BUYING AN ENERGY-EFFICIENT ELECTRIC MOTOR

Efficiency is an important factor to consider when buying or rewinding an electric motor. This fact sheet shows you how to obtain the most efficient motor at the lowest price and avoid common problems. It answers the following frequently asked questions:

1. Why is improving motor efficiency important?

2. What is an energy-efficient motor?

3. What efficiency values should I use when comparing motors?

4. When should I consider buying an energy-efficient motor?

5. When is an energy-efficient motor cost effective?

6. Should I rewind a failed motor?

7. What design factors should I consider when choosing a new motor?

8. How should I begin a motor efficiency improvement program?

9. How can I obtain motor prices and efficiency values?

10. Where can I find additional information?

1. Why is improving motor efficiency important?

Over half of all electrical energy consumed in the United States is used by electric motors. Improving the efficiency of electric motors and the equipment they drive can save energy, reduce operating costs, and improve our nation's productivity.

Energy efficiency should be a major consideration when you purchase or rewind a motor. The annual energy cost of running a motor is usually many times greater than its initial purchase price. For example, even at the relatively low energy rate of $0.04/kWh, a typical 20-horsepower (hp) continuously running motor uses almost $6,000 worth of electricity annually, about six times its initial purchase price.

2. What is an energy-efficient motor?

Motor efficiency is the ratio of mechanical power output to the electrical power input, usually expressed as a percentage. Considerable variation exists between the performance of standard and energy-efficient motors (see Figure 1). Improved design, materials, and manufacturing techniques enable energy-efficient motors to accomplish more work per unit of electricity consumed.

Energy-efficient motors offer other benefits. Because they are constructed with improved manufacturing techniques and superior materials, energy-efficient motors usually have higher service factors, longer insulation and bearing lives, lower waste heat output, and less vibration, all of which increase reliability. Most motor manufacturers offer longer warranties for their most efficient models.

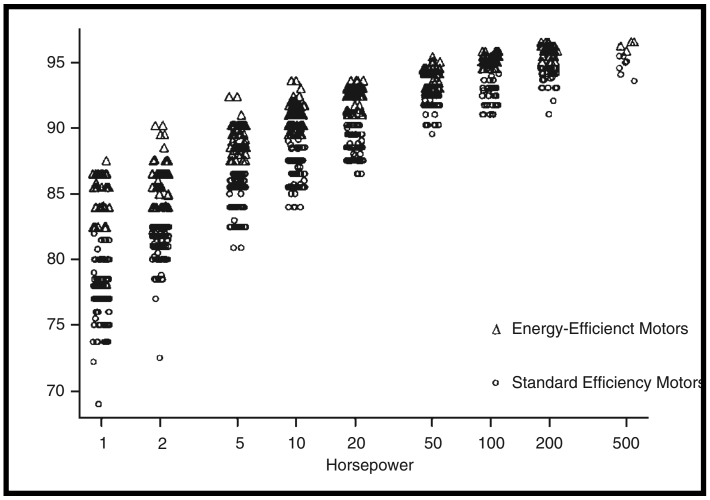

Figure 1
Standard and Energy-Efficient Motor Performances

To be considered energy efficient, a motor's performance must equal or exceed the nominal full-load efficiency values provided by the National Electrical Manufacturers Association (NEMA) in publication MG 1. Specific full-load nominal efficiency values are provided for each horsepower, enclosure type, and speed combination. A motor's performance must equal or exceed the efficiency levels given in Table 1 of this fact sheet (reprinted from Table 12-10 of NEMA MG-1-1993, Rev. 1) for it to be classified as "energy efficient."

The Energy Policy Act of 1992 (EPACT) requires that most general purpose motors manufactured for sale in the United States after October 24, 1997, meet new minimum efficiency standards. These standards are identical to the shaded area of Table 1. The Act applies to 1- through 200-hp general-purpose, T-frame, single-speed, foot-mounted, continuous-rated, polyphase, squirrel-cage, induction motors conforming to NEMA designs A and B. Covered motors are designed to operate with 230 or 460 volt power supplies, have open or "closed" (totally enclosed) enclosures, and operate at speeds of 1200, 1800, or 3600 rpm.

3. What efficiency values should I use when comparing motors?

When comparing motor efficiencies, be sure to use a consistent measure of efficiency. Nominal efficiency is best. Nominal efficiency is an average value obtained through standardized testing of a population of motors. Minimum guaranteed efficiency, which is based on nominal efficiency, is slightly lower to take into account typical population variations. Minimum guaranteed efficiency is also less accurate, because the value is rounded. Other efficiency ratings, including apparent and calculated, should not be used.

