 TEFC motors. 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.

DOE is considering defining the term "totally enclosed, non-ventilated electric motor" based on the definition of a "totally enclosed non-ventilated machine" in paragraph 1.26.1 in NEMA MG1–2011. DOE believes this definition is clear and concise and is considering the definition verbatim. DOE is considering the following definition of a TENV motor:

> *Totally enclosed non-ventilated (TENV) motor* means a motor that is a frame-surface cooled totally enclosed machine which is only equipped for cooling by free convection.

### 3.2.2 Equipment Class Groups and Equipment Classes

Within each category of electric motors it addressed, EISA 2007 set separate energy conservation standards by horsepower rating, enclosure type, and pole configuration. These standards correspond to Table 12-12 of NEMA MG 1–2011 (equivalent to NEMA Premium[a]) for general purpose electric motors (subtype I) and Table 12-11 of NEMA MG1–2011 (equivalent to EPACT 1992 values) for 1 to 200 horsepower general purpose electric motors (subtype II), fire pump electric motors, and NEMA Design B electric motors greater than 200 horsepower.[b] (42 U.S.C. 6313(b)(2))

In general, when DOE amends energy conservation standards, it 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 efficiency levels, such as features affecting consumer utility. (42 U.S.C. 6295(q)) As a result of changes in 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 considered in this rulemaking. In the following sections, DOE discusses the design features that it is considering as part of its analysis.

Due to the number of electric motor characteristics (e.g., horsepower rating, pole configuration, and enclosure), DOE is using two constructs, at this stage, 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

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[a] NEMA Premium efficiency levels refer to the efficiency values in NEMA MG1-2011 Table 12-12.
[b] EISA 2007 also set minimum conservation levels for subtype I motors from 201-500 horsepower at the EPACT 1992 levels.

equipment class group, while the combination of the remaining characteristics dictates the specific equipment class.

For the preliminary analysis DOE has created three equipment class groups based on two main motor 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 (including IEC-equivalent designs), NEMA Design C motors (including IEC-equivalent designs), and fire pump electric motors (including IEC-equivalent designs). 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 both be in the same equipment class group (for the preliminary analysis, group 1), but each motor would represent a unique equipment class, which will ultimately have its own efficiency standard. There are 478 potential equipment classes which consist of all permutations of electric motor design types (i.e., NEMA Design A and B, NEMA Design C, or fire pump electric motor), standard horsepower ratings (i.e., standard ratings from 1 to 500 horsepower), pole configurations (i.e., 2-, 4-, 6-, or 8-pole), and enclosure types (i.e., open or enclosed). Table 3.1 illustrates the relationships between equipment class groups and the characteristics used to define equipment classes. In the following sections, DOE discusses each of these design features.

**Table 3.1 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 |
| | | | | Closed |
| 2 | NEMA Design C* | 1-200 | 2, 4, 6, 8 | Open |
| | | | | Closed |
| 3 | Fire Pump* | 1-500 | 2, 4, 6, 8 | Open |
| | | | | Closed |

*Including IEC equivalents.

DOE notes that should it establish amended energy conservation standards for electric motors with this arrangement of equipment class groups and equipment classes, it would no longer disaggregate its standards by general purpose electric motor subtype I and II. Additionally, in light of DOE's plan to expand the scope of energy conservation standards in this rulemaking, the equipment class groups listed in Table 3.1 would include motor types that previously may not have been subject to energy conservation standards, including motors that may not fall under the categories of subtype I or II motors.

#### 3.2.2.1 Electric Motor Design

Various industry organizations, such as NEMA and IEC, publish performance criteria that provide specifications that electric motors must meet in order to be assigned different design types. As these design types represent a certain set of performance parameters, they provide electric motor users with an easy reference to use when designing their equipment and when purchasing a motor to drive their equipment. The electric motors covered under this rulemaking must meet one of three NEMA design types. For medium polyphase alternating current (AC) induction motors, the three NEMA design types considered general purpose and covered by EPCA, as amended by EISA 2007, are Design A, Design B, and Design C. The definitions for these three motor types are as follows:

In NEMA MG1–2011 paragraph 1.19.1.1, "A Design A motor is a squirrel-cage motor designed to withstand full-voltage starting and developing locked-rotor torque as shown in 12.38, pull-up torque as shown in 12.40, breakdown torque as shown in 12.39, with locked-rotor current higher than the values shown in 12.35.1 for 60 hertz and 12.35.2 for 50 hertz and having a slip at rated load of less than 5 percent."

Under 10 CFR 431.12,[c] "NEMA Design B motor means 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 Standards Publication 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 Standards Publication MG1–2009, and (4) has a slip at rated load of less than 5 percent for motors with fewer than 10 poles."

In NEMA MG1–2011 paragraph 1.19.1.3,"A Design C motor is a squirrel-cage motor designed to withstand full-voltage starting, developing locked-rotor torque for special high-torque application up to the values shown in 12.38, pull-up torque as shown in 12.40, breakdown torque up to the values shown in 12.39, with locked-rotor current not to exceed the values shown in 12.34.1 [12.35.1] for 60 hertz and 12.35.2 for 50 hertz, and having a slip at rated load of less than 5 percent."

NEMA Design A and NEMA Design B electric motors have different locked-rotor current requirements. NEMA Design A electric motors have no locked-rotor current limits whereas NEMA Design B electric motors are required to stay below certain maximums 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. However, NEMA Design A and NEMA Design B motors have the same requirements for locked-rotor, pull-up, and breakdown torque and are consequently used in many of the same applications. Additionally, as is shown in section 3.2.4 below, NEMA Design

[c] As this definition was adopted and codified into the CFR, DOE added some minor language to specify which version of NEMA MG1 should be used and DOE corrected some minor typographical errors that referred the reader to the wrong tables for locked rotor current specifications.

B motors constitute a significantly larger population of the electric motors that are shipped relative to NEMA Design A motors.

NEMA Design C electric motors, on the other hand, have different torque requirements than NEMA Design A or B motors. NEMA Design C electric motors typically have higher torque requirements. DOE believes that this performance change represents a change in utility which can also affect efficiency. Additionally, the difference in torque requirements will restrict which applications can use which NEMA Design types. As a result, NEMA Design C motors will not always be replaceable with NEMA Design A or B motors, or vice versa.

DOE notes that Congress held NEMA Design A and NEMA Design B motors to the same energy conservation standards prescribed by EPACT 1992 (42 U.S.C. 6311(13)(A)) and EISA 2007 (42 U.S.C. 6311 (13)(A)) (see requirements for general purpose electric motors (subtype I)). For the preliminary analysis, DOE has followed the precedent set by EPACT 1992 and EISA 2007 and has considered NEMA Design A and B motors in a group together, while placing NEMA Design C motors in their own equipment class group. Finally, DOE notes that all equivalent IEC design types are also covered by this energy conservation standards rulemaking and should be considered with their corresponding NEMA Design type.

#### 3.2.2.2 Fire Pump Electric Motors

EISA 2007 prescribed energy conservation standards for fire pump electric motors. (42 U.S.C. § 6313(b)(2)(B)) Fire pump electric motors are motors with special design characteristics that make them more suitable for emergency operation. As stated previously, DOE adopted a definition of "fire pump electric motor," which incorporated portions of the National Fire Protection Association (NFPA) Standard 20, "Standard for the Installation of Stationary Pumps for Fire Protection" (2010). Such electric motors, per the requirements of NFPA 20, are required to be marked as complying with NEMA Design B performance standards and be capable of operating even if it overheats or may be damaged due to continued operation. These additional requirements for a fire pump electric motor constitute a change in utility, apart from other general purpose electric motors, which DOE believes could also affect its performance and efficiency. Therefore, DOE has preliminarily established a separate equipment class group for fire pump electric motors.

#### 3.2.2.3 Horsepower Rating

Horsepower is a measurement directly related to the capacity of an electric motor to perform useful work and, therefore, it is one of DOE's primary criteria in designating equipment classes. Horsepower rating defines the output power of an electric motor, where 1 horsepower equals 745.7 Watts. It is generally true that efficiency scales with horsepower. In other words, a 50-horsepower motor is usually more efficient than a 10-horsepower motor. Also, because of its larger frame size and additional active material (e.g., copper wiring and electrical steel), the 50-horsepower motor will be able to achieve a higher, maximum level of efficiency. Horsepower is a critical performance attribute of an electric motor, and because there is a direct correlation between horsepower and efficiency, DOE is preliminarily using horsepower rating as an equipment class setting criterion.

#### 3.2.2.4 Pole configuration

An electric motor's pole configuration corresponds to the number of magnetic poles present in the motor. Consequently, the number of magnetic poles (or "poles") dictates the revolutions per minute (RPM) of the rotor and shaft. For each pole configuration there is a corresponding synchronous speed, in RPMs, which is the theoretical maximum speed at which a motor might operate without a load. All of the electric motors covered by this rulemaking are asynchronous motors, meaning they cannot reach this speed. 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 RPMs. Because the number of poles has a direct impact on the rotational speed of a motor shaft, it also affects a motor's utility and performance, including efficiency. Therefore, DOE is also using pole configuration as a means of differentiating equipment classes for the preliminary analysis.

