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Energy-Efficient Electric Motor Selection Handbook

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BONNEVILLE POWER ADMINISTRATION

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REPORT SUMMARY

SUBJECT High Efficiency Electric Motors

TITLE ENERGY-EFFICIENT MOTOR SELECTION GUIDEBOOK

SUMMARY Substantial reductions in energy and operational costs can be achieved through the use of energy-efficient electric motors. A handbook was compiled to help industry identify opportunities for cost-effective application of these motors. It covers the economic and operational factors to be considered when motor purchase decisions are being made. Its audience includes plant managers, plant engineers, and others interested in energy management or preventative maintenance programs.

BPA PERSPECTIVE Conservation is a cornerstone of the Bonneville Power Administration's (BPA) resource program. A major concern of the BPA is to promote the use of cost effective electric power conservation technologies. The industrial sector is the largest of the 4 electric energy consuming sectors. Within the sector electric motors are the largest users of that energy. One study estimated recently that 52.7 average megawatts of electric power, valued at \$13.8 million, could be saved in the Northwest through the replacement of standard motors with high efficiency models. Of the 2 million industrial motors sold nationwide each year, energy efficient motors represent only 15 percent of the sales. That figure is probably even lower in the Northwest where electricity is cheap. Assisting industry in considering the high efficiency motor option was the goal of this project.

BACKGROUND The efficiency of an electric motor can only be improved through a reduction in motor losses. Improvements in the design, materials, and construction have resulted in efficiency gains of 2 to 6 percent which translates into a 25 percent reduction in losses. A small gain in efficiency can produce significant energy savings and lower operating costs over the life of the motor. Consequently, the higher purchase price of high efficiency motors (15 to 30 percent) can, in most cases, be recovered in 2 years through cost savings in energy and operation. Because energy-efficient motors are a proven technology in terms of durability and reliability, their use should be considered for new installations, major modifications, replacement of failed motors or those that require rewinding, or extreme cases of oversized or underloaded motors.

OBJECTIVE

To assist the industrial sector in identifying cost effective opportunities for application of energy-efficient motors.

APPROACH

The Handbook contains a discussion on the characteristics, economics, and benefits of standard versus high efficiency motors in the 1 to 200 horsepower range. A motor performance database is supplied for use in identifying, evaluating, and purchasing energy-efficient motors and includes information on full and part load nominal efficiency and power factor as well as material on specific models and costs. Descriptions of how operating factors such as speed and design voltage effect performance are included. Atypical operating conditions are also covered. A case study is presented and steps are outlined for launching a motor improvement program, which includes a worksheet, to determine potential energy savings and the economic feasibility of an energy-efficient motor project.

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Preface

Efficient use of energy enables industrial facilities to minimize production costs, increase profits, and stay competitive. The majority of electrical energy consumed in most industrial facilities is used to run electric motors. Energy-efficient motors now available are typically from 2 to 6 percent more efficient than their standard motor counterparts. This efficiency improvement translates into substantial energy and dollar savings. For instance, a recent study of Northwest industrial sector energy conservation measures revealed a potential for 52.7 MWa of energy savings by replacing standard motors with high-efficiency motors. This savings is annually valued at \$13.8 million given an electricity price of only \$0.03/kWh.

The price premium for an energy-efficient motor is typically 15 to 30 percent of the cost of a standard motor. Over a 10-year operating life, a motor can easily consume electricity valued at over 57 times its initial purchase price. This means that when you spend \$1,600 to purchase a motor, you are obligating yourself to purchase over \$92,000 worth of electrical energy to operate it. A price premium of \$400 is negligible compared to saving 3 percent of \$92,000 or \$2,760. Purchasing new or replacement energy-efficient motors makes good economic sense.

Energy-efficient motors are truly premium motors. The efficiency gains are obtained through the use of refined design, better materials, and improved construction. Yet only 15 percent of motor sales nationwide are of high-efficiency units. Because of our low-cost electricity, this percentage is undoubtedly even lower in the Northwest region.

Durable and reliable energy-efficient motors can be extremely cost effective with simple paybacks on investment of less than 2 years—even in the Northwest. Energy-efficient motors should be considered in the following instances.

- For new facilities or when modifications are made to existing installations or processes
- When procuring equipment packages
- Instead of rewinding failed motors
- To replace oversized and underloaded motors
- As part of an energy management or preventative maintenance program
- When utility rebates are offered that make high-efficiency motor retrofits even more cost effective

This Energy-Efficient Electric Motor Selection Handbook (Handbook) shows you how to assess energy savings and cost effectiveness when making motor purchase decisions. The Handbook also discusses high-efficiency motor speed characteristics, performance under part-load conditions, and operation with an abnormal power supply.

Additionally, the Handbook tells you where assistance is available. For example, you can obtain performance and price data for both standard and energy-efficient motors from the Electric Ideas Clearinghouse 1-800-872-3568, or 206-586-8588 outside of BPA's service area. Finally, the Handbook contains a motor test data sheet (Appendix A) and a list of Northwest motor manufacturers' representatives (Appendix B).

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Chapter 1

Introduction

When to Buy Energy-Efficient Motors

This Energy-Efficient Electric Motor Selection Handbook (Handbook) contains criteria to help you identify motors that are candidates for replacement with energy-efficient electric motors. Using readily available information such as motor nameplate capacity, operating hours, and electricity price you can quickly determine the simple payback for motor replacement, new purchase, and retrofit scenarios.

Energy-efficient motors can save energy and reduce your operating costs. By using energy efficiently, you can increase profits while keeping your facility competitive. Installing energy conservation measures not only reduces your utility bill today, but it helps keep the cost of energy down in the future. Lower demand enables utilities to defer building expensive new power production capacity, resulting in lower costs for you, the consumer.

The opportunity for capturing energy savings through energy-efficient motor changeouts depends primarily on proper selection and use.¹ Motor energy conservation opportunities can be classified into three general areas: 1) making new purchases, 2) providing alternatives to rewinding failed motors, and 3) retrofitting operable, standard-efficiency motors with comparable high-efficiency units. Energy-efficient motors should be considered in the following instances.²

- For all new installations
- When major modifications are made to existing facilities or processes
- For all new purchases of equipment packages that contain electric motors, such as air conditioners, compressors, and filtration systems
- When purchasing spares or replacing failed motors
- Instead of rewinding old, standard-efficiency motors
- To replace grossly oversized and underloaded motors
- As part of an energy management or preventative maintenance program
- When utility conservation programs, rebates, or incentives are offered that make energy-efficient motor retrofits cost-effective

Industrial Motor Populations and Uses

In 1987, industrial sector use of electricity in the Northwest amounted to 6,062 average megawatts (MWa). This is equivalent to 38.8 percent of the region's 15,618 MWa of total electricity sales to final consumers. Five industries—food, chemicals, paper, lumber, and metals—accounted for more than 90 percent of the region's industrial use of electricity.³ A 1988 study of possible industrial sector energy conservation measures revealed a potential of approximately 345 MWa of energy savings, with changeouts of standard to energy-efficient motors accounting for 52.7 MWa or 15.2 percent of the total savings.⁴ Replacing standard with energy-efficient motors saves \$13.8 million annually given an electricity price of only \$.03/kWh.

A nationwide survey by a major motor manufacturer indicates that approximately 35.2 million motors larger than 1 horsepower (hp) are used within the commercial and industrial sectors.⁵ Approximately 6.7 million units drive centrifugal pumps and fans in industrial applications while over 23 million motors are used for constant torque conveyor and positive displacement pumping applications. Figure 1 breaks down motor population by end-use.

Figure 1
US Motor Population by End-Use Application

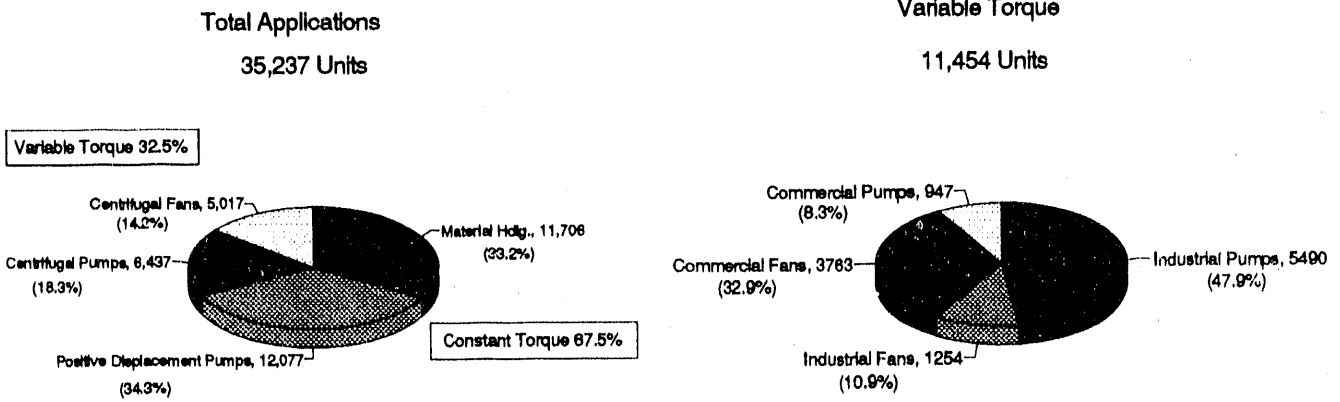
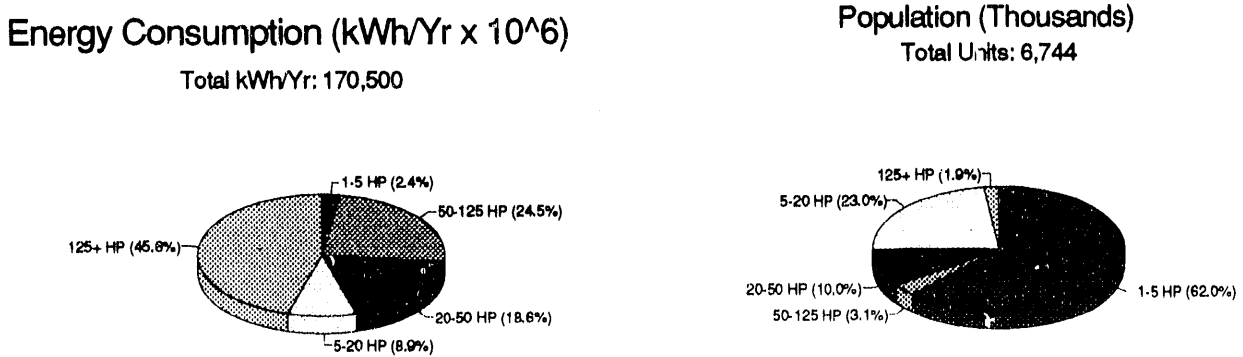


Figure 2
Motor Population and Energy Consumption by Motor Size for Industrial Sector Variable Torque Applications



While 62 percent of the motors used in variable torque centrifugal pump and fan applications in the industrial sector are in the 1- to 5-hp size range, these small motors account for only 2.4 percent of total motor energy consumption. Motors in the 5- to 125-hp size range use 52 percent of the sector's energy, while large motors account for 45.6 percent of electricity consumption. Figure 2 summarizes motors and energy consumption by motor size.⁵

Motors are the largest single use of electricity in most industrial plants. A study conducted for Seattle City Light indicates that 42 percent of that utility's industrial customer electrical consumption goes to motor driven end uses.⁶ The dominance of motor loads can be even greater in some industries. For instance, energy audits conducted by the Washington State Energy Office reveal the following motor loads at various manufacturing plants. A saw and planer mill has 65 motors with 6,215 hp of connected load. Approximately 94 percent of the 13.8 million kWh of that facility's annual electrical energy consumption goes to motors driving boiler feedwater pumps, forced draft fans, hydraulic systems, air compressors, planer drives, blowers, feeders, chippers, edgers, hoggers, debarkers, radial saws, and slabbers. A small cedar mill similarly has 37 motors with 2,672 total hp. A Northwest plywood drying facility uses 72 motors with 3,275 hp of nameplate capacity. These motors drive combustion air fans, scrubbers, circulating air fans, condensate pumps, charging pumps, hoggers, fines and chip blowers, bag house blowers, and glue mixers. Forty-seven percent of the electrical consumption at a controlled-atmosphere cold storage facility is due to refrigeration system compressor, evaporator fan, and condenser fan motors while a potato processing plant has 17 motors with 1,115 hp driving ammonia compressors, hydraulic pumps, and air compressors.