In the United States, the recognized motor efficiency testing protocol is the Institute of Electrical and Electronics Engineers (IEEE) 112 Method B, which uses a dynamometer to measure motor output under load. Different testing methods yielding significantly different results are used in other countries. The NEMA nameplate labeling system for design A and B motors in the 1- to 500-hp range uses bands of efficiency values based on IEEE 112 testing.

4. When should I consider buying an energy-efficient motor?

Energy-efficient motors should be considered in the following circumstances:

- For all new installations
- When purchasing equipment packages, such as compressors, HVAC systems, and pumps
- When major modifications are made to facilities or processes
- Instead of rewinding older, standard efficiency units
- To replace oversized and underloaded motors
- As part of a preventive maintenance or energy conservation program.

The cost effectiveness of an energy-efficient motor in a specific situation depends on several factors, including motor price, efficiency rating, annual hours of use, energy rates, costs of installation and downtime, your firm's payback criteria, and the availability of utility rebates. Check with your utility to determine whether it can fund a portion of your motor replacement costs through its energy conservation programs. Question 5 addresses methods for evaluating the cost effectiveness of energy-efficient motors.

Table 1
NEMA Threshold Full-Load Nominal Efficiency Values for Energy-Efficient Motors (from NEMA MG1 Table 12-10)[1]

Open Motors						Enclosed Motors				
hp	**3600**	**1800**	**1200**	**900**		**hp**	**3600**	**1800**	**1200**	**900**
1	—	82.5	80.0	74.0		1	72.5	82.5	80.0	74.0
1.5	82.5	84.0	84.0	75.5		1.5	82.5	84.0	85.5	77.0
2	84.0	84.0	85.5	85.5		2	84.0	84.0	86.5	82.5
3	84.0	86.5	86.5	86.5		3	85.5	87.5	87.5	84.0
5	85.5	87.5	87.5	87.5		5	87.5	87.5	87.5	85.5
7.5	87.5	88.5	88.5	88.5		7.5	88.5	89.5	89.5	85.5
10	88.5	89.5	90.2	89.5		10	89.5	89.5	89.5	88.5
15	89.5	91.0	90.2	89.5		15	90.2	91.0	90.2	88.5
20	90.2	91.0	91.0	90.2		20	90.2	91.0	90.2	89.5
25	91.0	91.7	91.7	90.2		25	91.0	92.4	91.7	89.5
30	91.0	92.4	92.4	91.0		30	91.0	92.4	91.7	91.0
40	91.7	93.0	93.0	91.0		40	91.7	93.0	91.7	91.0
50	92.4	93.0	93.0	91.7		50	92.4	93.0	93.0	91.7
60	93.0	93.6	93.6	92.4		60	93.0	93.6	93.0	91.7
75	93.0	94.1	93.6	93.6		75	93.0	94.1	93.6	93.0
100	93.0	94.1	94.1	93.6		100	93.6	94.5	93.6	93.0
125	93.6	94.5	94.1	93.6		125	94.5	94.5	94.1	93.6
150	93.6	95.0	94.5	93.6		150	94.5	95.0	94.1	93.6
200	94.5	95.0	94.5	93.6		200	95.0	95.0	95.0	94.1
250	94.5	95.4	95.4	94.5		250	95.4	95.0	95.0	94.5
300	95.0	95.4	95.4	—		300	95.4	95.4	95.0	—
350	95.0	95.4	95.4	—		350	95.4	95.4	95.0	—
400	95.4	95.4	—	—		400	95.4	95.4	—	—
450	95.8	95.8	—	—		450	95.4	95.4	—	—
500	95.8	95.8	—	—		500	95.4	95.8	—	—

[1] The shaded area indicates motor classes covered by the efficiency standards contained within the Energy Policy Act of 1992.

5. When is an energy-efficient motor cost effective?

The extra cost of an energy-efficient motor is often quickly repaid in energy savings. As illustrated in Table 2, each point of improved motor efficiency can save significant amounts of money each year. In typical industrial applications, energy-efficient motors are cost effective when they operate more than 4000 hours a year, given a 2-year simple payback criterion. For example, with an energy cost of $0.04/kWh, a single point of efficiency gain for a continuously operating 50-hp motor with a 75% load factor saves 4079 kWh, or $163 annually. Thus, an energy-efficient motor that offers four points of efficiency gain can cost up to $1,304 more than a standard model and still meet a 2-year simple payback criterion. A utility rebate program would further enhance the benefits of an energy-efficient motor.