#### 3.2.2.5 Enclosure type

In general, there are two variations of enclosure types, either open or enclosed. DOE currently defines both of these terms under 10 CFR 431.12. An electric motor meets the current definition of an "enclosed motor" if it is "an electric motor so constructed as to prevent the free exchange of air between the inside and outside of the case but not sufficiently enclosed to be termed airtight." An open motor is defined under 10 CFR 431.12 as "an electric motor having ventilating openings which permit passage of external cooling air over and around the windings of the machine." As in EPACT 1992, EISA 2007 prescribes separate energy conservation standards for open and enclosed electric motors. (42 U.S.C. 6313 (b)(1))

DOE is aware that given two motors of the same horsepower rating, pole configuration, and frame size, an open machine is typically more efficient than an enclosed motor. This occurs because enclosure type affects an electric motor's ability to dissipate heat (the open motor's free air exchange allows for better thermal dissipation), which enables open motors to achieve higher efficiency levels than their enclosed counterparts. Additionally, whether an electric motor is open or enclosed affects its utility in that open motors are generally not used in harsh operating environments, whereas enclosed electric motors often are. Therefore, because of the effects on both efficiency and consumer utility, DOE is using motor enclosure as an equipment class-setting criterion for the preliminary analysis.

Table 3.2, Table 3.3, and Table 3.4 illustrate the relationship between equipment class and various motor design characteristics.

**Table 3.2 NEMA Design A and B Equipment Classes**

| Horsepower | Enclosure | Two Poles | Four Poles | Six Poles | Eight Poles |
|---|---|---|---|---|---|
| 1.0 | Open | - | EC#1 | EC#2 | EC#3 |
| | Enclosed | - | EC#4 | EC#5 | EC#6 |
| 1.5 | Open | EC#7 | EC#8 | EC#9 | EC#10 |
| | Enclosed | EC#11 | EC#12 | EC#13 | EC#14 |
| 2.0 | Open | EC#15 | EC#16 | EC#17 | EC#18 |
| | Enclosed | EC#19 | EC#20 | EC#21 | EC#22 |
| 3.0 | Open | EC#23 | EC#24 | EC#25 | EC#26 |

| | | | | | |
|---|---|---|---|---|---|
| | Enclosed | EC#27 | EC#28 | EC#29 | EC#30 |
| | Open | EC#31 | EC#32 | EC#33 | EC#34 |
| **5.0** | Enclosed | EC#35 | EC#36 | EC#37 | EC#38 |
| | Open | EC#39 | EC#40 | EC#41 | EC#42 |
| **7.5** | Enclosed | EC#43 | EC#44 | EC#45 | EC#46 |
| | Open | EC#47 | EC#48 | EC#49 | EC#50 |
| **10.0** | Enclosed | EC#51 | EC#52 | EC#53 | EC#54 |
| | Open | EC#55 | EC#56 | EC#57 | EC#58 |
| **15.0** | Enclosed | EC#59 | EC#60 | EC#61 | EC#62 |
| | Open | EC#63 | EC#64 | EC#65 | EC#66 |
| **20.0** | Enclosed | EC#67 | EC#68 | EC#69 | EC#70 |
| | Open | EC#71 | EC#72 | EC#73 | EC#74 |
| **25.0** | Enclosed | EC#75 | EC#76 | EC#77 | EC#78 |
| | Open | EC#79 | EC#80 | EC#81 | EC#82 |
| **30.0** | Enclosed | EC#83 | EC#84 | EC#85 | EC#86 |
| | Open | EC#87 | EC#88 | EC#89 | EC#90 |
| **40.0** | Enclosed | EC#91 | EC#92 | EC#93 | EC#94 |
| | Open | EC#95 | EC#96 | EC#97 | EC#98 |
| **50.0** | Enclosed | EC#99 | EC#100 | EC#101 | EC#102 |
| | Open | EC#103 | EC#104 | EC#105 | EC#106 |
| **60.0** | Enclosed | EC#107 | EC#108 | EC#109 | EC#110 |
| | Open | EC#111 | EC#112 | EC#113 | EC#114 |
| **75.0** | Enclosed | EC#115 | EC#116 | EC#117 | EC#118 |
| | Open | EC#119 | EC#120 | EC#121 | EC#122 |
| **100.0** | Enclosed | EC#123 | EC#124 | EC#125 | EC#126 |
| | Open | EC#127 | EC#128 | EC#129 | EC#130 |
| **125.0** | Enclosed | EC#131 | EC#132 | EC#133 | EC#134 |
| | Open | EC#135 | EC#136 | EC#137 | EC#138 |
| **150.0** | Enclosed | EC#139 | EC#140 | EC#141 | EC#142 |
| | Open | EC#143 | EC#144 | EC#145 | EC#146 |
| **200.0** | Enclosed | EC#147 | EC#148 | EC#149 | EC#150 |
| | Open | EC#151 | EC#152 | EC#153 | EC#154 |
| **250.0** | Enclosed | EC#155 | EC#156 | EC#157 | EC#158 |
| | Open | EC#159 | EC#160 | EC#161 | - |
| **300.0** | Enclosed | EC#162 | EC#163 | EC#164 | - |
| | Open | EC#165 | EC#166 | EC#167 | - |
| **350.0** | Enclosed | EC#168 | EC#169 | EC#170 | - |
| | Open | EC#171 | EC#172 | - | - |
| **400.0** | Enclosed | EC#173 | EC#174 | - | - |
| | Open | EC#175 | EC#176 | - | - |
| **450.0** | Enclosed | EC#177 | EC#178 | - | - |
| | Open | EC#179 | EC#180 | - | - |
| **500.0** | Enclosed | EC#181 | EC#182 | - | - |

**Table 3.3 NEMA Design C Equipment Classes**

| Horsepower | Enclosure | Four Poles | Six Poles | Eight Poles |
|---|---|---|---|---|
| | Open | EC#1 | EC#2 | EC#3 |
| **1.0** | Enclosed | EC#4 | EC#5 | EC#6 |
| | Open | EC#7 | EC#8 | EC#9 |
| **1.5** | Enclosed | EC#10 | EC#11 | EC#12 |
| **2.0** | Open | EC#13 | EC#14 | EC#15 |

| | | | | |
|---|---|---|---|---|
| | Enclosed | EC#16 | EC#17 | EC#18 |
| | Open | EC#19 | EC#20 | EC#21 |
| **3.0** | Enclosed | EC#22 | EC#23 | EC#24 |
| | Open | EC#25 | EC#26 | EC#27 |
| **5.0** | Enclosed | EC#28 | EC#29 | EC#30 |
| | Open | EC#31 | EC#32 | EC#33 |
| **7.5** | Enclosed | EC#34 | EC#35 | EC#36 |
| | Open | EC#37 | EC#38 | EC#39 |
| **10.0** | Enclosed | EC#40 | EC#41 | EC#42 |
| | Open | EC#43 | EC#44 | EC#45 |
| **15.0** | Enclosed | EC#46 | EC#47 | EC#48 |
| | Open | EC#49 | EC#50 | EC#51 |
| **20.0** | Enclosed | EC#52 | EC#53 | EC#54 |
| | Open | EC#55 | EC#56 | EC#57 |
| **25.0** | Enclosed | EC#58 | EC#59 | EC#60 |
| | Open | EC#61 | EC#62 | EC#63 |
| **30.0** | Enclosed | EC#64 | EC#65 | EC#66 |
| | Open | EC#67 | EC#68 | EC#69 |
| **40.0** | Enclosed | EC#70 | EC#71 | EC#72 |
| | Open | EC#73 | EC#74 | EC#75 |
| **50.0** | Enclosed | EC#76 | EC#77 | EC#78 |
| | Open | EC#79 | EC#80 | EC#81 |
| **60.0** | Enclosed | EC#82 | EC#83 | EC#84 |
| | Open | EC#85 | EC#86 | EC#87 |
| **75.0** | Enclosed | EC#88 | EC#89 | EC#90 |
| | Open | EC#91 | EC#92 | EC#93 |
| **100.0** | Enclosed | EC#94 | EC#95 | EC#96 |
| | Open | EC#97 | EC#98 | EC#99 |
| **125.0** | Enclosed | EC#100 | EC#101 | EC#102 |
| | Open | EC#103 | EC#104 | EC#105 |
| **150.0** | Enclosed | EC#106 | EC#107 | EC#108 |
| | Open | EC#109 | EC#110 | EC#111 |
| **200.0** | Enclosed | EC#112 | EC#113 | EC#114 |