Annual Electric Motor Sales Volume

A major manufacturer estimates that U.S. annual sales exceed 2 million motors. Table 1 describes sales

volume by motor horsepower. Only 15 percent of these sales involve premium or high-efficiency motors.⁷ A survey of motor manufacturers conducted by the Washington State Energy Office (WSEO) indicates that the highest priorities of motor buyers are availability/quick delivery, reliability, and price. Energy efficiency was ranked 5th out of 11 purchaser concerns.

Table 1

Polyphase Induction Motor Annual Sales Volume

hp	Units (Thousands)
1- 5	1,300
7 1/2- 20	500
25- 50	140
60- 100	40
125- 200	32
250- 500	11
Total	2,023

It is likely that the percentage of energy-efficient motor sales is even lower in the Pacific Northwest. Motor dealers state that..."customers don't ask for efficiency data and we don't tell them...", "...I haven't sold a high-efficiency motor in a year and a half...", "...high-efficiency motors just don't make sense with the low electrical rates we have in the Northwest...", and "...customers get turned off when we tell them that high-efficiency motors have a price premium of 15 to 20 percent and an efficiency improvement of only 2 to 3 percent."

Contrary to "common knowledge," energy-efficient motor purchases can be quite cost effective with simple paybacks on investment of less than 2 years—even in the Northwest.

Chapter 2

Energy-Efficient Motor Performance and Price

The efficiency of a motor is the ratio of the mechanical power output to the electrical power input. This may be expressed as:

$$\text{Efficiency} = \frac{\text{Output}}{\text{Input}} = \frac{\text{Input} - \text{Losses}}{\text{Input}} = \frac{\text{Output}}{\text{Output} + \text{Losses}}$$

Design changes, better materials, and manufacturing improvements reduce motor losses, making premium or energy-efficient motors more efficient than standard motors. Reduced losses mean that an energy-efficient motor produces a given amount of work with less energy input than a standard motor.²

In 1989, the National Electrical Manufacturers Association (NEMA) developed a standard definition for energy-efficient motors. The definition, designed to help users identify and compare electric motor efficiencies on an equal basis, includes a table of nominal (average) and minimum efficiency levels.⁸ A motor must equal or exceed the nominal efficiency values listed in Table 2 to be classified as "energy-efficient."

Nominal full-load efficiencies for currently available energy-efficient and standard motors are shown in Figure 3. Figure 3 clearly indicates that the NEMA standards are easy for motor manufacturers to exceed. In fact, most motors on the market qualify as "high-efficiency" machines. It is also apparent that you can improve efficiency by as much as 6 points through simply buying a "premium-efficiency" motor, one whose

performance lies near the top of the range of available efficiencies, rather than one that just meets the NEMA minimum standard. Frequently, one manufacturer's energy-efficient motor performs with approximately the same efficiency as another manufacturer's standard unit. Average nominal efficiencies and list prices for standard and energy-efficient motors are summarized in Table 3.

In order to help you identify, evaluate, and procure energy-efficient motors, WSEO has prepared a motor performance database. The database contains full- and part-load nominal efficiencies and power factors for approximately 2,700, 5- to 300-hp NEMA Design B poly-phase motors. Information contained in the database was extracted from manufacturers' catalogs with each manufacturer given an opportunity to review performance information for accuracy. Users can query the database to produce a listing, ranked in order of descending full-load efficiency, for all motors within a stated size, speed, and enclosure classification.

A sample database listing is shown in Table 4. The database also contains the manufacturers' name, motor model, full-load RPM, service factor, frame size, and list price. Note that the nominal full-load motor efficiencies vary from 86.5 to 93.2 percent. Prices also vary. In many cases, two motors with identical list prices will exhibit very different efficiency ratings.

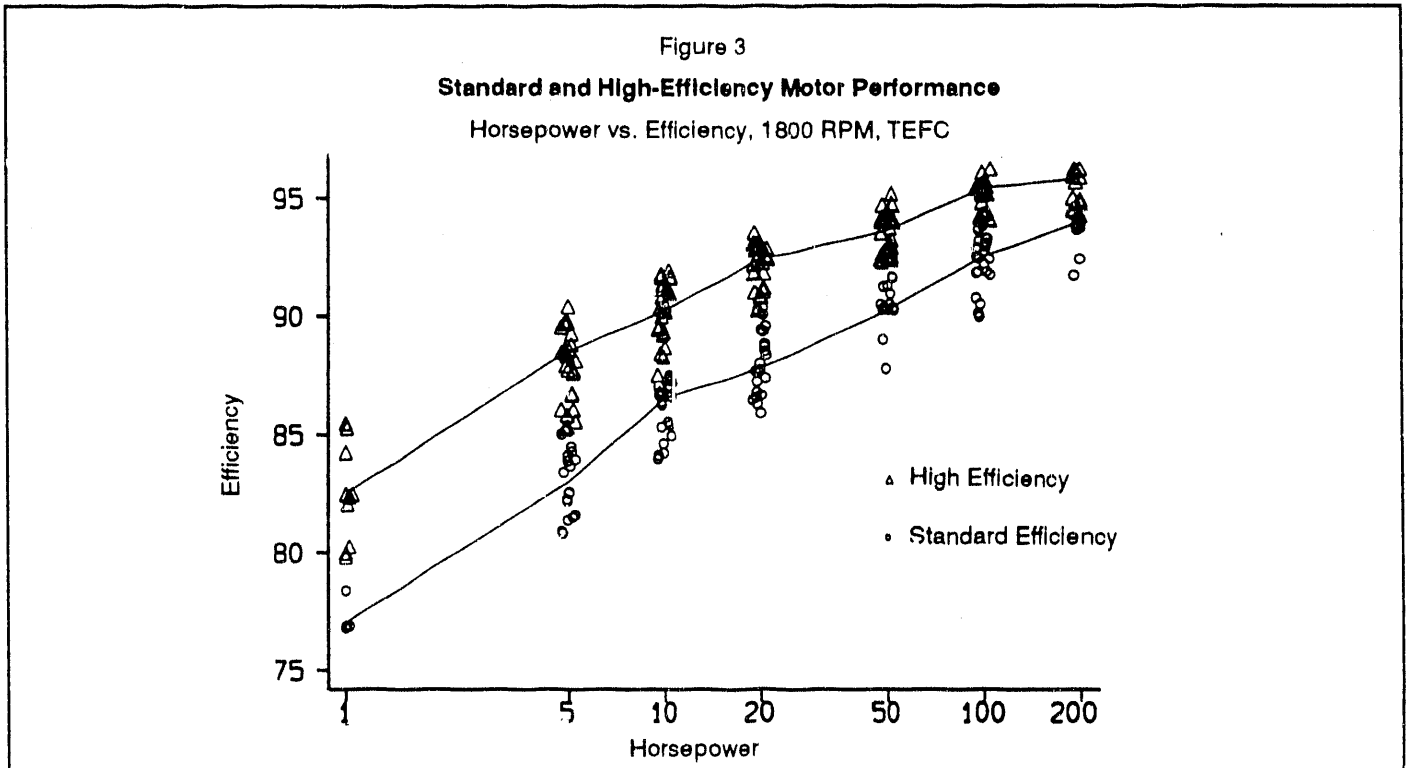
Table 2
**NEMA Minimum Nominal Full Load Efficiencies
 For Energy-Efficient Motors**

Open Motors

hp	3600	1800	1200	900 (RPM)
1.0	—	82.5	77.0	72.0
1.5	80.0	82.5	82.5	75.5
2.0	82.5	82.5	84.0	85.5
3.0	82.5	86.5	85.5	86.5
5.0	85.5	86.5	86.5	87.5
7.5	85.5	88.5	88.5	88.5
10.0	87.5	88.5	90.2	89.5
15.0	89.5	90.2	89.5	89.5
20.0	90.2	91.0	90.2	90.2
25.0	91.0	91.7	91.0	90.2
30.0	91.0	91.7	91.7	91.0
40.0	91.7	92.4	91.7	90.2
50.0	91.7	92.4	91.7	91.7
60.0	93.0	93.0	92.4	92.4
75.0	93.0	93.6	93.0	93.6
100.0	93.0	93.6	93.6	93.6
125.0	93.0	93.6	93.6	93.6
150.0	93.6	94.1	93.6	93.6
200.0	93.6	94.1	94.1	93.6

Enclosed Motors

hp	3600	1800	1200	900 (RPM)
1.0	—	80.0	75.5	72.0
1.5	78.5	81.5	82.5	75.5
2.0	81.5	82.5	82.5	82.5
3.0	82.5	84.0	84.0	81.5
5.0	85.5	85.5	85.5	84.0
7.5	85.5	87.5	87.5	85.5
10.0	87.5	87.5	87.5	87.5
15.0	87.5	88.5	89.5	88.5
20.0	88.5	90.2	89.5	89.5
25.0	89.5	91.0	90.2	89.5
30.0	89.5	91.0	91.0	90.2
40.0	90.2	91.7	91.7	90.2
50.0	90.2	92.4	91.7	91.0
60.0	91.7	93.0	91.7	91.7
75.0	92.4	93.0	93.0	93.0
100.0	93.0	93.6	93.0	93.0
125.0	93.0	93.6	93.0	93.6
150.0	93.0	94.1	94.1	93.6
200.0	94.1	94.5	94.1	94.1



Motor Losses and Loss Reduction Techniques

A motor's function is to efficiently convert electrical energy into mechanical energy to perform useful work. The primary way to improve motor efficiency is to reduce motor losses. Even though standard motors operate efficiently, with typical efficiencies ranging between 83 and 92 percent, energy-efficient motors perform significantly better. An efficiency gain from only 92 to 94 percent results in a 25 percent reduction in losses. Since motor losses result in heat rejected into the atmosphere, reducing losses can significantly reduce cooling loads on an industrial facility's air conditioning system.

Motor energy losses can be segregated into five major areas, each of which is influenced by design and construction decisions.⁹ One design consideration, for example, is the size of the air gap between the rotor and the stator. Large air gaps tend to maximize efficiency at the expense of power factor, while small air gaps compromise efficiency and improve power factor.¹⁰ Motor losses may be categorized as those which are fixed,

occurring whenever the motor is energized, and remaining constant for a given voltage and speed, and those which are variable and increase with motor load.¹¹ These losses are described below.

1. **Core loss** represents energy required to magnetize the core material (hysteresis) and includes losses due to creation of eddy currents that flow in the core. Core losses are decreased through the use of improved permeability electromagnetic (silicon) steel and by lengthening the core to reduce magnetic flux densities. Eddy current losses are decreased by using thinner steel laminations.
2. **Windage and friction** losses occur due to bearing friction and air resistance. Improved bearing selection, air-flow, and fan design are employed to reduce these losses. In an energy-efficient motor, loss minimization results in reduced cooling requirements so a smaller fan can be used. Both core losses and windage and friction losses are independent of motor load.