Table 2
Annual Value of a One-Point Efficiency Gain (Based on $0.04/kWh, 8000 Hours of Use, Full Load)

Horsepower	Annual Savings
5	$17
10	$32
20	$61
50	$142
100	$278
200	$537

Whenever possible, obtain actual price quotes from motor distributors to calculate simple paybacks. Motors rarely sell at full list price. You can typically obtain a 20% to 60% discount from vendors, with specific prices depending on the distributor's pricing policies, the number and type of motors you buy, and fluctuations in the motor market. Comparison shop when purchasing motors. The following three techniques can help you determine whether an energy-efficient motor is cost effective:

1. Use the MotorMaster or Windows-based MotorMaster+ software program to calculate the dollar savings and simple payback from using a more efficient motor, taking into account motor size, price, efficiency, annual hours of use, load factor, electricity costs, and utility rebates. MotorMaster can be used to analyze a new motor purchase, rewind of a failed motor, or replacement of a working motor. This program is described in further detail in the answer to Question 9.

2. Use the following formulas to calculate the annual energy savings and simple payback from selecting a more efficient motor. Simple payback is defined as the time required for the savings from an investment to equal the initial or incremental cost.

Annual Energy Savings

$$\text{Savings} = hp \times L \times 0.746 \times hr \times C \times \left[\frac{100}{Estd} - \frac{100}{Eee}\right]$$

E Savings = Expected annual dollar savings
hp = Motor rated horsepower
L = Load factor (percentage of full load/100)
hr = Annual operating hours
C = Average energy costs ($/kWh)
Estd = Standard motor efficiency rating, %
Eee = Energy-efficient motor efficiency rating, %
0.746 = Conversion from horsepower to kW units

Simple Payback

For a new motor purchase, the simple payback is the price premium minus any utility rebate for energy-efficient motors, divided by the annual dollar savings:

$$\text{Simple payback (years)} = \frac{\text{Price premium} - \text{Utility rebate}}{\text{Annual dollar savings}}$$

When calculating the simple payback for replacing an operating motor, you must include the full purchase price of the motor plus any installation costs:

$$\text{Simple payback (years)} = \frac{\text{Motor price} + \text{Installation charge} - \text{Utility rebate}}{\text{Annual dollar savings}}$$

3. Use Table 3 to determine whether a new energy-efficient motor will meet common payback criteria. Table 3, which is based on typical motor efficiencies and prices, indicates the minimum number of hours a year a motor must be used at various energy prices in order to obtain a 2-, 3-, and 4-year simple payback. This technique is less accurate than a more detailed analysis. The calculation of values for Table 3 assumes that an energy-efficient motor has a 15% to 25% price premium with no utility rebate, and it ignores other benefits of energy-efficient motors. A lower price premium, a rebate program, or reliability benefits make energy-efficient motors even more cost effective.

Choose a new energy-efficient 1- to 100-hp motor if it will be used more than the indicated number of hours each year.

6. Should I rewind a failed motor?

Although failed motors can usually be rewound, it is often worthwhile to replace a damaged motor with a new energy-efficient model to save energy and improve reliability. When calculating operating costs for rewound motors, deduct one efficiency point for motors exceeding 40 hp and two points for smaller motors. Have motors rewound only at reliable repair shops that use low temperature (under 700°F) bakeout ovens, high quality materials, and a quality assurance program based on EASA-Q or ISO-9000. Ask the repair shop to conduct a core loss or loop test as part of their rewind procedures.

Select a new energy-efficient motor under any of the following conditions:

- The motor is less than 40 hp.
- An energy-efficient motor is recommended according to Table 3.
- The cost of the rewind exceeds 65% of the price of a new motor.
- The motor was rewound before 1980.

Table 3
Minimum Hours per Year of Motor Use that Meet Various Simple Payback Criteria

(Choose a new energy-efficient 1- to 100-hp NEMA design A or B motor if it will be used more than the indicated number of hours each year.)

Simple payback period	Average Energy Price (Cents/kWh)			
	2	4	6	8
2 years	8750	6000	4000	3000
3 years	7000	4000	3000	2000
4 years	6000	3000	2000	1500

7. What design factors should I consider when choosing a new motor?

Motor Size. Size motors for efficiency. Motors should be sized to operate with a load factor between 65% and 100%. The common practice of oversizing results in less efficient motor operation. For example, a motor operating at a 35% load is less efficient than a smaller motor that is matched to the same load (see Figure 2). Of course, some situations may require oversizing for peak loads, but in such cases alternative strategies should be considered, such as a correctly sized motor backed up with a pony motor.