**Table 3.4 Fire Pump Electric Motor Equipment Classes**

| **Horsepower** | **Enclosure** | **Two Poles** | **Four Poles** | **Six Poles** | **Eight Poles** |
|---|---|---|---|---|---|
| | Open | - | EC#1 | EC#2 | EC#3 |
| **1.0** | Enclosed | - | EC#4 | EC#5 | EC#6 |
| | Open | EC#7 | EC#8 | EC#9 | EC#10 |
| **1.5** | Enclosed | EC#11 | EC#12 | EC#13 | EC#14 |
| | Open | EC#15 | EC#16 | EC#17 | EC#18 |
| **2.0** | Enclosed | EC#19 | EC#20 | EC#21 | EC#22 |
| | Open | EC#23 | EC#24 | EC#25 | EC#26 |
| **3.0** | Enclosed | EC#27 | EC#28 | EC#29 | EC#30 |
| | Open | EC#31 | EC#32 | EC#33 | EC#34 |
| **5.0** | Enclosed | EC#35 | EC#36 | EC#37 | EC#38 |
| | Open | EC#39 | EC#40 | EC#41 | EC#42 |
| **7.5** | Enclosed | EC#43 | EC#44 | EC#45 | EC#46 |
| | Open | EC#47 | EC#48 | EC#49 | EC#50 |
| **10.0** | Enclosed | EC#51 | EC#52 | EC#53 | EC#54 |
| **15.0** | Open | EC#55 | EC#56 | EC#57 | EC#58 |

| | | | | | |
|---|---|---|---|---|---|
| | Enclosed | EC#59 | EC#60 | EC#61 | EC#62 |
| | Open | EC#63 | EC#64 | EC#65 | EC#66 |
| **20.0** | Enclosed | EC#67 | EC#68 | EC#69 | EC#70 |
| | Open | EC#71 | EC#72 | EC#73 | EC#74 |
| **25.0** | Enclosed | EC#75 | EC#76 | EC#77 | EC#78 |
| | Open | EC#79 | EC#80 | EC#81 | EC#82 |
| **30.0** | Enclosed | EC#83 | EC#84 | EC#85 | EC#86 |
| | Open | EC#87 | EC#88 | EC#89 | EC#90 |
| **40.0** | Enclosed | EC#91 | EC#92 | EC#93 | EC#94 |
| | Open | EC#95 | EC#96 | EC#97 | EC#98 |
| **50.0** | Enclosed | EC#99 | EC#100 | EC#101 | EC#102 |
| | Open | EC#103 | EC#104 | EC#105 | EC#106 |
| **60.0** | Enclosed | EC#107 | EC#108 | EC#109 | EC#110 |
| | Open | EC#111 | EC#112 | EC#113 | EC#114 |
| **75.0** | Enclosed | EC#115 | EC#116 | EC#117 | EC#118 |
| | Open | EC#119 | EC#120 | EC#121 | EC#122 |
| **100.0** | Enclosed | EC#123 | EC#124 | EC#125 | EC#126 |
| | Open | EC#127 | EC#128 | EC#129 | EC#130 |
| **125.0** | Enclosed | EC#131 | EC#132 | EC#133 | EC#134 |
| | Open | EC#135 | EC#136 | EC#137 | EC#138 |
| **150.0** | Enclosed | EC#139 | EC#140 | EC#141 | EC#142 |
| | Open | EC#143 | EC#144 | EC#145 | EC#146 |
| **200.0** | Enclosed | EC#147 | EC#148 | EC#149 | EC#150 |
| | Open | EC#151 | EC#152 | EC#153 | EC#154 |
| **250.0** | Enclosed | EC#155 | EC#156 | EC#157 | EC#158 |
| | Open | EC#159 | EC#160 | EC#161 | - |
| **300.0** | Enclosed | EC#162 | EC#163 | EC#164 | - |
| | Open | EC#165 | EC#166 | EC#167 | - |
| **350.0** | Enclosed | EC#168 | EC#169 | EC#170 | - |
| | Open | EC#171 | EC#172 | - | - |
| **400.0** | Enclosed | EC#173 | EC#174 | - | - |
| | Open | EC#175 | EC#176 | - | - |
| **450.0** | Enclosed | EC#177 | EC#178 | - | - |
| | Open | EC#179 | EC#180 | - | - |
| **500.0** | Enclosed | EC#181 | EC#182 | - | - |

### 3.2.3 Expanded Scope of Coverage

During the October 18, 2010, framework public meeting, DOE received comments regarding the energy savings potential from expanding the scope of coverage beyond subtype I, subtype II, and fire pump electric motors. DOE addresses these comments in chapter 2 of the preliminary TSD DOE's discussion of expanding the scope of coverage refers to the decision to analyze energy conservation standards for electric motor types that currently do not have energy conservation standards. DOE has the statutory authority to establish such standards without first promulgating a coverage determination rulemaking based on the modifications resulting from EISA 2007, which struck the statutory definition for "electric motors." DOE recognizes the energy savings potential of scope expansion for motors previously exempt from conservation standards, as well as motors that may not fall into the subtype I, subtype II, and fire pump electric motor categories. DOE plans on expanding the scope of conservation standards to all motors with characteristics listed in Table 3.5 and then specifically naming motors for which no standards are established.

**Table 3.5 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, |
| Has a 2-, 4-, 6-, or 8-pole configuration, |
| Is rated 600 volts or less, |
| 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) |

Table 3.6 lists electric motors that are not currently subject to efficiency standards, but would be subject to minimum efficiency standards if DOE decides to expand energy efficiency standards to electric motors with all of the characteristics listed in Table 3.5 (with the exception of specifically named motors that would otherwise not be covered). Such motors would fall into the equipment class groups listed in Table 3.1 based on their respective NEMA Design type. See chapter 2 of the preliminary TSD for an in-depth discussion of the decision to include these motors in the expansion of energy conservation standards.

**Table 3.6 Electric Motor Types DOE Plans on Regulating Under Newly-Expanded Scope of Conservation Standards**

| | |
|---|---|
| Electric Motors with Customer Defined Endshields or Special Flanges | Encapsulated Electric Motor |
| Electric Motors with Single and Double Shafts of Non-Standard Shaft Dimensions or Additions | Immersible Electric Motor |
| Electric Motors with Sleeve Bearings | Inverter-Capable Electric Motor |
| Electric Motors with Special Base or Mounting Feet | Partial Electric Motor |
| Electric Motors with Thrust Bearings | Totally Enclosed, Non-Ventilated Electric Motor |
| Vertical Hollow-Shaft Electric Motor | - |

In the March 30, 2011, Request For Information related to electric motors, DOE requested comment on expanding the scope of energy conservation standards to motors that were not currently subject to standards, including some motor types listed in Table 3.6 and Table 3.7. (76 FR 17577) The motor types listed in Table 3.7 are motor types which, at this time, DOE does not plan on subjecting to energy conservation standards. While some of these motors conform to many or all of the characteristics listed in Table 3.5, DOE understands that covering such motors might not be warranted due to special operating conditions or testing difficulties as discussed below.

**Table 3.7 Electric Motors Excluded from Expanded Scope of Coverage**

| Electric Motor Type | |
|---|---|
| Air-Over Electric Motors | Direct Current Motors |
| Component Sets | Single Phase Motors |
| Intermittent Duty Motors | Liquid-Cooled Motors |
| Inverter-Only Duty Motors | Submersible Motors |
| Multispeed Motors | - |

*Air-Over Electric Motors*

Air-over electric motors require an external means of cooling to allow continuous duty operation. These motors may be subject to over-heating and therefore cannot run continuously without a specified amount of air flowing over the motor housing. The required air flow amount is usually determined by the manufacturer as part of the motor design and performance characteristics.

DOE is not planning on covering air-over motors because of the test setup complexities required for these motors. DOE's primary test procedure, the Institute of Electrical and Electronics Engineers, Inc. (IEEE) Standard 112–2004 Test Method B (IEEE 112B), requires certain measurements to be taken at a steady-state temperatures[d]. Reaching a steady-state temperature requires a motor to be rated and operate under continuous-duty conditions; otherwise the motor could overheat and be damaged before reaching a steady-state temperature. IEEE 112B does not provide directions on how to setup an air-over motor for testing, which would otherwise require an external cooling apparatus. DOE is not aware of test procedures that provide guidance on how to test such motors. DOE requests comment on testing non-continuous duty motors in chapter 2 of the preliminary TSD.

*Liquid-Cooled Motors*

Liquid-cooled electric motors rely on a special cooling apparatus that pumps liquid into and around the motor housing. The liquid is circulated around the motor to dissipate heat and prevent the motor from overheating during continuous-duty operation. The user of a liquid-cooled motor could employ different liquids or liquid temperatures which could affect the measured efficiency of a motor. IEEE 112B does not provide standardized direction for testing liquid-cooled motors, and therefore DOE does not plan on including them in the scope of coverage. DOE requests comment on the testing of liquid-cooled electric motors, including any test procedure that is capable of testing these motor types.