Table 3
**Average Efficiencies and Typical List Prices
 for Standard and Energy-Efficient Motors
 1800 RPM Open Drip-Proof Motors**

hp	Average Standard Motor Efficiency, %	Average Energy-Efficient Motor Efficiency, %	Efficiency Improvement, %	Typical Standard ODP Motor List Price	Typical Energy-Efficient ODP Motor List Price	List Price Premium
5	83.8 (15)	87.9 (12)	4.7	\$329 (4)	\$370 (4)	\$41
7.5	85.3 (14)	89.6 (15)	4.8	408 (6)	538 (5)	130
10	87.2 (21)	91.1 (7)	4.3	516 (6)	650 (5)	134
15	87.6 (15)	91.5 (11)	4.3	677 (5)	864 (5)	187
20	88.4 (14)	92.0 (11)	3.9	843 (6)	1055 (5)	212
25	89.2 (14)	92.8 (11)	3.9	993 (5)	1226 (5)	233
30	89.2 (12)	92.8 (12)	3.9	1160 (4)	1425 (5)	265
40	90.2 (12)	93.6 (11)	3.6	1446 (4)	1772 (5)	326
50	90.1 (11)	93.6 (13)	3.7	1686 (6)	2066 (4)	378
60	91.0 (11)	94.1 (12)	3.3	2125 (7)	2532 (5)	407
75	91.9 (11)	94.5 (12)	2.8	2703 (5)	3084 (5)	381
100	91.7 (9)	94.5 (14)	3.0	3483 (6)	3933 (5)	450
125	91.7 (7)	94.4 (16)	2.9	4006 (6)	4709 (5)	703
150	92.9 (8)	95.0 (12)	2.2	5760 (5)	6801 (5)	1041
200	93.1 (8)	95.2 (12)	2.2	7022 (3)	8592 (3)	1570

1800 RPM Totally Enclosed Fan-Cooled Motors

hp	Average Standard Motor Efficiency, %	Average Energy-Efficient Motor Efficiency, %	Efficiency Improvement, %	Typical Standard TEFC Motor List Price	Typical Energy-Efficient TEFC Motor List Price	List Price Premium
5	83.3 (11)	87.3 (32)	4.6	\$344 (6)	\$448 (5)	\$104
7.5	85.2 (20)	89.5 (22)	4.8	494 (7)	647 (5)	153
10	86.0 (10)	89.4 (30)	3.8	614 (6)	780 (5)	166
15	86.3 (8)	90.4 (27)	4.5	811 (7)	1042 (5)	231
20	88.3 (13)	92.0 (20)	4.0	1025 (6)	1268 (5)	243
25	89.3 (14)	92.5 (19)	3.5	1230 (7)	1542 (5)	312
30	89.5 (9)	92.6 (23)	3.3	1494 (6)	1824 (5)	330
40	90.3 (10)	93.1 (21)	3.0	1932 (7)	2340 (5)	408
50	91.0 (9)	93.4 (22)	2.6	2487 (5)	2881 (4)	394
60	91.7 (11)	94.0 (19)	2.4	3734 (7)	4284 (5)	514
75	91.6 (6)	94.1 (24)	2.7	4773 (7)	5520 (5)	747
100	92.1 (13)	94.7 (17)	2.7	5756 (5)	6775 (4)	1019
125	92.0 (10)	94.7 (19)	2.9	7425 (5)	9531 (5)	2106
150	93.0 (10)	95.0 (18)	2.1	9031 (6)	11123 (3)	2092
200	93.8 (9)	95.4 (14)	1.7	10927 (5)	13369 (4)	2442

Note: Full-load efficiencies are given. The numbers in parenthesis indicate either the number of motors considered or number of motor manufacturers using the identical list price.

Table 4
**Washington State Energy Office
 Electric Motor Report**

20 HP/1800 RPM/TEFC

M A N U	Model	Full	3/4	1/2	Full	3/4	1/2	S.F	Frame Size	List Price
		Load Eff.	Load Eff.	Load Eff.	Load P.F.	Load P.F.	Load P.F.			
US	Premium Efficiency	93.2	94.0	94.1	84.6	82.8	76.7	0.00	286T	1268
TO	E.Q.P./Premium Eff.	93.2	0.0	0.0	87.2	0.0	0.0	1.15	256T	1268
GE	Energy Saver	93.0	93.7	93.6	85.0	83.4	76.1	0.0	256T	1268
ST	Silver Line	93.0	91.7	88.2	89.4	83.3	74.5	1.15	256T	1146
MG	E-Plus III	93.0	94.3	90.1	86.5	82.5	76.3	1.15	256T	1884
TE	MAX-E1/HE	93.0	93.0	93.2	83.0	82.9	78.3	1.15	256T	558
BA	High Efficiency	93.0	0.0	0.0	85.0	0.0	0.0	1.15	256T	1266
RE	XE	92.4	0.0	0.0	86.1	0.0	0.0	1.15	256T	1268
SI	Premium Efficiency	92.4	93.4	93.6	89.2	87.5	81.5	1.15	256T	1535
ST	U Series/High Eff.	92.4	91.5	89.2	84.3	80.1	72.0	1.15	256T	0
TO	Standard Eff.	91.9	92.5	92.2	87.2	86.6	81.4	1.15	256T	1025
MA	Blue Chip XRI/HE	91.7	92.4	92.4	85.0	80.0	70.5	1.15	256T	1268
MG	E-Plus	91.7	0.0	0.0	85.4	0.0	0.0	1.15	256T	1559
LE	Standard Efficiency	91.2	0.0	0.0	0.0	0.0	0.0	1.15	256T	642
ST	K Series	91.0	90.0	88.5	85.0	81.5	72.0	1.15	256T	942
ST	J Series	91.0	91.0	90.0	85.0	82.3	75.2	1.15	256T	942
DY	Cast Iron	90.2	0.0	0.0	0.0	0.0	0.0	1.15	256T	767
TE	Standard Efficiency	90.2	90.4	90.7	90.5	90.5	87.1	1.15	256T	445
US	High Efficiency	89.8	90.6	89.8	85.3	82.7	75.5	1.15	286T	1025
DE	C.I.M./Energy Eff.	89.6	90.4	90.3	75.5	71.8	60.4	1.15	256T	1535
DY	Rugged Duty	89.5	0.0	0.0	0.0	0.0	0.0	1.15	256T	957
MA	Blue Chip	89.5	90.0	89.0	84.5	81.0	72.0	1.15	256T	1025
DE	T Line	88.61	88.9	88.0	78.9	74.3	64.0	1.15	256T	1025
ST	U Series	88.5	85.4	82.1	89.4	87.3	80.4	1.15	286U	1612
BA	Standard Efficiency	88.0	0.0	0.0	84.0	0.0	0.0	1.15	256T	1040
MG	Standard Efficiency	87.5	88.4	87.0	89.9	86.4	81.0	1.15	256T	1038
MG	Standard Efficiency	87.5	88.4	87.0	89.9	86.4	81.0	1.15	256T	1327
SI	Standard Efficiency	87.5	87.5	88.5	85.5	83.0	77.0	1.15	256T	1025
GE	Standard Efficiency	87.5	88.5	87.5	81.5	80.0	72.0	0.00	256T	1025
DY	Standard	86.5	0.0	0.0	0.0	0.0	0.0	0.00	256T	834
RE	Standard Efficiency	86.5	0.0	0.0	0.0	0.0	0.0	0.00	256T	1102
LI	Standard Efficiency	86.5	0.0	0.0	86.6	0.0	0.0	1.15	256T	672

Key: Motor manufacturers include:

(BA) Baldor
 (DY) Dayton
 (DE) Delco
 (GE) General Electric
 (LE) Leeson
 (LI) Lincoln
 (MG) Magnetek/Century
 (MA) Marathon
 (RE) Reliance
 (SI) Siemens
 (ST) Sterling
 (TE) Teco
 (TO) Toshiba
 (US) US Motors

Purchase Price Versus Running Cost - A Comparison

Let's compare the fuel cost savings of an efficient automobile over a less efficient automobile with savings obtained from purchase of an energy-efficient over a standard-efficiency motor. Based upon 15,000 miles per year at a fuel economy of 25 miles per gallon with gasoline priced at \$1.00 per gallon, the fuel cost of a typical car is \$600 per year or about 6.6 percent of the \$9,000 purchase price. A 5-mile-per-gallon improvement in fuel economy saves 100 gallons of gasoline valued at \$100 annually.

In contrast, a 15-hp standard efficiency motor, continuously operating at 75 percent of its full rated load, would consume 85,189 kWh/year of electrical energy. At an electricity rate of only \$.03/kWh, this energy is valued at \$2,555 or 315 percent of the motor's list price. A typical 15-hp continuously operating energy-efficient motor conserves 3,863 kWh of electricity valued at \$116 annually. Vehicle and motor purchase alternatives are summarized below.

Vehicle Versus Motor Purchase—Comparison Base Case

New Car (25 MPG)		New 15-hp Standard-Efficiency Motor	
Purchase Price:	\$9,000	List Price:	\$811
Drive:	15,000 miles/yr	Use:	Continuous
MPG:	25	Load Factor:	75 Percent
Gal/Yr:	600	kWh/Yr:	85,189
Fuel Cost Value @ \$1.00/gal:	\$600	Electricity Cost @ .03/kWh:	\$2,555
Ratio of Annual Fuel Cost To Initial Cost:	6.6 Percent		315 Percent

Alternatives

Fuel-Efficient Car (30 MPG)		New 15-hp Energy-Efficient Motor	
Efficiency Improvement:	5 MPG	Efficiency Improvement:	86.3 to 90.4 percent
Annual Fuel Savings:	100 Gal.	Annual kWh Savings:	3,863
Value of Savings:	\$100/year	Value of Savings:	\$115/year
Savings over 150,000 mile operating life: 1,000 gallons, \$1,000		Savings over 20-year service life: 77,260 kWh and \$2,320	

Over a 20-year operating period, the standard motor would consume approximately 1.7 million kWh of electrical energy. This energy is valued at \$51,100 or more than 6,300 percent of the initial motor purchase price.