Operating Speed. Select replacement energy-efficient motors with a comparable full-load speed for centrifugal load applications (pumps and fans). Induction motors have an operating speed that is slightly lower than their rated synchronous speed. For example, a motor with a synchronous speed of 1800 rpm will typically operate under full load at about 1750 rpm. Operating speed (full-load rpm) is stamped on motor nameplates. The difference between the synchronous speed and the operating speed is called slip. Slip varies with load and the particular motor model.

Every pump and fan has a design speed. Centrifugal pump and fan loads are extremely sensitive to speed variations; an increase of just 5 rpm can significantly affect the pump or fan operation, leading to increased flow, reduced efficiency, and increased energy consumption. Whenever a pump or fan motor is replaced, be sure to select a model with a full-load rpm rating equal to or less than that of the motor being replaced.

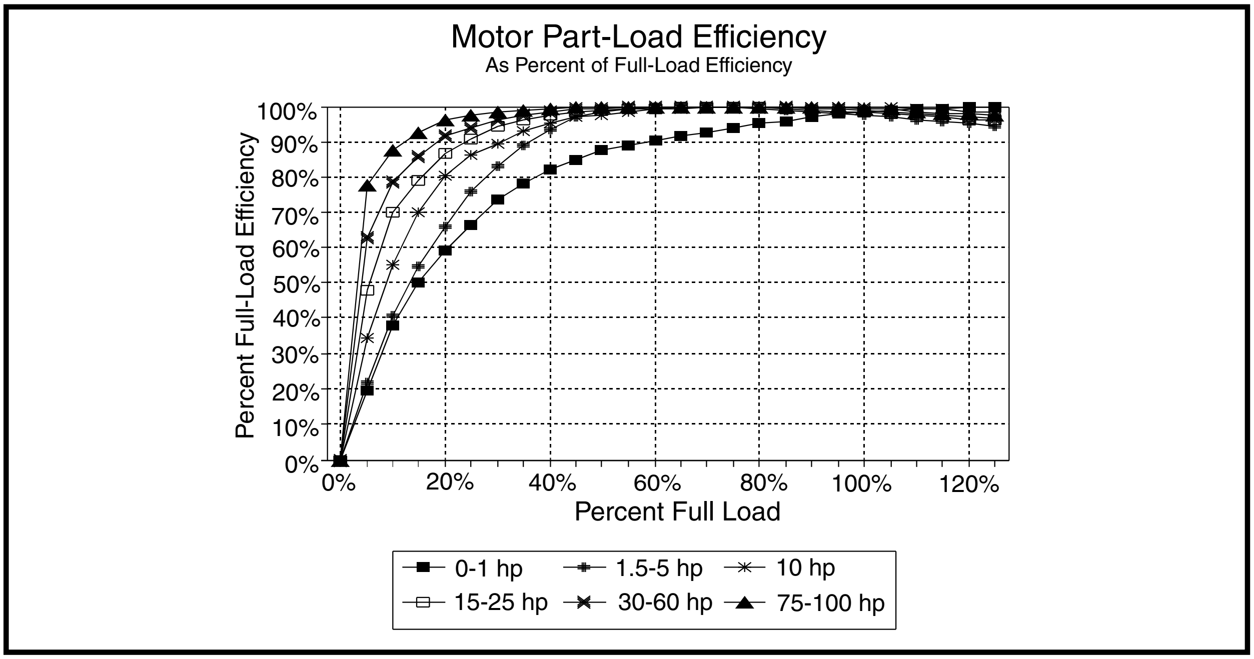

Figure 2
Part-Load Motor Efficiency Range

Inrush Current. Avoid overloading circuits. Energy-efficient motors feature low electrical resistance and thus exhibit higher inrush currents than standard models. The inrush current duration is too short to trip thermal protection devices, but energy-efficient motors equipped with magnetic circuit protectors can sometimes experience nuisance starting trips.

8. How should I begin a motor efficiency improvement program?

Survey your motors. Gather nameplate information and obtain field measurements (voltage, amperage, power factor, operating speed) under typical operating conditions. Initially focus on motors that exceed minimum size and operating duration criteria. Typical selection criteria include:

- Three-phase NEMA design B motor
- Non-specialty motor
- 10 to 600 hp
- At least 2000 hours per year of operation
- Constant load (not intermittent, cyclic, or fluctuating)

- Older or rewound standard efficiency motors
- Easy access
- Readable nameplate.