*Submersible Motors*

Submersible motors are similar to liquid-cooled motors in that they use liquid to dissipate the heat produced during continuous duty operation. However, unlike liquid-cooled motors,

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[d] Section 3.3.2 of IEEE 112B requires the conductor losses to be measured when the machine is at a specified temperature.

submersible motors are only meant to operate while completely submerged in water, as opposed to having a hose and pump apparatus circulating liquid around the motor enclosure.

DOE is not aware of any test procedures for motors that can only operate continuously in special environments, such as underwater. Therefore, DOE does not plan on including submersible motors in the expanded scope of coverage. DOE requests comment on the testing of submersible electric motors, including any test procedure that is capable of testing these motor types.

*Component Sets*

Component sets are comprised of any combination of motor parts, such as a stator, rotor, shaft, stator housing, shaft bearings, endshields, or other electrical parts. DOE delineated between component sets and partial motors in chapter 2 of the preliminary TSD when it called out partial motors as motors only missing one or both endshields. Component sets are typically sold to be turned into complete electric motors or installed in equipment by the end-user.

DOE believes component sets do not constitute a complete motor that could be tested under IEEE 112B. Additionally, DOE is not aware of any test procedures that would accommodate the testing of component sets of motors. While DOE is planning on including partial motors in the expansion of energy conservation standards by testing them with a custom-built endshield that could be attached as a 'dummy' endplate for testing, DOE believes component sets would require too many or various hardware additions to make a complete motor. Therefore, DOE does not plan on including component sets in the expanded scope of coverage. DOE requests comment on the decision not to subject these motor types to efficiency standards due to testing difficulties. DOE requests comment on any applicable testing standards that are capable of testing component sets of electric motors.

*Intermittent-Duty Electric Motors*

Intermittent-duty motors are motors that, by definition, are not able to operate continuously under full load. DOE does not plan to include such motors in the expanded scope for energy conservation standards because it does not believe intermittent-duty motors present significant opportunities for energy savings. Additionally, IEEE 112B requires measurements to be taken at a steady-state temperatures. Reaching a steady-state temperature requires a motor to be rated and operate under continuous-duty conditions; otherwise the motor could overheat and be damaged before reaching a steady-state temperature. Intermittent-duty motors are not capable of continuous-duty operation and, therefore, never reach a steady-state temperature which IEEE 112B requires for certain calculations. Otherwise, DOE is not aware of any test procedures which provide for testing an intermittent or non-continuous-duty motor. DOE requests comment on this matter in chapter 2 of the preliminary TSD.

*Inverter-Only Electric Motors*

Inverter-only motors cannot be run continuously when directly connected to a 60-hertz, AC polyphase sinusoidal power source. Therefore a separate, special electronic controller, called an inverter, is used to alter the power signal to the motor. For a more in-depth discussion of how inverter controllers work, see chapter 2 of the preliminary TSD.

Inverter controllers are not necessarily 100 percent efficient when manipulating the power signal being fed into the motor. Consequently, the IEEE 112B-measured efficiency of an inverter-only motor would not reflect the true efficiency of that motor, but would also include any losses inherent in the inverter controller. DOE believes testing an inverter-only motor with the inverter controller connected would not accurately record the efficiency of the motor per se. DOE is not planning to include inverter-only motors under the expanded scope motors covered by energy conservation standards, because it is not aware of any test procedures that recognize and differentiate losses caused by the inverter controller. DOE requests comment on this issue in chapter 2 of the preliminary TSD.

*Multispeed Motors*

For this rulemaking, the speed of an electric motor subject to energy conservation standards is determined by its magnetic pole configuration (2-, 4-, 6-, or 8-pole), and the frequency (60-hertz) of the motor's incoming power signal. The pole configuration is directly determined by the stator winding configuration as discussed in section 3.2.2.4.

In general, multispeed motors are motors with multiple, separate stator winding configurations that enable the motor to perform at different speeds contingent upon which winding configuration is connected to the power source. For example, a multispeed motor could be wound with a 2-pole winding configuration and a 4-pole winding configuration. When the power source is connect to the 2-pole winding configuration, the motor shaft will rotate at or near (depending on slip) 3,600 revolutions per minute (RPM), and when the 4-pole winding configuration is connected to the power source the same motor shaft will rotate at or near 1,800 RPM.

DOE is not planning to include multispeed motors in the expanded scope of motors covered under conservation standards, because it is not aware of any test procedures that provide methods for testing a motor with more than one nameplate-rated speed. DOE requests comment on any test procedures that are capable of testing multispeed electric motors.

*Direct Current Motors*

Direct current (DC) motors are motors that run on DC power input. For this rulemaking, DOE is covering only electric motors that operate on polyphase, sinusoidal AC power and can be tested under IEEE 112B. DC motors cannot be tested under IEEE 112B, but require testing under other methods.

*Single Phase Motors*

Single phase motors operate on a single phase, AC power source. For this rulemaking, DOE is covering only electric motors that operate on polyphase, sinusoidal AC power and can be tested for efficiency under IEEE 112B. DOE does not plan to include single phase motors in this rulemaking because they cannot be tested according to IEEE 112B.

### 3.2.4 Electric Motor Shipments

To prepare an estimate of the national impact of energy conservation standards for electric motors, DOE needed to estimate annual motor shipments. For this stage of the rulemaking, DOE used publically available shipment data from the U.S. Census Bureau, NEMA, and the Annual Energy Outlook provided by the U.S. Energy Information Administration.

DOE used this data for three main purposes. First, the shipment data and market trend information contributed to the shipments analysis and base-case forecast for electric motors (chapter 9 of the preliminary TSD). Second, DOE used the shipment and catalog data to select the representative equipment classes and units for analysis (chapter 5 of the preliminary TSD). Third, DOE used the data to develop the installed stock of equipment for the national impact analysis (chapter 10 of the preliminary TSD). Although more detailed shipments data are given in chapter 9, the shipments shown in this chapter illustrate which electric motor characteristics were the most common in 2011.

#### 3.2.4.1 NEMA Design Type

As discussed previously, the scope of DOE's energy conservation standards for electric motors covers four design types: NEMA Design A, NEMA Design B, NEMA Design C, and fire pump electric motors.[e] In 2011, Design B motors were by far the most common electric motor type, comprising of 98.7 percent of all shipments. NEMA Design A was the second most common design type, consisting of 1.0 percent of shipments. Finally, NEMA Design C and fire pump electric motors constituted just 0.2 percent and 0.1 percent of shipments, respectively.

[e] DOE notes that IEC-equivalent design types are also covered.

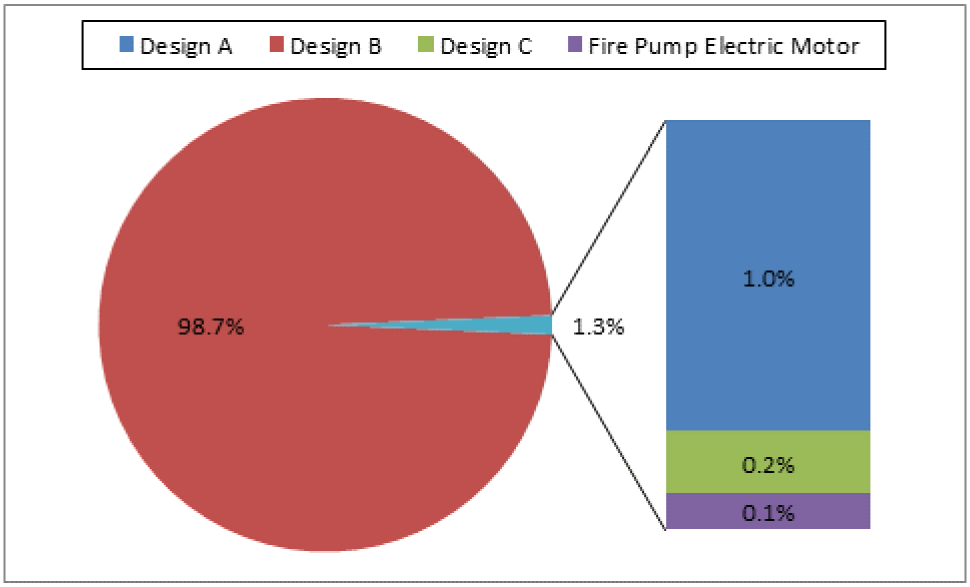


**Figure 3.2.1 Electric Motor Shipments by Design Type for 2011**

As will be discussed in more detail in chapter 5 of the preliminary TSD, DOE focused its engineering analysis on NEMA Design B motors based on the popularity of the design type. Although NEMA Design C motors consist of a small portion of the motor market, DOE has separately analyzed these motors because of the different utility and performance characteristics that these motors have relative to Design A and B motors.

#### 3.2.4.2 Horsepower Ratings

For 2011 NEMA supplied shipments data broken down by horsepower rating.