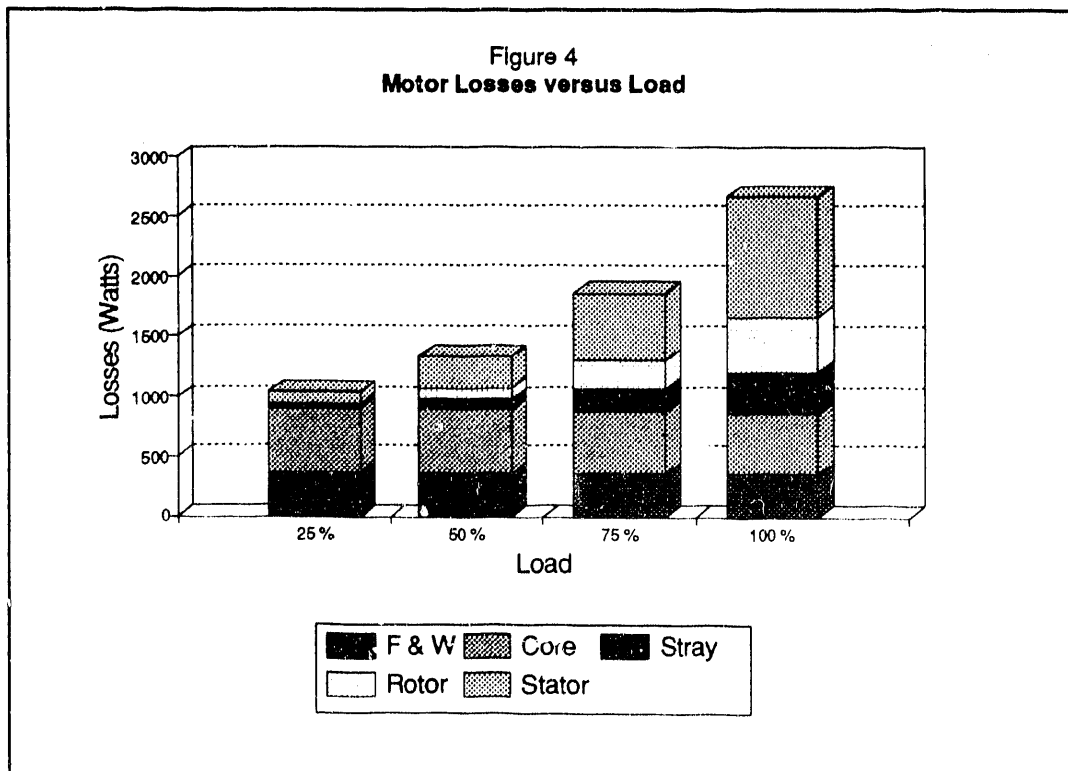
3. **Stator losses** appear as heating due to current flow (I) through the resistance (R) of the stator winding. This is commonly referred to as an I^2R loss. I^2R losses can be decreased by modifying the stator slot design to increase the volume of wire in the stator.
4. **Rotor losses** appear as I^2R heating in the rotor winding. Rotor losses can be reduced by increasing the size of the conductive bars and end rings to produce a lower resistance, or by reducing the electrical current.
5. **Stray load losses** are the result of leakage fluxes induced by load currents. Both stray load losses and stator and rotor I^2R losses increase with motor load. Motor loss components are summarized in Table 5. Loss distributions as a function of motor horsepower are given in Table 6 while variations in losses due to motor loading are shown in Figure 4.^{13,14}

**Table 5
Motor Loss Categories**

No Load Losses	Typical Losses (%)	Factors Affecting these Losses
Core Losses	15 - 25	Type and quantity of magnetic material
Friction and Windage Losses	5 - 15	Selection and design of fans and bearings
Motor Operating Under Load		
Stator I^2R Losses	25 - 40	Stator conductor size
Rotor I^2R Losses	15 - 25	Rotor conductor size
Stray Load Losses	10 - 20	Manufacturing and design methods

**Table 6
Typical Distributions of Motor Losses, %
(1800 RPM Open Drip-Proof Enclosure)**

Types of Loss	Motor Horsepower		
	25	50	100
Stator I^2R	42	38	28
Rotor I^2R	21	22	18
Core Losses	15	20	13
Windage and Friction	7	8	14
Stray Load	15	12	27



Determining and Comparing Motor Efficiencies

Efficiency Definitions Vary

It may be difficult to accurately compare manufacturers' published, quoted, or tested efficiencies, as various values are used in catalogues and vendor literature. When evaluating motors on the basis of efficiency improvements or energy savings, it is essential that a uniform efficiency definition be used. Common definitions include:¹¹

- **Average Expected or Nominal Efficiency.** These terms are identical and refer to the average full-load efficiency value obtained through testing a sample population of the same motor model. These are the most common standards used to compare motors.
- **Guaranteed Minimum or Expected Minimum Efficiency.** All motors purchased or a stated percentage of the motors purchased are guaranteed to have efficiencies that equal or exceed this full-load value.
- **Apparent Efficiency.** "Apparent efficiency" is the product of motor power factor and minimum efficiency. With this definition energy consumption can vary considerably as the power factor can be high while the efficiency is low. Specifications should **not** be based on "apparent" efficiency values.
- **Full-Load Efficiency.** This term is not specific. In addition, motors typically are not continually operated under fully-loaded conditions.
- **Calculated Efficiency.** This term refers to an average expected efficiency based upon a relationship between design parameters and test results. Specifications should not be based on "calculated" efficiency values.

Motor Efficiency Testing Standards

It is critical that motor efficiency comparisons be made using a uniform product testing methodology. There is no single standard efficiency testing method that is used throughout the industry.^{2,10} The most common standards are:

- IEEE 112 (United States)
- IEC 34-2 (International Electrotechnical Commission)

- JEC - 27 (Japanese Electrotechnical Committee)
- BS - 269 (British)
- ANSI C50.20 same as IEEE 112 (United States)

IEEE Standard 112-1984, *Standard Test Procedure for Polyphase Induction Motors and Generators*, is the common method for testing induction motors in the United States. Five methods for determining motor efficiency are recognized. The common practice for motors in the 1- to 125-hp size range is to measure the motor power output directly with a dynamometer while the motor is operating under load. Motor efficiency is then determined by carefully measuring the electrical input and the mechanical power output.¹⁰

The motor efficiency testing standards differ primarily in their treatment of stray load losses. The Canadian Standards Association (CSA) methodology and IEEE 112 - Method B determine the stray load loss through an indirect process. The IEC standard assumes stray load losses to be fixed at 0.5 percent of input, while the JEC standard assumes there are no stray load losses.² As indicated in Table 7, the efficiency of a motor, when tested under the different standard conventions, can vary by several percentage points.^{2,15}

Table 7
Efficiency Results From Various Motor Testing Standards

Standard	Full-Load Efficiency (%)	
	7.5 hp	20 hp
Canadian (CSA C390)	80.3	86.9
United States (IEEE-112, Test Method B)	80.3	86.9
International (IEC - 34.2)	82.3	89.4
British (BS - 269)	82.3	89.4
Japanese (JEC - 37)	85.0	90.4

Testing Equipment Accuracy Limitations

Each motor manufacturer has its own test equipment. The accuracy of this equipment varies. Three types of dynamometers are commonly used for testing medium- and large-scale motors: eddy current clutches, water brakes, and direct current generators. These units have different speed and accuracy limitations.¹⁰ Instrumentation in use during the motor test can also affect accuracy.

The variation in testing ability was illustrated by a round robin test sponsored by the National Electrical Manufacturers Association (NEMA) in 1978. Three motors of different ratings (5, 25, and 100 hp) were shipped to nine different motor manufacturers with the request that they be tested in accordance with IEEE 112 - Method B practices.⁶ A second test examined efficiency changes due to variations in materials and manufacturing tolerances. This exercise involved testing motors of a common design that were manufactured over a period of months. These tests show that variation in measured losses frequently exceed ± 10 percent for specific motor designs while the combined variation from manufacturing and testing with state-of-the-art techniques can exceed ± 19 percent. Test results are given in Table 8.⁹

What does an efficiency uncertainty mean to motor purchasers? It means that a motor rated at 92.5 percent efficiency is essentially comparable to one with a 92.0 percent value. Purchasers of energy-efficient motors should select a unit that has a measured efficiency value within 1.5 percent or less of the maximum value available within a given size, enclosure, and speed class. Motors that barely exceed the NEMA minimum qualifying standards are not recommended.

Table 8
Variations in Full-Load Efficiency Measurements

Motor hp	IEEE 112-Method B Testing of Identical Motors
5	87.1 \pm 0.7 percent
25	89.5 \pm 0.8 percent
100	91.9 \pm 0.9 percent

NEMA Motor Nameplate Labeling Standards

NEMA instituted a nameplate labeling standard (MG1 - 12.542) for NEMA Design A and B polyphase induction motors in the 1 to 125 hp size range. The stamped full-load motor nameplate efficiency is selected from a table of nominal efficiencies and represents a value that

is "not greater than the average efficiency of a large population of motors of the same design," tested in accordance with IEEE 112. In addition, the full-load efficiency, when the motor is operated at rated voltage and frequency, shall not be less than the **minimum value** associated with a nominal value in Table 9.

Efficiencies shall be identified on the nameplate by the caption "NEMA Nominal Efficiency" or "NEMA Nom. Eff."¹⁰

NEMA nominal efficiency bands are selected to "avoid the inference of undue accuracy that might be assumed from using an infinite number of nominal efficiency values."⁹ The efficiency bands vary between 0.4 to 1.5 percent between the 84 and 95.5 percent nominal efficiency range. Motors with efficiencies falling within a given band may be treated as having essentially equivalent operating efficiencies. The nameplate nominal efficiency thus represents a value that may be used to compare the relative energy consumption of a motor or group of motors.¹⁰

Table 9
NEMA Motor Nameplate Efficiency Marking Standard

Nominal Efficiency (%)	Minimum Efficiency (%)	Nominal Efficiency (%)	Minimum Efficiency (%)
98.0	97.6	87.5	85.5
97.8	97.4	86.5	84.0
97.6	97.1	85.5	82.5
97.4	96.8	84.0	81.5
97.1	96.5	82.5	80.0
96.8	96.2	81.5	78.5
96.5	95.8	80.0	77.0
96.2	95.4	78.5	75.5
95.8	95.0	77.0	74.0
95.4	94.5	75.5	72.0
95.0	94.1	74.0	70.0
94.5	93.6	72.0	68.0
94.1	93.0	70.0	66.0
93.6	92.4	68.0	64.0
93.0	91.7	66.0	62.0
92.4	91.0	64.0	59.5
91.7	90.2	62.0	57.5
91.0	89.5	59.5	55.0
90.2	88.5	57.5	52.5
89.5	87.5	55.0	50.5
88.5	86.5	52.5	48.0

Chapter 3

How Much Can You Save?

The amount of money you can save if you purchase an energy-efficient motor instead of a standard motor depends on motor size, annual hours of use, load factor, efficiency improvement, and the serving utility's charges for power and energy consumed.

Three pieces of information are required to evaluate the economic feasibility of procuring an energy-efficient motor instead of a standard motor. First, obtain a copy of your utility's rate schedule. Then determine load factor or percentage of full rated output. Finally, determine the number of motor operating hours at rated load. With this information you can determine your annual energy and cost savings.

Understanding Your Utility's Rate Schedule

The first step is to determine your utility's rate schedule. The cost of electricity for a commercial or industrial facility is typically composed of four components:

1. **Basic or Hookup Charge.** A fixed amount per billing period that is independent of the quantity of electricity used. This charge covers the cost of reading the meter and servicing your account.
2. **Energy Charges.** A fixed rate (\$/kWh) or rates, times the electrical consumption (kWh) for the billing period. Energy charges are frequently seasonally differentiated and may also vary with respect to the quantity of electricity consumed. Utility tariffs may feature declining block or inverted rate schedules. With a declining block rate schedule, illustrated in Table 10, energy unit prices decrease as consumption increases.
3. **Demand Charge.** A fixed rate (\$/kW) times the billable demand (kW) for the billing period. Demand charges are often based upon the highest power draw for any 15-minute time increment within the billing period. Some utilities feature ratcheted demand charges. Here, the applicable monthly demand charge is the highest value incurred during the preceding year.
4. **Power Factor Penalty or Reactive Power Charge.** A penalty is frequently levied if power factor falls below an established value (typically 90 or 95 percent). A low power factor indicates that a facility is consuming a proportionally larger share of reactive power. While reactive power (VAR) does not produce work and is stored and discharged in the inductive and capacitive elements of the circuit, distribution system or I²R losses occur. The utility requires compensation for these losses.