Conduct motor replacement analyses (with MotorMaster+) and divide your motors into the following three categories:

Replace Immediately — Motors Offering Rapid Payback through Energy Savings, Improved Reliability, or Utility Rebates. These include motors that run continuously (typically 8000 or more hours a year), are currently inefficient (including oversized motors), must be reliable, or are covered by attractive utility rebate programs. Order an efficient replacement motor soon and install it at the next available opportunity, such as during a scheduled downtime.

Replace at Time of Failure — Motors with Intermediate Payback. When these motors fail, you will want to replace them with an energy-efficient model. Now is the time to contact motor dealers to review the efficiency and prices of available motors. After identifying the most cost-effective replacement model, you must decide whether to purchase it and keep it on hand as a spare, or wait to purchase it until the existing motor fails. This choice depends on how quickly an energy-efficient motor can be obtained through suppliers, how quickly a failed motor must be replaced, and how many motors of the same size and type are used in your facility.

Leave Present Situation as is — Motors with Extended Payback. These motors are already reasonably efficient or are used less than 2000 hours each year. They can be rewound or replaced with a similar motor.

Motors and drive systems have a long useful life. The cost of running a motor may increase significantly in the future. Energy efficiency improvements that are not justified today may become worthwhile in a few years, so periodically reevaluate paybacks and reliability. It is also important to operate your motor efficiently. Keep the following two issues in mind:

Power Quality. Address power quality problems. To improve motor reliability and efficiency, it is important to maintain the correct voltage and phase balance, identify and eliminate current leaks, and prevent harmonics in the electrical supply. It is a good idea to have an electrical engineer review the electrical system periodically, especially before installing a new motor or after making changes to the system and its loads. Consult the manufacturer before installing any motor under conditions of poor power quality.

Periodic Maintenance. It is important to maintain motors according to manufacturers' instructions. Although energy-efficient motors with higher temperature-rated insulation may be able to handle higher temperatures and other abuse, there is no reason to reduce maintenance. Motors should have good ventilation and be periodically inspected for increased vibration or power supply problems.

9. How can I obtain motor prices and efficiency values?

MotorMaster+ software helps you choose the most efficient and cost-effective motor for your application. The MotorMaster+ database contains performance information and list prices for over 13,800 NEMA design B motors, ranging from 1 to 600 hp. Full- and part-load efficiencies, power factor, full-load rpm, voltage, frame size, service factor, and list price are available for each model. You specify the horsepower, speed, enclosure type, and operating voltage to obtain a list of available models ranked in order of descending full-load efficiency values.

MotorMaster+ calculates the energy consumption of a motor in a specific application, taking into account efficiency ratings, energy costs, hours of use, and load factor. It calculates the load and annual energy efficiency of the existing motor (based upon field measurements), demand and dollar savings, and simple payback period due to selecting a more efficient motor model. Utility rebate values can be incorporated in payback or life-cycle cost calculations.

MotorMaster+ can be obtained by contacting the Motor Challenge Information Clearinghouse at (800) 862-2086. You will receive disks, telephone support, and a users' manual. MotorMaster+ requires an IBM-compatible computer with the capacity to run Windows 3.1, Windows for Workgroups, or Windows 95. This means a 386 or higher microprocessor, at least 8 MB of memory, and a hard disk with at least 15 MB of free disk space.

10. Where can I find additional information?

The Motor Challenge Program, Washington State University Cooperative Extension, and the Bonneville Power Administration have prepared a number of publications on motor efficiency topics. Examples include: *The Motor Challenge Sourcebook, An Energy Management Guide for Motor-Driven Systems, the Energy Efficient Electric Motor Selection Handbook, the Adjustable Speed Drive Applications Guidebook, Optimizing Your Motor Drive System, Determining Electric Motor Load Factor,* and *Reducing Power Factor Cost.* Call the Motor Challenge Clearinghouse for details about ordering these or other motor-related documents.

About Motor Challenge

Motor Challenge is a partnership program between the U.S. Department of Energy and the nation's industries. The program is committed to increasing the use of industrial energy-efficient electric motor systems and related technologies.

The program is wholly funded by the U.S. Department of Energy and is dedicated to helping industry increase its competitive edge, while conserving the nation's energy resources and enhancing environmental quality.

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For More Information

Contact the Motor Challenge Information Clearinghouse: 1-800-862-2086. The Motor Challenge Information Clearinghouse is your one-stop resource for objective, reliable, and timely information on electric motor-driven systems.

Access the Motor Challenge website on the Internet at www.motor.doe.gov.

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