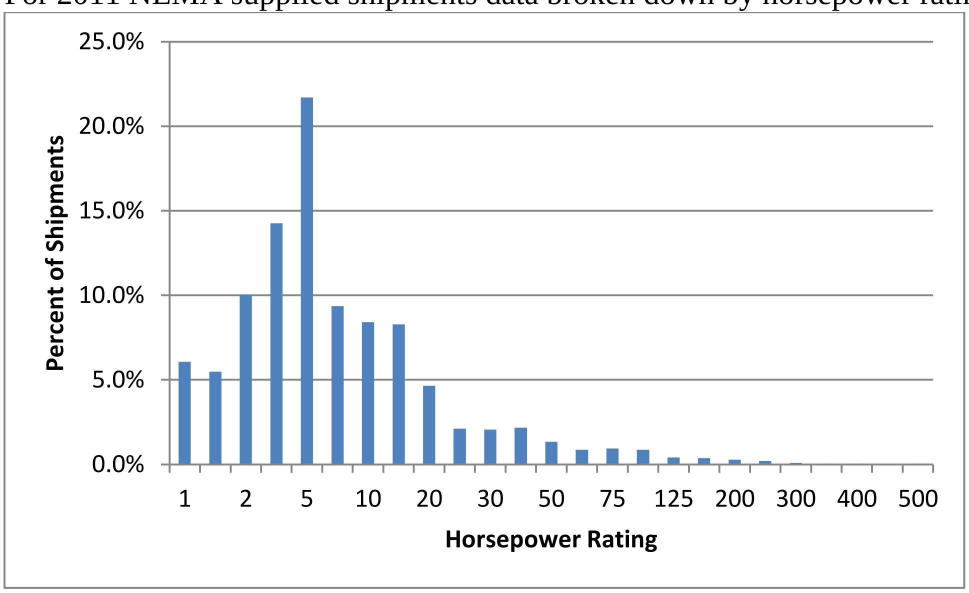


**Figure 3.2.2** illustrates the total shipments of electric motors broken down by horsepower rating. As is evident by the graph, the vast majority of shipments occurred in the lower range of horsepower rating, with 5-horsepower being the most common rating.

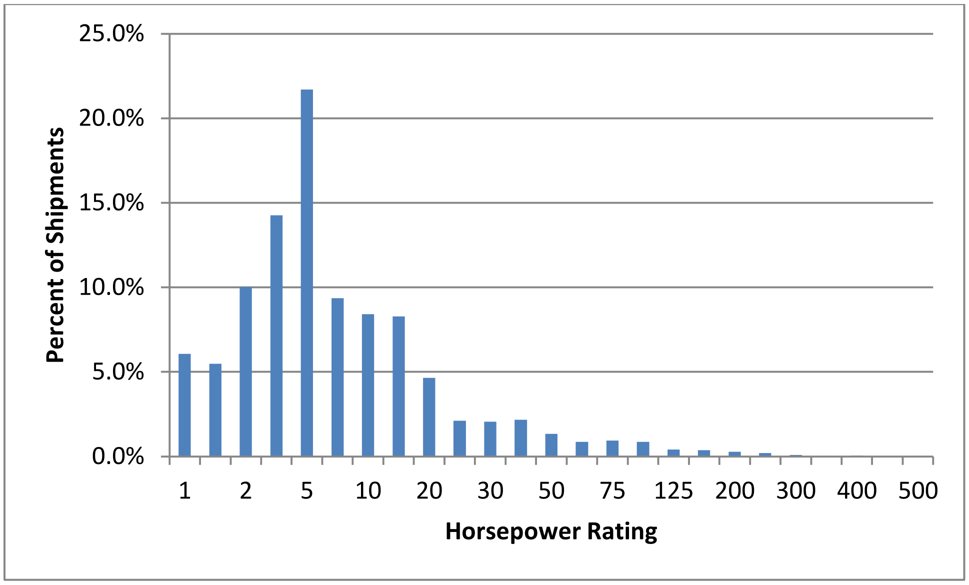


**Figure 3.2.2 Electric Motor Shipments by Horsepower Rating for 2011**

#### 3.2.4.3 Pole Configuration

NEMA also supplied 2011 shipments data broken down by pole configuration. As illustrated in

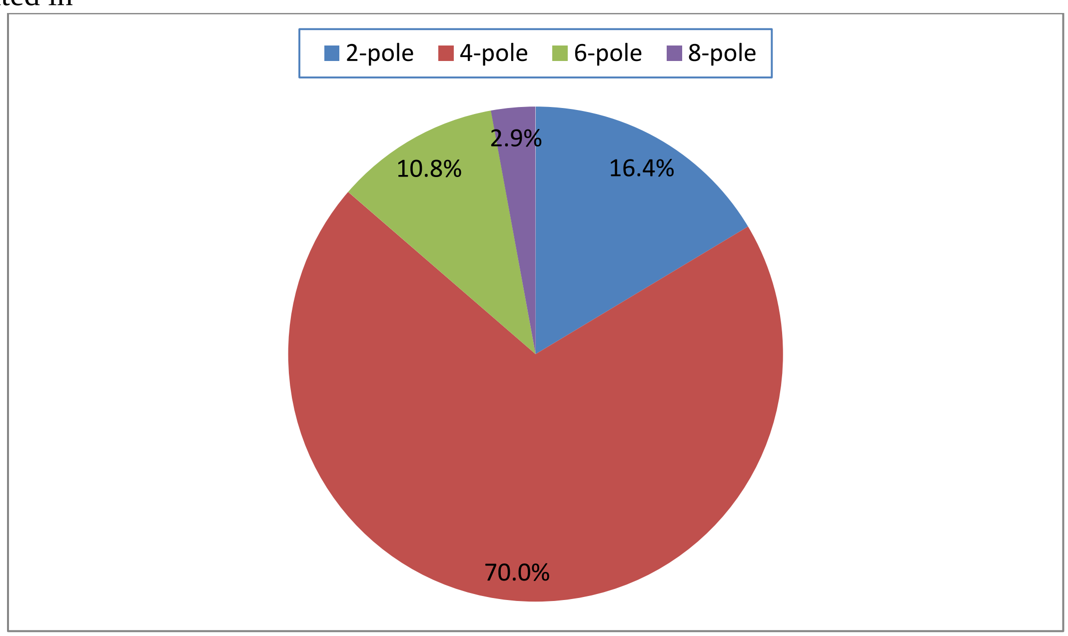


Figure 3.2.3, 4-pole electric motors were by far the most commonly shipped. The next highest group of shipments was 2-pole motors, constituting 18 percent of all shipments. Then, 6-pole and 8-pole motors accounted for 10 percent and 3 percent of electric motor shipments, respectively.

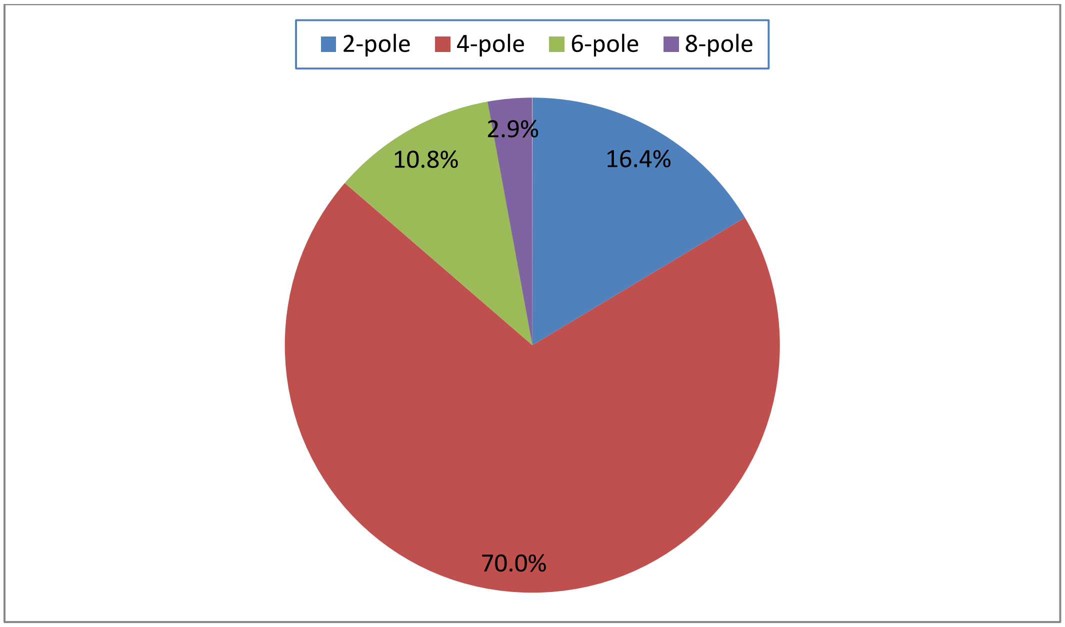

**Figure 3.2.3 Electric Motor Shipments by Pole Configuration for 2011**

#### 3.2.4.4 Enclosure Types

Finally, NEMA provided shipment estimates broken down by enclosure types, that is, open or enclosed. In 2011, enclosed motors were shipped roughly three times as frequently as open motors. In 2011, enclosed consisted of about 77 percent of electric motor shipments and open electric motors consisted of about 23 percent of motor shipments.