Table 10
Puget Sound Power and Light Company Rate
Schedule 24 - General Service

Monthly Rate:	
Basic Charge:	\$4.55 for single-phase or \$19.00 for three-phase service.
Demand Charge: No charge for the first 50 kW of billing demand. \$5.35 per kW for all over 50 kW of billing demand.	
Energy Charge:	
October - March	April - September
5.2156	4,9672 cents per kWh for the first 20,000 kWh
4.1820	3,9829 cents per kWh for the next 155,000 kWh
2.9695	2,8281 cents per kWh for all over 175,000 kWh

Determining Load Factor

Secondly, determine the load factor or average percentage of full-rated output for your motor. To calculate the load factor, compare the power draw (obtained through watt meter or voltage, amperage, and power factor measurements) with the nameplate rating of the motor. For a three-phase system, wattage draw equals the product of power factor and volts times amps times 1.732.

Determining Operating Hours

Lastly, determine the number of motor operating hours at rated load. Electrical energy savings are directly proportional to the number of hours a motor is in use. All things being equal, a high-efficiency motor operated 8,000 hours per year will conserve four times the quantity of energy of an equivalent motor that is used 2,000 hours per year.

Determining Annual Energy Savings

Before you can determine the annual dollar savings, you need to estimate the annual energy savings.

Energy-efficient motors require fewer input kilowatts to provide the same output as a standard-efficiency motor. The difference in efficiency between the high-efficiency motor and a comparable standard motor determines the demand or kilowatt savings. For two similar motors operating at the same load, but having different efficiencies, the following equation is used to calculate the kW reduction.^{2,10}

Equation 1

$$kW_{saved} = hp \times L \times 0.746 \times \left(\frac{100}{E_{std}} - \frac{100}{E_{HE}} \right)$$

where:

- hp = Motor nameplate rating
- L = Load factor or percentage of full operating load
- E_{std} = Standard motor efficiency under actual load conditions
- E_{HE} = Energy-efficient motor efficiency under actual load conditions

The kW savings are the demand savings. The annual energy savings are calculated as follows:²

Equation 2

$$kWh_{savings} = kW_{saved} \times \text{Annual Operating Hours}$$

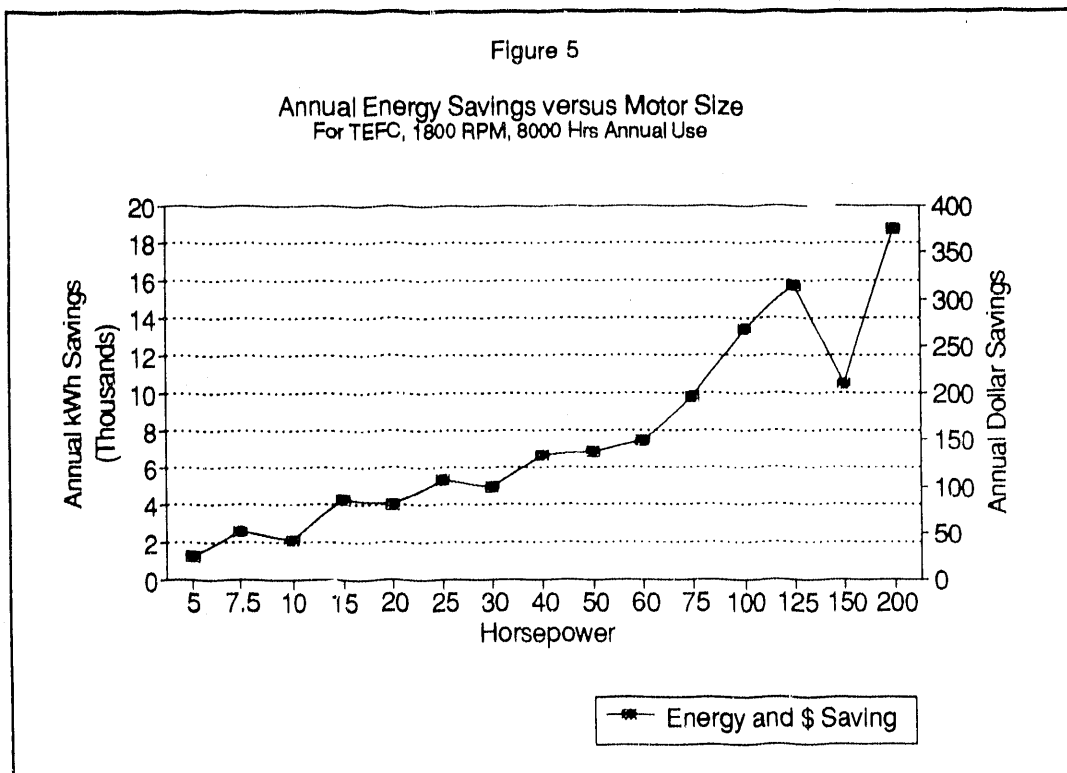
You can now use the demand savings and annual energy savings with utility rate schedule information to estimate your annual reduction in operating costs. Be sure to apply the appropriate seasonal and tailblock energy charges.

The total annual cost savings is equal to:

Equation 3

$$\begin{aligned} \text{Total savings} = & (kW_{saved} \times 12 \times \text{monthly demand charge}) + \\ & (kWh_{savings} \times \text{energy charge}) \end{aligned}$$

The above equations apply to motors operating at a specified constant load. For varying loads, you can apply the energy savings equation to each portion of the cycle where the load is relatively constant for an appreciable period of time. The total energy savings is then the sum of the savings for each load period. Determine the demand savings at the peak load point. The equations are not applicable to motors operating with pulsating loads or for loads that cycle at rapidly repeating intervals.¹⁰



Savings also depend on motor size and the gain in efficiency between a new high-efficiency motor and a new or existing standard efficiency unit. Energy-efficient motor savings, based upon an average energy charge of \$0.04/kWh, are shown in Figure 5. The performance gain for the energy-efficient motor is based on the difference between the average nominal full-load efficiencies for all energy-efficient motors on the market as compared to the average efficiency for all standard-efficiency units.

Motor Purchase Prices

Motor dealers rarely sell motors at the manufacturer's full list price. Even a customer walking in "off the street" would be offered a list price discount. Motor prices continuously vary, and rather than reprint catalogs and brochures, manufacturers advertise high list prices and authorize their dealers to provide discounts. The major manufacturers tend to use common list prices, given in Table 3, for both their lines of standard and energy-efficient motors. Each motor manufacturer, however, has a unique discounting policy, which typically varies with respect to dealer sales volume.

The discounting practice of one motor manufacturer is given in Table 11. The dealer's wholesale price is the list price times the appropriate multiplier for the dealer's sales volume. The dealer makes its profit through "marking up" the manufacturer's discounted list price. Typical dealer markups range from 10 to 25 percent and depend on dealership practices and the size of the purchase order or number of motors a customer buys. There is no difference in the discount for energy-efficient and standard motors. Thus, you can buy a standard or energy-efficient motor for 55 to 85 percent of the manufacturer's stated list price. Be sure to get quotes from vendors and use discounted motor prices or price premiums when determining the cost effectiveness of energy-efficient motor investments.

Table 11
Typical Motor Wholesale Pricing Practices

Annual Dealer Sales Volume	List Price Multiplier (%)
0 - \$35,000/year	70
\$35,001 - 100,000/year	57
\$100,000/year or more	50

Assessing Economic Feasibility

Because of better design and use of higher quality materials, energy-efficient motors cost 15 to 30 percent more than their standard efficiency counterparts. In many cases, however, this price premium is quickly recovered through energy cost savings. To determine the economic feasibility of installing energy-efficient motors, assess the total annual energy savings in relation to the price premium.

Common methods of assessing the economic feasibility of investment alternatives include:

- Simple payback
- Life cycle costing methodologies
 - Net Present Value (NPV)
 - Benefit to Cost Ratio
 - Internal Rate of Return (ROR)

Most industrial plant managers require that investments be recovered through energy savings within 1 to 3 years based on a simple payback analysis. The simple payback is defined as the period of time required for the savings from an investment to equal the initial or incremental cost of the investment. **For initial motor purchases** or the replacement of burned-out and unrewindable motors, the simple payback period for the extra investment associated with an energy-efficient motor purchase is the ratio of the price premium less an available utility rebate, to the value of the total annual electrical savings.

Equation 4

$$\text{Simple payback, years} = \frac{\text{Price premium} - \text{utility rebate}}{\text{Total annual cost savings}}$$

For replacements of operational motors, the simple payback is the ratio of the full cost of purchasing and installing a new energy-efficient motor relative to the total annual electrical savings.

Equation 5

$$\text{Simple payback, years} = \frac{\text{New motor cost} + \text{installation charge} - \text{utility rebate}}{\text{Total annual cost savings}}$$

Example:

The following analysis for a 75 hp TEFC motor operating at 75 percent of full rated load illustrates how to determine the cost effectiveness of obtaining an energy-efficient versus a standard-efficiency motor for the initial purchase case.

Kilowatts saved:

$$\begin{aligned} kW_{\text{saved}} &= hp \times Load \times 0.746 \times \left(\frac{100}{E_{\text{std}}} - \frac{100}{E_{\text{HE}}} \right) \\ &= 75 \times .75 \times 0.746 \times \left(\frac{100}{91.6} - \frac{100}{94.1} \right) \\ &= 1.21 \end{aligned}$$

Where E_{std} and E_{HE} are the efficiencies of the standard motor and the alternative energy-efficient unit.

This is the amount of energy conserved by the energy-efficient motor during each hour of use. Annual energy savings are obtained by multiplying by the number of operating hours at the indicated load.

Energy saved:

$$\begin{aligned} kWh_{\text{savings}} &= \text{Hours of operation} \times kW_{\text{saved}} \\ &= 8,000 \text{ hours} \times 1.21 \\ &= 9,680 \text{ kWh/year} \end{aligned}$$

Annual cost savings:

$$\begin{aligned} \text{Total cost savings} &= \\ &= (kW_{\text{saved}} \times 12 \times \text{Monthly demand charge}) + \\ &= (kWh_{\text{savings}} \times \text{Energy charge}) \\ &= 1.21 \times 12 \times \$5.35/kW + 9,680 \times \$0.03/kWh \\ &= \$368 \end{aligned}$$

In this example, installing an energy-efficient motor reduces your utility billing by \$368 per year. The simple payback for the incremental cost associated with an energy-efficient motor purchase is the ratio of the discounted list price premium (from Table 3) or incremental cost to the total annual cost savings. A list price discount of 75 percent is used in this analysis.

Cost Effectiveness

$$\begin{aligned} \text{Simple payback} &= \frac{\text{Price premium} \times \text{Discount factor}}{\text{Total annual cost savings}} \\ &= \frac{\$747 \times 0.75}{\$368} = 1.5 \text{ years} \end{aligned}$$

Thus, the additional investment required to buy this energy-efficient motor would be recovered within 1.5 years. Energy-efficient motors can rapidly "pay for themselves" through reduced energy consumption. After this initial payback period, the annual savings will continue to be reflected in lower operating costs and will add to your firm's profits.²

Recommendations for Motor Purchasers

As a motor purchaser you should be familiar with and use consistent sets of nomenclature. You should also refer to standard testing procedures. Be sure to:¹⁰

- Insist that all guaranteed quotations are made on the same basis (i.e., nominal or guaranteed minimum efficiency).
- Prepare specifications that identify the test standard to be used to determine motor performance.
- Recognize the variance in manufacturing and testing accuracy and establish a tolerance range for acceptable performance.
- Comparison shop.
- Obtain an energy-efficient motor with a nominal efficiency within 1.5 percent of the maximum value available within an enclosure, speed, and size class.

Energy consumption and dollar savings estimates should be based upon a comparison of nominal efficiencies as determined by IEEE 112 - Method B for motors operating under appropriate loading conditions. Note that the NEMA marking standard only refers to efficiency values stamped on the motor nameplate. In contrast, manufacturers' catalogues contain values derived from dynamometer test data. When available, use catalogue information to determine annual energy and dollar savings.

Making the Right Choice

Comparison shop when purchasing a motor, just as you would when buying other goods and services. Other things being equal, seek to maximize efficiency while minimizing the purchase price. Frequently, substantial efficiency gains can be obtained without paying a higher price. Figure 6 illustrates the list price versus full-load efficiency for currently marketed 10 hp/1800 RPM standard and energy-efficient motors. It is readily

Figure 6
List Price versus Efficiency for Standard and Energy-Efficient Motors
 Efficiency vs. Cost, 10 HP, 1800 RPM, TEFC

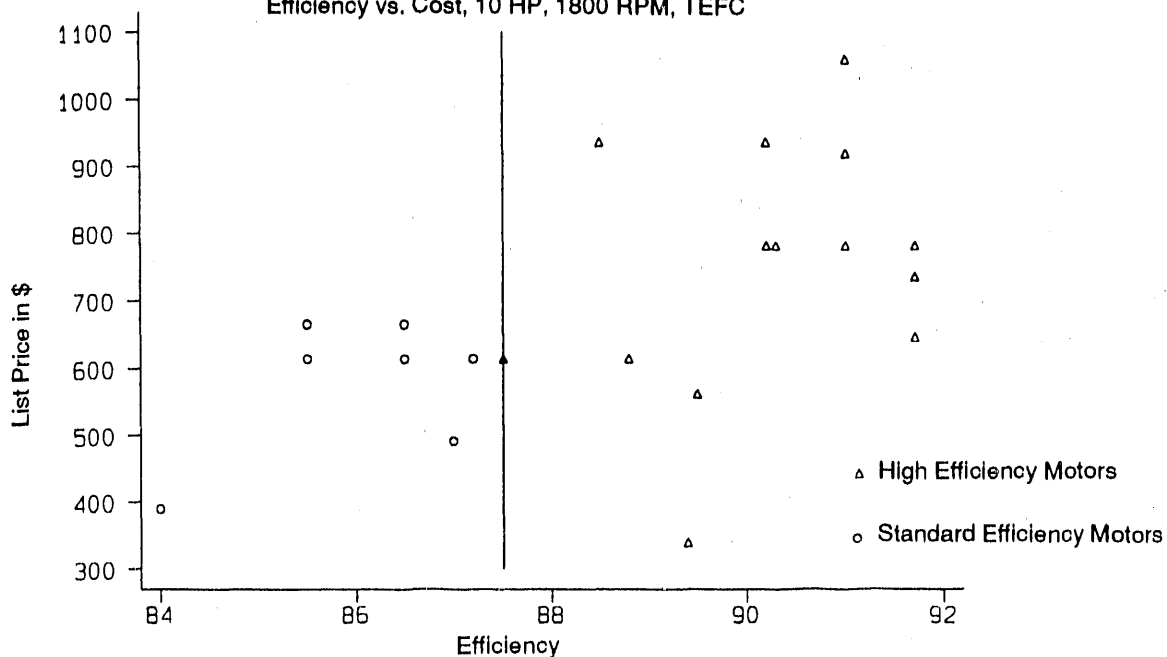


Figure 7
Value of 1 Percent Efficiency by HP
 Annual Energy and Dollar Values

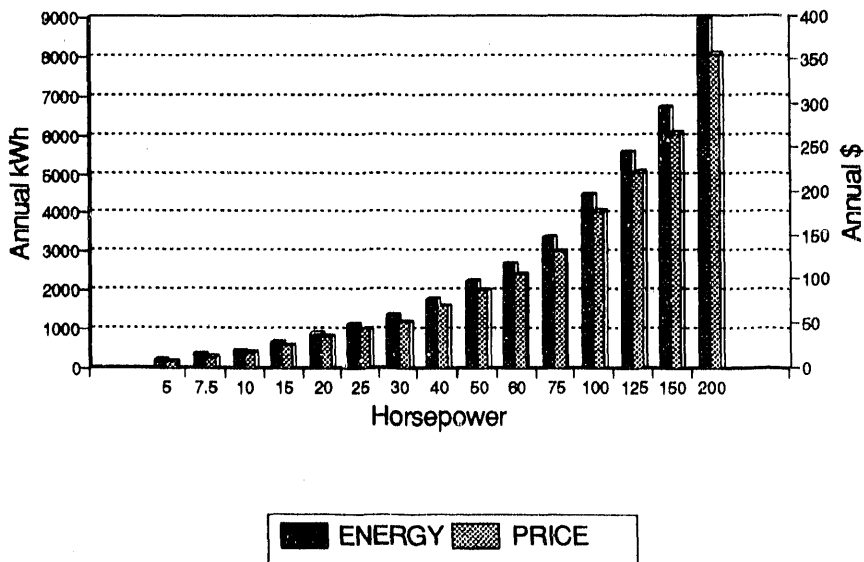
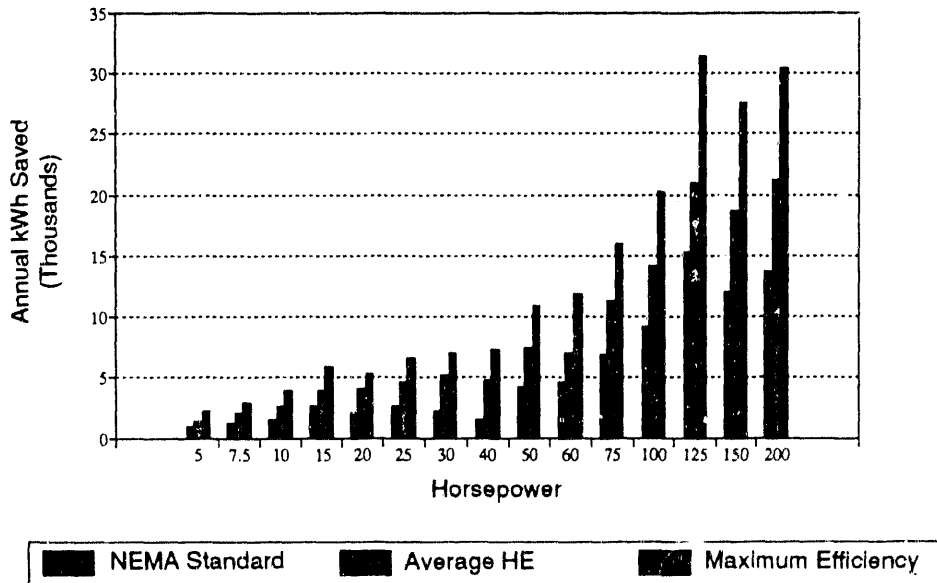


Figure 8
Energy Savings of HE Motors for TEFC, 1800RPM, 8000 HR Use



Note: Figure 8 illustrates the annual energy savings available through selection of an energy-efficient TEFC motor that just satisfies the NEMA minimum energy-efficient motor standards; for a motor that exhibits average high-efficiency performance; and for a motor with superior performance for a given speed, enclosure, and size class. The base case is the purchase of a "typical" standard-efficiency motor. Base case and average energy-efficient motor efficiencies are taken from Table 3.

apparent that you can obtain an efficiency improvement of as much as 6 points without paying any price penalty.

With the right information, you can choose a motor that produces substantial energy and cost savings for little or no extra investment. The value of a 1-point efficiency improvement is shown with respect to motor horsepower in Figure 7. At an electricity price of \$.04/kWh, a single point of efficiency gain for a 50 hp motor can result in an annual savings of approximately 2,600 kWh, worth \$104.

Because so many motors exceed the minimum NEMA energy-efficiency standards, it is not enough to simply

specify a "high-efficiency" motor. Be certain to purchase a true "premium-efficiency" motor, an energy-efficient motor with superior efficiency characteristics.

The value associated with "making the right choice" is graphically characterized by the minimum/maximum savings analysis illustrated in Figure 8. You can often triple the available savings by choosing the motor with the top performance in its class instead of a motor that barely satisfies NEMA minimum energy-efficiency standards.

Chapter 4

Obtaining Motor Efficiency Data

When choosing between rewinding a failed motor or replacing an operable standard-efficiency motor with an energy-efficient unit, you can obtain annual energy savings and cost-effectiveness data by assuming that the existing motor operates at the average efficiency for all standard-efficiency units currently on the market (see Table 3) or by interpolating from Table 12. Table 12 indicates changes in full-load motor efficiency over time.¹¹ It is evident that efficiency of the mid-1960s era T-frame motors decreased relative to the U-Frame machines available in the 1950s. The efficiency of premium efficiency motors improved dramatically in the 1980s as energy costs increased and a demand for energy-conserving motors developed.

Table 12
History of Motor Efficiency Improvements

hp	1944 Design (%)	1955 U Frame (%)	1965 Nominal Efficiency (%)	1981 Premium Efficiency (%)	1988 Premium Efficiency (%)
7.5	84.5	87.0	84.0	91.0	91.0
15	87.0	89.5	88.0	92.4	92.4
25	89.5	90.5	89.0	93.6	92.4
50	90.5	91.0	91.5	94.1	92.4
75	91.0	90.5	91.5	95.0	95.4
100	91.5	92.0	92.0	95.0	95.4

You can use multimeters and contact or stroboscopic tachometers to measure the voltage, amperage, RPM, power factor, and power draw for a motor under its normal operating conditions. The slip, or difference between the synchronous and the operating speed for the motor, can be used to determine output kW, process load, and subsequently, the efficiency of the motor. An Induction Motor Test Data Sheet is included as Appendix A.

The synchronous speed of an induction motor depends on the frequency of the power supply and on the number of poles for which the motor is wound. The higher the frequency, the faster a motor runs. The more poles the motor has, the slower it runs.¹⁶ The synchronous

speed (N_s) for a squirrel-cage induction motor is given by Equation 6. Typical synchronous speeds are indicated in Table 13.

Equation 6

$$N_s = \frac{60 \times 2f}{p}$$

where:

- f = frequency of the power supply
 p = poles for which the motor is wound

Table 13
Induction Motor Synchronous Speeds

Poles	Motor Synchronous Speed, RPM	
	60 Hertz	50 Hertz
2	3,600	3,000
4	1,800	1,500
6	1,200	1,000
8	900	750
10	720	600
12	600	500

The actual speed of the motor is less than its synchronous speed. This difference between the synchronous and actual speed is referred to as slip. Slip is typically expressed as a percentage where:¹⁶

$$\text{Percent slip} = \frac{(\text{Synchronous speed} - \text{Actual speed}) \times 100}{\text{Synchronous speed}}$$

You can now estimate motor load and efficiency with slip measurements.

Equation 7

$$\text{Slip} = \text{RPM}_{\text{sync}} - \text{RPM}_{\text{measured}}$$

$$\text{Motor load} = \frac{\text{Slip}}{\text{RPM}_{\text{sync}} - \text{RPM}_{\text{full load (nameplate)}}}$$

Equation 8

Approximate Output hp = Motor Load x Nameplate hp

$$\text{Motor efficiency} = \frac{(0.746 \times \text{Output hp})}{\text{Measured input kW}}$$

An example:¹⁷

Given: $RPM_{sync} = 1,800$ $RPM_{measured} = 1,770$

$RPM_{nameplate} = 1,750$ $Nameplate\ hp = 25$

$Measured\ kW = 13.1$

Then: $Slip = 1,800 - 1,770 = 30$

$Motor\ load = \frac{30}{50} = 0.6$

$Output\ hp = 0.6 \times 25 = 15$

$Motor\ efficiency = \frac{(0.746 \times 15) \times 100\ percent}{13.1} = 85\ percent$

The slip technique should not be used with rewind motors or with motors that are not operated at their design voltage. Slip versus load curves can also be obtained from your motor manufacturer.