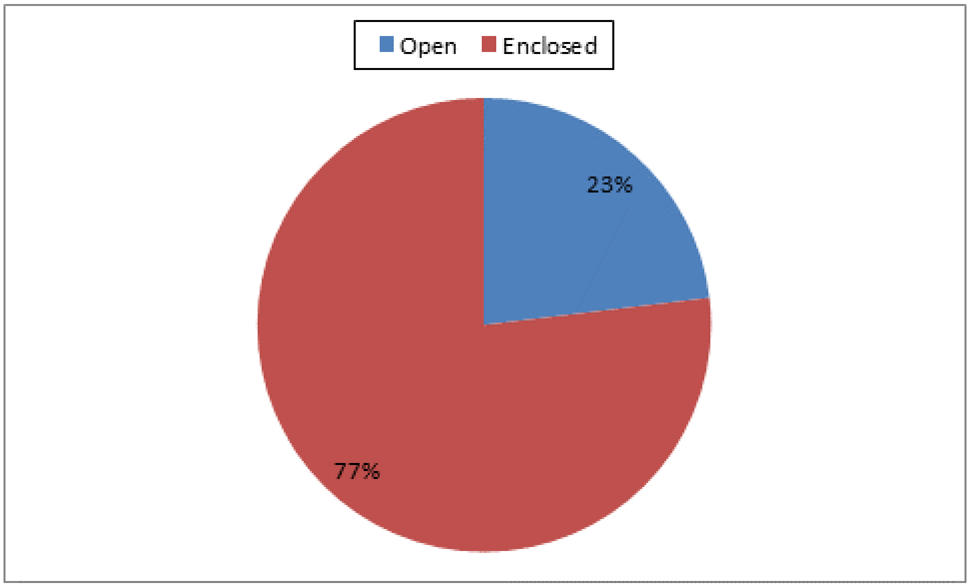

**Figure 3.2.4 Electric Motor Shipments by Enclosure Type for 2011**

### 3.2.5 Manufacturers and Market Share

The major manufacturers that dominate the electric motor market for this rulemaking, in alphabetical order, are:

- A.O. Smith Electrical Products Company;
- Baldor Electric Company;
- General Electric Company;
- Nidec Motor Corporation;
- Regal-Beloit Corporation.;
- Siemens Industry, Inc.;
- Toshiba; and
- WEG

The manufacturers identified above are all major manufacturers with diverse portfolios of equipment offerings, including electric motors covered under EPCA. Over the past decade, there has been a consolidation of motor manufacturing in the United States and this list is a result of those mergers and acquisitions.

DOE does not have empirical data on the market shares of particular manufacturers of electric motors. Nevertheless, estimates of available cumulative data indicate that shipments of electric motors from these companies constitute over a significant portion of the total U.S. market. Further, DOE believes that the cumulative shipment estimates provided by NEMA constitute a good estimate of overall national shipments.

#### 3.2.5.1 Small Businesses

Although the electric motor market is predominantly supplied by large manufacturers, DOE will examine those small businesses that manufacture electric motors during the NOPR stage of the rulemaking. In general, the Small Business Administration (SBA) defines a small business manufacturing enterprise for "motor and generator manufacturing" as one that has 1,000 or fewer employees. The number of employees in a small business is rolled up with the total employees of the parent company; it does not represent the division manufacturing electric motors. SBA lists small business size standards for industries as they are described in the North American Industry Classification System (NAICS). For electric motors, the size standard is matched to NAICS code 335312, Motor and Generator Manufacturing.[1]

### 3.2.6 Application and Performance of Existing Equipment

The general purpose electric motors as well as the definite and special purpose electric motors that can be used in general purpose applications covered in the preliminary analysis are used in a wide range of applications that include the following:

- blowers
- business equipment
- commercial food processing
- compressors
- conveyors
- crushers
- fans
- farm equipment
- general industrial applications
- grinders
- heating, ventilation, and air-conditioning equipment
- machine tools
- milking machines
- pumps
- winches
- woodworking machines

### 3.2.7 Trade Associations

DOE is aware of one trade association for manufacturers of medium electric motors, the National Electrical Manufacturers Association (NEMA).

#### 3.2.7.1 National Electrical Manufacturers Association

NEMA was established as a trade association in 1926, and has since been divided into five core departments that provide different functions for its members. Those departments are:

- Technical Services

- Government Relations
- Industry Operations
- Business Information Services
- Medical

Through these groups, NEMA establishes voluntary standards for the performance, size, and functionality of electrical equipment to facilitate communication among motor manufacturers, original equipment manufacturers, engineers, purchasing agents, and users. An example of NEMA's role in standardization is the NEMA Standards Publication MG-1, "Motors and Generators," (MG 1) document,[f] which is a reference document for motor and generator manufacturers and users. MG 1 provides guidance to motor manufacturers on performance and construction specifications for a broad range of electric motors. By standardizing around certain parameters, NEMA makes it easier for users to identify and purchase electric motors. MG 1 is a complete industry reference document for standardizing the motors offered in the market. The groups above also set up work that NEMA, as a whole, does to contribute to U.S. public policy and the economic data analysis it performs.[2]

In addition to MG 1, NEMA established and promoted a high efficiency standard through a "NEMA Premium®" label for qualifying motors.[g] NEMA motor manufacturers attach a label to motors that are built to high efficiency standards. These standards exceed those set by EPACT 1992, which requires general-purpose motors from 1 to 200 horsepower to meet certain minimum efficiency levels. See section 3.2.2 and 3.2.9 for more discussion on these minimum efficiency levels.

### 3.2.8 Regulatory Programs

EPCA, 42 U.S.C. 6311, *et seq.*, as amended by 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 passed into law EISA 2007. (Pub. L. No. 110–140) Section 313(b)(1) of EISA 2007 updated the energy conservation standards for those electric motors already covered by EPCA and established energy conservation standards for a larger scope of motors not previously covered. (42 U.S.C. 6313(b)(2))

EPCA also directs that the Secretary [of Energy] shall 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 product. 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))

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[f] NEMA's MG 1 document can be purchased online at www.nema.org/stds/MG 1.cfm.
[g] NEMA's Premium® Motors program can be reviewed at www.nema.org/gov/energy/efficiency/premium.

As described earlier, EISA 2007 constitutes the most recent amendment to EPCA and energy conservation standards for electric motors. Because these amendments became effective on December 19, 2010, DOE is required by statute to publish a determination by December 19, 2012, whether to further amend the EISA 2007 energy conservation standards for electric motors. As such, DOE will determine whether to promulgate amended energy conservation standards for electric motors and, if so, at what levels. Sections 325(o)-(p) of EPCA require any such levels to be technologically feasible, economically justified, and save a significant amount of energy. (42 U.S.C. 6295(o)-(p), 6316(a)) Any such amended standards that DOE establishes would require compliance two years after publication of a final rule.

### 3.2.9 Non-Regulatory Programs

DOE reviewed voluntary programs that promote energy efficient electric motors in the United States, including the DOE Motor Challenge and Best Practices programs, NEMA Premium energy efficient motors program, and Consortium for Energy Efficiency (CEE) Premium Efficiency motors program.

#### 3.2.9.1 Department of Energy Motor Challenge Program

In general, motor-driven equipment accounts for almost 70 percent of all electricity consumption by U.S. industries. In 1993, DOE launched its industry/government partnership, Motor Challenge Program with the goals of increasing the energy-efficiency of electric motor-driven systems in domestic industry and enhancing environmental quality. The program uses a market-driven approach to promote the design, purchase, installation, and management of energy-efficient electric motors and motor-driven systems and equipment, such as pumps, fans, and compressors. It was designed to help industry capture 5 billion kilowatt-hours per year of electricity savings and 1.2 million metric tons of carbon-equivalent by the year 2000, with projections of much larger and longer-term national energy savings opportunities of over 100 billion kilowatt-hours per year by the year 2010.[h]

The Motor Challenge program encompasses three-phase 60 Hertz motors rated 1 horsepower and above. Its elements and offerings include: DOE Energy Efficiency and Renewable Energy (EERE) Information Center, which provides up-to-date information about the practicality and profitability of electric motor system strategies; design decision tools, such as MotorMaster+ software; Showcase Demonstration projects; training; workshops; and conferences. In general, the response to the program from industry has been overwhelmingly favorable. The Motor Challenge program is no longer active; however, the DOE Energy Efficiency and Renewable Energy (EERE) Information Center and the MotorMaster+ database of industrial motors remain viable.