Chapter 5

Energy-Efficient Motor Selection Guidelines

Initial Motor Purchases

When considering a new motor purchase, you have two choices: the less expensive standard-efficiency motor or the more costly energy-efficient unit. For this case, the cost premium of buying an energy-efficient motor over a standard motor is equal to the difference in prices. Motor installation labor costs are not included as they apply equally to either motor.

Consider a 50 hp standard-efficiency motor, purchased for \$1,620 and operated 8,000 hours per year at 75 percent of full rated load. At an efficiency of 91.1 percent and with an electrical rate of \$.03 per kilowatt hour, the motor will consume \$7,369 worth of electricity each year. Over an assumed 10-year motor operating life with an average 5 percent escalation in energy prices, the total electrical bill for operating this motor would exceed \$92,600, over 50 times the first cost of the motor.

While the improvement in efficiency associated with the purchase of an energy-efficient motor is typically only 2 to 5 percent, the incremental cost of the energy-efficient motor can often be rapidly recovered. This occurs because the price premium may be smaller than anticipated (in some cases you can actually purchase an energy-efficient motor for a lower price than the comparable standard-efficiency unit) and the ratio of the motor's annual operating cost to its initial purchase price is quite high.

Although the energy and dollar savings associated with buying an energy-efficient motor can be impressive, selecting the energy-efficient unit is not always appropriate. Motors that are lightly loaded or infrequently used, such as motors driving control valves or air compressors, may not consume enough electricity to make the energy-efficient alternative cost-effective. Remember that for a motor operating under a constant load, the electricity savings associated with an efficiency improvement are directly proportional to the hours of operation.

The simple payback is defined as the period of time required for the profit or savings from an investment decision to equal the incremental cost of the investment. This investment repayment period is directly dependent upon electricity costs—for example, the simple payback for a motor operating in a utility territory where electrical rates are \$.02/kWh will be twice that for a similar motor used where electricity is priced at \$.04/kWh.

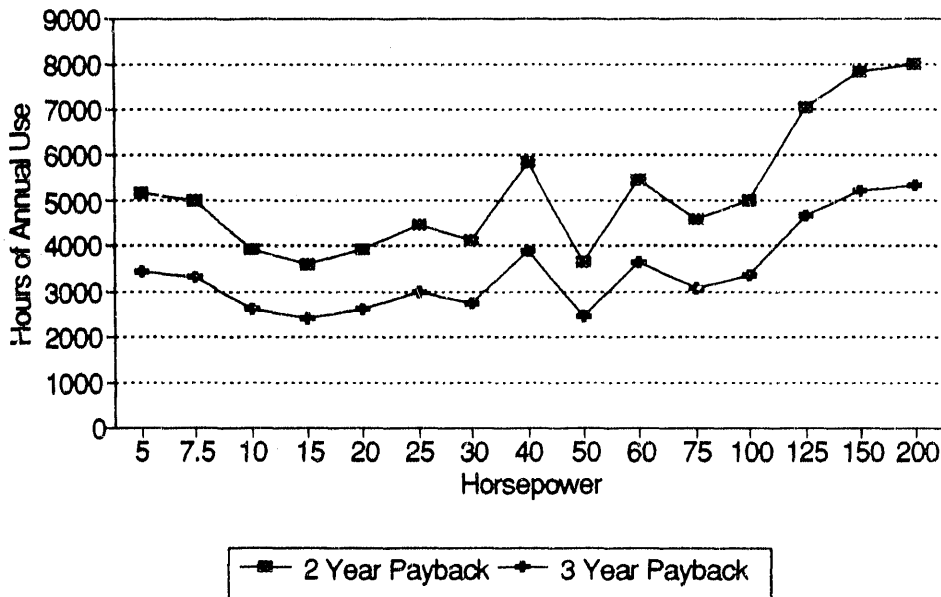
Different industries or facilities use different simple payback criteria or investment "hurdle rates." Industrial sector energy conservation measures typically must have simple paybacks in the 1- to 3- year range to be considered cost effective.

To help you decide whether or not to purchase a new energy-efficient motor, Figure 9 presents the minimum annual operating hours required to achieve 2- and 3- year simple paybacks as a function of motor size. Simple paybacks of 2 and 3 years are considered given an electrical rate of \$.04/kWh. This analysis uses the average standard- and energy-efficient motor performance data presented in Table 3 and assumes a 75 percent motor loading with a list price discount factor of 75 percent.

Several conclusions can be drawn from this analysis. In the 5- to 100-hp size range and without the availability of a utility rebate, an energy-efficient motor should be selected given the following.

- An average electricity cost of \$.04/kWh; a 3-year simple payback criteria; and operation under load for more than 3,500 hours per year
- \$.02/kWh electrical rate coupled with a 3-year simple payback criteria or a \$.03/kWh rate with a 2-year payback with at least 7,000 hours per year of operation

Figure 9
Annual Hours for Payback
For TEFC, 1800 RPM, 4 cents/kWh



Motor Failure or Burnout Scenario

Unlike an initial motor purchase where your decision is limited to procuring a standard versus a premium efficiency motor, a motor failure or burnout produces three alternatives. Your options are to rewind the failed motor, purchase a new standard-efficiency motor, or purchase an energy-efficient replacement motor. For this scenario, motor installation labor costs are again not included as the existing motor must be removed and reinstalled anyway.

Assuming that the failed motor can be rewound, the baseline or lowest initial cost approach is to rewind the motor to its original specifications. As some older motors were built with oversized slots, it is sometimes possible to perform a "high-efficiency" rewind and slightly increase the efficiency of the motor by adding more copper to reduce I^2R losses.¹¹ If the original unit was wound with aluminum wire, it should be replaced with copper.¹⁸

A motor should be rewound with the same (or larger) winding wire size and configuration. If a repair shop does not have the correct wire size in stock and uses a smaller diameter wire, stator I^2R losses will increase. While a decrease in the number of turns in a stator

winding reduces the winding resistance, it also shifts the point at which the motor's peak efficiency occurs toward higher loads and increases the motor's magnetic field, starting current, locked rotor, and maximum torque. A change from 10 to 9 turns will increase the starting current by 23 percent, which can cause problems in the electrical distribution and motor protection systems.¹⁹

In a typical rewind, the stator is heated to a temperature high enough to burn out its winding insulation. The windings are then removed and replaced.²⁰ In the past, many rewind shops emphasized speed. High temperatures were used to shorten repair times and get the motor back in service quickly. Hand-held torches were sometimes used to soften varnish for easier coil removal.^{11,18} The resulting higher temperatures increase losses by changing the electrical characteristics of the motor's core.

For both standard and high-efficiency motors, the rewind shop should follow the motor manufacturers' recommended burnout temperature specifications. When stripping out the old windings, it is essential to keep the stator core below 700°F. If the stator core gets too hot, the insulation between the stator laminations will break down, increasing eddy current losses and lowering the motor's operating efficiency. After being damaged, the

lamination insulation cannot be repaired nor the efficiency loss restored without undergoing a major repair such as restacking the iron. The motor also becomes less reliable.^{18,20}

Insulation removal techniques vary between rewind shops and should be investigated prior to deciding where to have the motor rewound. Always choose a shop with a controlled temperature winding burnout oven to minimize core loss. Some shops have core loss testers and can screen motors to determine if they are repairable prior to stripping.¹⁸

The repair shop should also determine and eliminate the cause for a motor's failure. Aside from proper stripping procedures, the motor owner should ensure that the rewind shop does the following.¹⁸

- Uses proper methods of cleaning
- Installs Class F or better insulation
- Uses phase insulation between all phase junctions
- Uses tie and blocking methods to ensure mechanical stability
- Brazes rather than crimps connections
- Uses proper lead wire and connection lugs
- Applies a proper varnish treatment

As motor design characteristics (such as slot geometry and configuration), failure modes, rewind practices, and materials specifications and treatments vary, it is impossible to identify a "typical" rewind cost for a motor with a given horsepower, speed, and enclosure.

Motor efficiency losses after rewinds also vary considerably. While dynamometer tests conducted by the Electrical Apparatus Service Association indicate that new motors, when properly stripped and rewound, can be restored to their original efficiency, field tests on motors from a variety of manufacturing plants indicate that losses are typically higher in motors that have been rewound—perhaps because of thermal shock suffered during the motor failure.

An analysis of core loss tests taken over a 1-year period in General Electric repair facilities indicates that average core losses are 32 percent higher than normal for motors that had been previously rewound.¹⁹

General Electric also conducted a test of 27 rewind motors in the 3- to 150-hp size range. The test indicates that total losses increased by 18 percent for motors that have been rewound compared to those that have not

been rewound.²⁰ An 18 percent increase in losses corresponds to an approximate 1.5 to 2.5 percent decrease in full-load efficiency.

Rewound motors can exhibit severe efficiency losses, especially if they were rewound more than 15 years ago or have been rewound several times. Rewind losses of 5 percent or more are possible.

When should a energy-efficient motor be purchased in lieu of rewinding a failed standard-efficiency motor? This decision is quite complicated as it depends on such variables as the rewind cost, expected rewind loss, energy-efficient motor purchase price, motor horsepower and efficiency, load factor, annual operating hours, electricity price, and simple payback criteria.

Several rewind "rules of thumb" are appropriate given the low electrical rates that are typical of the Northwest Region:

- Always use a qualified rewind shop. A quality rewind can maintain original motor efficiency. However, if a motor core has been damaged or the rewind shop is careless, significant losses can occur.
- Motors less than 100 hp in size and more than 15 years old (especially previously rewound motors) often have efficiencies significantly lower than current models. It is usually best to replace them.
- If the rewind cost exceeds 65 percent of a new energy-efficient motor price, buy the new motor. Increased reliability and efficiency should quickly recover the price premium.
- If your energy costs average 3¢/kWh or more, and a motor is operated for at least 4,000 hours per year, an energy-efficient motor is a worthwhile investment. The higher purchase price will be repaid through energy savings within 2 years. Here is a chart to help decide when to select an energy-efficient motor:

Choose an energy-efficient motor if:

Your energy costs are:	and annual hours of use equals or exceeds:
2 ¢/kWh	6,000
3 ¢/kWh	4,000
4 ¢/kWh	3,000
5 ¢/kWh	2,000

Table 14 indicates how breakeven rewind costs vary with respect to motor operating hours and simple payback criteria. The breakeven cost is expressed as a percentage of a replacement energy-efficient motor price. A new energy-efficient motor should be purchased if the rewind cost exceeds the stated breakeven point. Table 14 may be used for NEMA Design B motors in the 5- to 125-hp size range. Assumptions used in the preparation of this table include an expected 2 percent loss in an average standard motor efficiency due to rewinding, replacement with an average energy-efficient motor operated at a 75 percent load factor, and a list price discount rate of 65 percent.

Table 14
Breakeven Rewind Cost as a Percentage of
an Energy-Efficient Motor Price

Simple Payback Criteria, Years ¹	Annual Operating Hours		
	8,000	6,000	4,000
3	30%	45%	65%
2	55%	65%	70%

¹For an electrical rate of \$.03/kWh.

You can easily complete a cost-effectiveness analysis for a rewinding. Two points should be subtracted from your standard motor efficiency to reflect expected rewind losses. Annual energy and cost savings are determined by inputting the appropriate energy-efficient motor performance, operating hours, electricity price, and load factor into Equations 1 through 3. The incremental cost of procuring the premium-efficiency unit is the quoted price for the new motor less the rewind price and any utility rebate. The simple payback for the energy-efficient motor is simply the incremental cost divided by the total annual energy conservation benefits.