The EERE Information Center answers questions on energy efficient products and services and refers callers to the most appropriate DOE/EERE resources. Industrial callers are eligible for an advanced level of service that includes engineering assistance, research, and

[h] For more information about DOE "Best Practices," under the DOE Industrial Technologies Program, and Motor Challenge, visit http://www1.eere.energy.gov/industry/bestpractices/index.html.

software support for plant staff and industrial service providers working on industrial energy savings projects.[i]

MotorMaster+ is an energy-efficient motor selection and management tool, which includes a database of over 20,000 AC motors. It features motor inventory management tools, maintenance log tracking, efficiency analysis, savings evaluation, energy accounting, and environmental reporting capabilities.[j]

### 3.2.9.2 National Electrical Manufacturers Association Premium Efficiency Motor Program

On January 11, 1989, NEMA established voluntary energy efficiency levels for 1 through 200 horsepower, polyphase squirrel-cage induction motors. For an electric motor to be classified as “energy efficient,” it was required to meet certain levels of efficiency in NEMA Standards Publication MG 1–1987 (Revised March 1991). In 1992, the NEMA efficiency levels were incorporated into section 342(b) of EPACT 1992 and subsequently codified in 10 CFR 431.25. In 2001, the NEMA Premium Efficiency Motor Program was established to provide special recognition to electric motors that exceed the required efficiency levels established by EPACT 1992. NEMA Premium-labeled motors help purchasers identify more efficient motors and optimize motor system efficiency commensurate with a particular application.[3k]

Going a step beyond EPACT, NEMA Premium applies to single-speed, polyphase; 1 to 500 horsepower; 2-, 4-, and 6-pole; squirrel-cage; induction motors; NEMA Designs A or B; 600 volts or less; and rated for continuous duty operation.[4] Such electric motors are typically used in industrial applications operating more than 2000 hours per year.

### 3.2.9.3 Consortium for Energy Efficiency

The Consortium for Energy Efficiency (CEE) is a nonprofit corporation that develops initiatives for its North American members to promote the manufacture and purchase of energy efficient equipment, including electric motors and services. Its members include utilities, statewide and regional market transformation administrators, environmental groups, research organizations and state energy offices in the U.S. and Canada. Also included in the CEE collaborative process are manufacturers, retailers, and government agencies.

In 1996, CEE began its Premium-Efficiency Motors Initiative to promote the production, distribution, and adoption of premium efficiency motors over motors meeting the minimum efficiency levels established under EPACT 1992. In 1999, CEE took a systems approach to energy savings and launched its Motor Systems Initiative that viewed the motor as a component of a larger system, where efficient motors, adjustable-speed drives, and system-specific design strategies would provide the greatest opportunity for savings. Then, in 2001, CEE launched its

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[i] For more information about the EERE Information Center, visit http://www1.eere.energy.gov/industry/bestpractices/info_center.html.
[j] For more information about MotorMaster+, visit www1.eere.energy.gov/industry/bestpractices/software.html#mm.
[k] For more information about the NEMA Premium Efficiency Motor Program, visit http://www.nema.org/gov/energy/efficiency/premium/.

Motor Decisions Matter to promote greater awareness of the benefits of motor systems efficiency. In June 2001, CEE and NEMA aligned to promote NEMA Premium motor efficiency levels that are roughly .5 to 3 percentage points above EPACT 1992 requirements.[5]

In May 2007, CEE published the Energy-Efficiency Incentive Programs – Premium-Efficiency Motors & Adjustable Speed Drives in the U.S and Canada, which provides information about the incentive-based programs in North America. These programs concentrate on 1 to 200 horsepower motors, but some include 201 to 500 horsepower motors. It appears that the programs cover commercial and industrial motors rated from 1 to 500 horsepower.[1] There are a number of different programs broken down by region. For more information on these programs, download the report from CEE.[6]

## 3.3 TECHNOLOGY ASSESSMENT

The electric motors covered in the framework document are all AC induction motors. Induction motors have two core components: a stator and a rotor. The components work together to convert electrical energy into rotational mechanical energy. This is done by creating a rotating magnetic field in the stator, which induces a voltage across the rotor-stator air gap which in turn causes current to flow within the squirrel cage of the rotor. The squirrel cage of the rotor is so named because without the core steel stack, the rotor conductor bars and end rings resemble the exercise wheels that domesticated squirrels would run in. The stator and rotor magnetic fields interact to create torque. This torque provides the rotational force delivered to the load via a shaft.

The purpose of the technology assessment is to develop a preliminary list of technology options that may improve the efficiency of electric motors. For the electric motors covered in this rulemaking, energy efficiency losses are grouped into five main categories: stator $I^2R$ losses, rotor $I^2R$ losses, core losses, friction and windage losses, and stray load losses.

Designers have to balance the five basic losses to optimize the various motor performance criteria. There are numerous trade-offs that have to be considered. Efficiency is only one parameter that has to be met. Reducing one loss may increase another. What may be desirable on a 4-pole motor may not be on a 2-pole motor. Increasing the air gap is a good example: a larger air gap may reduce the stray loss but may increase the losses associated with the magnetizing current. A complete discussion of these trade-offs is beyond the scope of this report. Different companies utilize different approaches for minimizing motor losses.

### 3.3.1 Technology Options for $I^2R$ Losses

$I^2R$ losses are produced from either the current flow through the copper windings in the stator (stator $I^2R$ losses) or the squirrel cage of the rotor (rotor $I^2R$ losses). Stator $I^2R$ losses are

[1] For more information about CEE motor and motor systems programs, visit http://www.cee1.org/ind/mot-sys/mtr-ms-main.php3.

reduced by decreasing resistance to current flow in the electrical components of a motor. These losses are manifested as heat, which can shorten the service life of a motor. Another way to decrease stator $I^2R$ losses is to increase the cross sectional area of the stator winding conductors (e.g., copper wire diameter). This can also be accomplished by either increasing the slot fill and/or increasing the size of the stator slots. However, this method replaces some of the stator magnetic cross sectional area and increases the flux density in the stator. Increasing the flux density may increase core losses. The motor designer must make a trade-off between these two options to streamline the motor design.

There are also various ways to reduce rotor $I^2R$ losses. Rotor conductor bars are the areas in the rotor where current flows. These bars are usually made of aluminum in electric motors. However, one method of increasing the efficiency of the motor is to substitute copper bars for aluminum bars. Aluminum has a higher electrical resistivity ($2.65 \times 10^{-8}$ ohm-m) than copper ($1.68 \times 10^{-8}$ ohm-m). Copper's 63 percent lower electrical resistance compared to aluminum would result in reduced rotor $I^2R$ losses if copper bars are used instead of aluminum.

Manipulation of the rotor's geometrical design is another approach to reduce rotor $I^2R$ losses. The conductor bars of the rotor cage may be skewed. This means the conductor bars are slightly offset from one end of the rotor to the other. By skewing the rotor bars, motor designers can reduce harmonics that add cusps to the speed-torque characteristics of the motor. The cusps in the speed-torque curves mean that the acceleration of the motor will not be completely smooth. The degree of skew matters because reducing the skew will help reduce the rotor resistance and reactance, thereby providing gains in efficiency. However, reducing the skew may have adverse impacts on the speed-torque characteristics.

Another change to the rotor bar geometry that can reduce resistance is increasing the cross-sectional area of the conductor bars. Resistance is inversely proportional to the cross-sectional area of the material through which current is flowing. By increasing the cross-sectional area, rotor bar resistance will decrease which may reduce rotor $I^2R$ losses.

Manufacturers may also alter the end rings of the rotor to increase efficiency. Current flows through the end rings of the rotor and increasing the size of the end ring may decrease resistance and reduce the associated rotor $I^2R$ losses.

Another approach to improve motor efficiency is increasing the number of steel laminations to the rotor and stator (i.e., increasing the "stack" length). Increasing the stack length reduces the flux densities and therefore the iron loss. However, usually other parameters in the motor design must be modified to achieve an efficiency improvement with a longer stack length. Improving the grade of electrical steel used in the motor laminations will also reduce the iron losses.

Another way manufacturers may improve efficiency is to reduce the air gap between the stator and rotor. Within limits, decreasing the air gap decreases the magneto-motive force drop across the air gap. This will improve the motor's power factor and reduce stator $I^2R$ losses. Reducing the air gap has some manufacturing limitations and it may also increase other loss components, so again design optimization is a must.

### 3.3.2 Technology Options for Core Losses

Core losses are losses created in the electrical steel components of a motor. These losses, like $I^2R$ losses, manifest themselves as heat. Core losses are generated in the steel by two electromagnetic phenomena: hysteresis losses and eddy currents. Hysteresis losses are caused by magnetic domains resisting reorientation to the alternating magnetic field (i.e., 60 times per second, or 60 hertz). Eddy currents are currents that are induced in the steel laminations by the pulsating magnetic flux.

Another common technique for reducing steel losses is using a higher quality, more efficient electrical steel in the core. Hysteresis losses are reduced because the magnetic permeability improves and grain size increases, reducing the magnetic domain resistance. Eddy currents are reduced because the resistivity of the laminations is higher, reducing the magnitude of the currents. In studying the techniques used to reduce steel losses, DOE considered two types of materials: conventional silicon steel and so-called “exotic” steels, which contain a relatively high percentage of boron or cobalt.

Conventional steels are commonly used in electric motors manufactured today. There are three types of steel that DOE considers “conventional” or cold-rolled magnetic laminations (CRML), fully processed non-oriented electrical steel, and semi-processed non-oriented electrical steel. Each steel type is sold in a range of grades. In general, as the grade number goes down, so does the amount of loss associated with the steel (i.e., watts of loss per pound of steel). The induction saturation level also drops, causing the need for increased stack length. Of these three types, CRML steels are the most commonly used, but also the least efficient. The fully processed steels are annealed before punching and therefore do not require annealing after being punched and assembled, and are available in a range of steel grades from M56 through M15. Semi-processed electrical steels are designed for annealing after punching and assembly.

The exotic steels are generally not manufactured for specific use in electric motors. However, these steels offer a lower loss level than the best electrical steels, but are more expensive per pound. From a manufacturing perspective, these steels also present problems because they come in non-standard thicknesses that are harder to manufacture.

Another possible option for reducing core loss is to use thinner laminations. Thinner laminations generally have less eddy current losses and this contributes toward improving motor efficiency.

Manufacturers may also reduce eddy currents by using improved insulating coatings between the steel laminations. Improved coatings increase the resistance between the steel laminations, which makes it more difficult for eddy currents to flow from lamination to lamination.

Annealing the core steel is another technique manufacturers use to reduce hysteresis losses. Annealing is a heating process that alters the grain structure of the steel and alleviates any stresses introduced during punching and assembly. After being annealed, the material becomes much easier to magnetize, which means the magnetic domains reorient more easily. Manufacturers will incur more cost if they anneal the steel because they are adding another step to the manufacturing process and that increases production time. The necessary annealing equipment also requires a large capital investment.

Table 3.8 presents the core steels used in manufacturing electric motors, including some more efficient steels that are not as common, which DOE considered in its analysis. In addition to the steel grade name, the table presents nominal thickness and core losses at a fixed magnetic flux density.

**Table 3.8 Core Steel Grades, Thicknesses, and Associated Losses**

| Steel Grade | Nominal Thickness (inches) | Core Loss at 60 Hz Watts per Pound at Magnetic Flux Density | Remarks |
|---|---|---|---|
| 24 M56* | 0.025 | 4.30 Watts/lb at 1.5 T† | Cold-rolled magnetic laminations (semi-processed) |
| 26 M47* | 0.019 | 2.80 Watts/lb at 1.5 T | Non-oriented electrical steel (fully processed) |
| 24 M36* | 0.025 | 2.35 Watts/lb at 1.5 T | Non-oriented electrical steel (fully processed) |
| 24 M19* | 0.025 | 2.00 Watts/lb at 1.5 T | Non-oriented electrical steel (fully processed) |
| 29 M15* | 0.014 | 1.45 Watts/lb at 1.5 T | Non-oriented electrical steel (fully processed) |
| Hiperco 50 | 0.006 | 1.00 Watts/lb at 1.5 T | Iron-cobalt-vanadium soft magnetic alloy |

* Denotes a steel used in the engineering analysis.
†Watts of loss per pound of core steel are only comparable at the same magnetic flux density, measured in tesla. The tesla (symbol T) is the SI-derived unit of magnetic field, which is also known as "magnetic flux density."

#### 3.3.2.1 Plastic Bonded Iron Powder

Recently, DOE became aware of a new technology that Lund University researchers in Sweden developed in the production of magnetic components for electric motors from plastic bonded iron powder (PBIP). The technique has the potential to cut production costs by 50 percent while doubling motor output.

The method uses two main ingredients: metal powder and plastics. Combining the ingredients creates a material with low conductivity and high permeability. The metal particles are surrounded by an insulating plastic, which prevents electric current from developing in the material. This is critical because it essentially eliminates losses in the core due to eddy currents. Properties of PBIP can differ depending on the processing. If the metal particles are too closely compacted and begin to touch, the material will gain electrical conductivity, counteracting one of its most important features.

Another advantage of PBIP is a reduction in the number of production steps. The number of steps in manufacturing a rotor and stator is reduced from roughly 60 to just a few. A second way to increase savings is to build an inductor with PBIP. During processing, the plastic and metal are molded together using a centrifugal force. During this process, the inductor core consisting of PBIP and pre-wound windings are baked into the core. This inductor is then used as a filter for grid power application. The filter then reduces the use of cooling equipment in the motor design.[7]

### 3.3.3 Technology Options for Friction and Windage Losses

Bearing friction and the cooling fan system create what is called "friction and windage losses" in AC induction motors. The bearing friction also adds heat to the motor's system which adds losses and decreases the motor's efficiency.

To decrease the losses caused by motor bearings, manufacturers can change the bearings or bearing lubricant. Less friction, and thus less heat, is produced when manufacturers use a better bearing structure or bearing lubricant, but manufacturers must also consider issues such as temperature rating and speed.

Another way to reduce heat in an induction motor is to use a better cooling system. Changing the fan or adding baffles to the ventilation system can help reduce the motor temperature rise and therefore losses. Baffles help redirect airflow through the motor, creating better circulation and an overall cooler-running motor. With a well-designed cooling system, the motor should run more efficiently.

### 3.3.4 Technology Options for Stray-Load Losses

Stray-load loss is defined as the difference between the total motor loss and the sum of the other four losses referred to above. Stray-load loss is caused by many factors. Manufacturers alter different design parameters to reduce stray-load losses, including slot combination, skew, rotor cage insulation, etc. Stator and rotor lamination design can contribute toward reducing the high frequency losses that occur to some degree in all induction motors. Careful attention to the design and manufacturing processing of the motor can significantly reduce the stray-load loss.

### 3.3.5 Summary of the Technology Options Under Consideration

Table 3.9 summarizes the technology options discussed in this preliminary TSD technology assessment and those that DOE will consider in the screening analysis (see chapter 4). The options that pass all four screening criteria are considered "design options" and are used in the engineering analysis (see preliminary TSD chapter 5) as a means of improving the efficiency of electric motors.

**Table 3.9 Summary of Technology Options for Improving Efficiency**

| Type of Loss to Reduce | Technology Option Applied |
|---|---|
| Stator $I^2R$ Losses | Increase copper wire diameter to maximize slot fill |
| | Reduce end turn length |
| | Increase stator slot size |
| Rotor $I^2R$ Losses | Reduce rotor resistance by a change in volume or material conductivity |
| | Increase rotor slot size |
| | Manipulation rotor slot configuration |
| Core Losses | Select lamination with less watts loss/pound |
| | Optimize air gap |
| | Improve annealing process |
| | Add stack height (i.e., add electrical steel) |
| Friction and Windage Losses | Optimize bearing or lubrication selection |
| | Improve cooling system design |
| Stray-Load Losses | Optimize selection of rotor/stator slot combination |
| | Improve stator/rotor slot lamination designs |
| | Improve rotor surface machining |

Most of the design changes suggested in Table 3.9 produce interacting effects on the motor's breakdown torque, locked rotor torque, locked rotor current, and so forth. Therefore, motor designers making a specific design change must evaluate the effects against all of a motor's performance characteristics and not just focus on efficiency.

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[1]U.S. Small Business Administration. *Small Business Size Standards Matched to North American Industry Classification System.* 2007. (Last accessed November 09, 2011.) <http://www.sba.gov/sites/default/files/Size_Standards_Table.pdf> The November 09, 2011, material from this website is available in Docket #EERE–2010–BT–STD–0027.

[2]National Electric Manufacturers Association. (Last accessed November 09, 2011.) <http://www.nema.org/about/upload/NEMACorpBrochure05.pdf> The November 09, 2011, material from this website is available in Docket #EERE–2010–BT–STD–0027.

[3]National Electric Manufacturers Association. *NEMA Premium Efficiency Electric Motors Program.* 2008. (Last accessed November 09, 2011.) <http://www.nema.org/gov/energy/efficiency/premium/upload/nemaprem1p.doc> The November 09, 2011, material from this website is available in Docket #EERE–2010–BT–STD–0027.

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[5]Consortium for Energy Efficiency. *Industrial Programs Premium-Efficiency Motors*. 2008. (Last accessed November 09, 2011.) <http://www.cee1.org/ind/mot-sys/mtr-ms-main.php3> The November 09, 2011, material from this website is available in Docket #EERE–2010–BT–STD–0027.

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