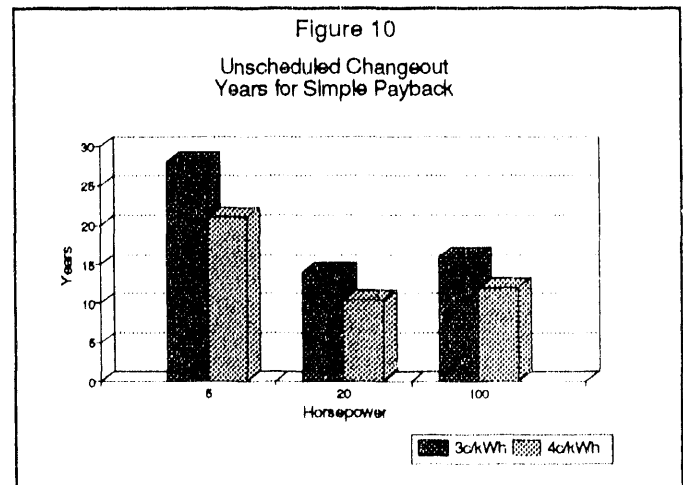
Replacement of Operable Standard-Efficiency Motors

This motor retrofit scenario occurs when you replace an existing, operable standard-efficiency motor with an energy-efficient unit to conserve energy. In this instance, the cost of replacement is the full purchase price for the new motor minus any utility rebate and the salvage value for the motor to be replaced. An installation cost, assumed to be \$500, is also levied. No downtime or loss of production costs are incurred as it is assumed that you can schedule the retrofit during a periodic maintenance shutdown. For this scenario, the entire cost of purchasing and installing the energy-

efficient motor must be returned through the energy savings achieved by the increased motor efficiency.

Based on average standard and premium-efficiency motor efficiencies, simple paybacks were determined for 5-, 20-, and 100-hp motors, operating 8,000 hours per year with electricity prices of \$.02 and \$.03/kWh. As indicated in Figure 10, simple paybacks typically exceed 10 years. Paybacks are substantially longer for the smaller 5-hp motor due to the assumption of a fixed installation cost. Based solely on energy savings, industrial users would typically find it not cost-effective to retrofit operable standard-efficiency motors with energy-efficient units. Such an action may, however, make sense if:

- Funding is available through a utility energy conservation program to partially offset the purchase price of the new energy-efficient motor.
- The standard-efficiency motor has been rewound several times.
- The standard-efficiency motor is oversized and underloaded.



Oversized and Underloaded Motors

When a motor has a significantly higher rating than the load it is driving, the motor operates at partial load. When this occurs, the efficiency of the motor is reduced. Motors are often selected that are grossly underloaded and oversized for a particular job.

For instance, field measurements made at four industrial plants in Northern California indicate that, on the average, motors are operating at 60 percent of their rated load. The energy conservation recommendation for 17 out of the 29 motors tested was downsizing or

replacement with a smaller energy-efficient motor.²¹ Despite the fact that oversized motors reduce energy efficiency and increase operating costs, industries use oversized motors:^{1,2}

- To ensure against motor failure in critical processes
- When plant personnel do not know the actual load and thus select a larger motor than necessary
- To build in capability to accommodate future increases in production
- To conservatively ensure that the unit has ample power to handle load fluctuations
- When maintenance staff replace a failed motor with the next larger unit if one of the correct size is not available
- When an oversized motor has been selected for equipment loads that have not materialized
- When process requirements have been reduced
- To operate under adverse conditions such as voltage imbalance

As a general rule, motors that are undersized and overloaded have a reduced life expectancy with a greater probability of unanticipated downtime, resulting in loss of production. On the other hand, motors that are over-

sized and thus lightly loaded suffer both efficiency and power factor reduction penalties.

Maximum efficiency does not always occur at full load. As long as the motor is operating above 60 percent of rated load, the efficiency does not vary significantly.²² Motor efficiencies typically improve down to about 75 percent of full-rated load, then, especially for smaller motors, rapidly begin to decline below 40 percent of full-load. It is almost always a good idea to downsize a motor that is less than 50 percent loaded.²³ Power factor declines sharply when the motor is operated below 75 percent of full-load amperage, especially in the smaller horsepower size ranges. Typical part-load motor efficiency and power factor characteristics are indicated in Figures 11 and 12.

The cost penalties associated with using an oversized motor can be substantial and include:²

- A higher motor purchase price
- Increased electrical supply equipment cost due to increased KVA and KVAR requirements
- Increased energy costs due to decreased part-load efficiency
- Power factor penalties

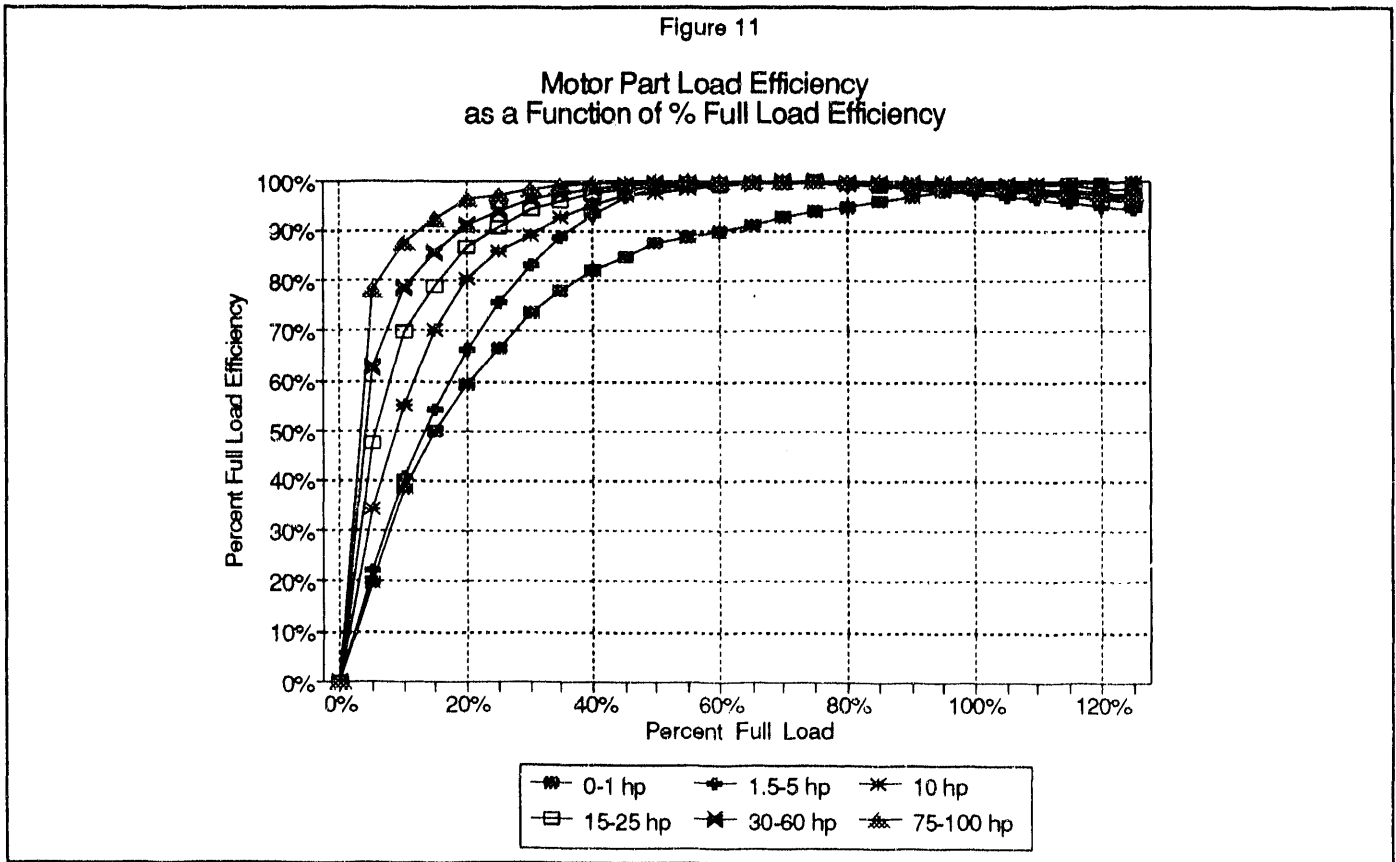
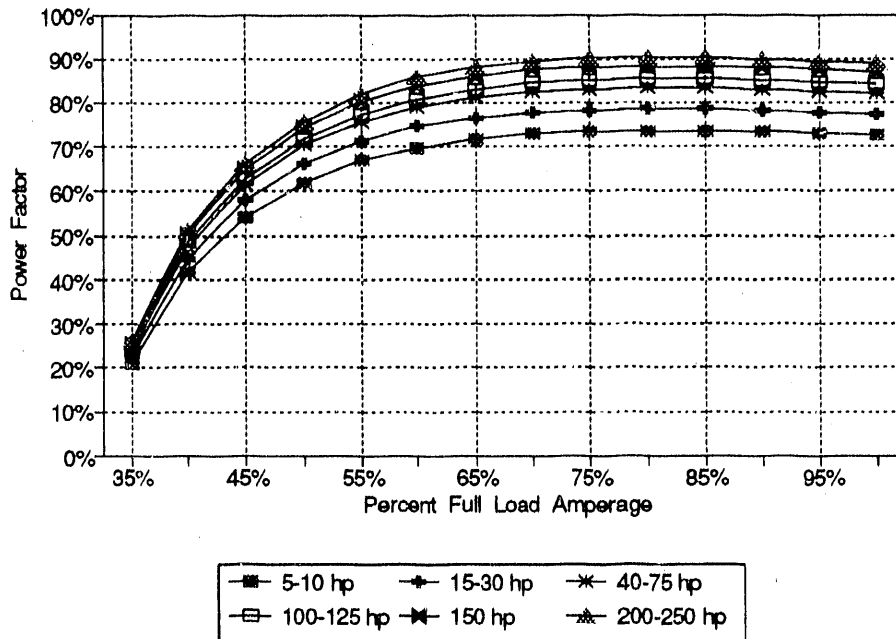


Figure 12

Motor Power Factor As a Function of % Full Load Amperage



Replacing underloaded motors with smaller standard or energy-efficient motors improves efficiency.¹ Care must be taken, however, to fully understand the characteristics of the driven load before changing out existing motors.

For instance, with a variable load, such as a variable air volume HVAC system, the motor must be sized to operate under fully loaded conditions. Inlet vanes or other throttling devices must be set at "full open" so that efficiency and load factor measurements can be taken at maximum load.²³ Worn belts and pulleys can result in a reduced load being applied to the motor, giving the impression that it is underloaded. To eliminate this problem, worn belts or pulleys should be replaced before load and efficiency tests are made.²³ Load types include:¹⁹

- Continuous-running steady loads
- Continuous-running with intermittent loading
- Variable-speed loads
- Cyclic loads

It is easiest to take measurements and properly size a motor driving a continuously-running steady load. Be sure to take torque characteristics into consideration for intermittent or cyclic loading patterns. Also, make sure

to provide adequate fan circulation and cooling for motors coupled to adjustable-speed loads or variable speed drives. Overheating is a particular concern at either reduced or full-loads with the non-ideal voltage and current waveforms encountered with electronic variable-frequency drives.^{24,25}

It is reasonable to operate an induction motor at 75 to 90 percent of full-rated load. When a motor is used on non-critical constant load applications, such as a centrifugal fan, it should be sized as closely to 100 percent load as possible.² You can save the most when the motor is properly matched with respect to the work that must be performed.

The replacement of an operable standard-efficiency motor with a premium efficiency unit may be justified if the existing motor is operating inefficiently due to improper oversizing. In this instance, the cost effectiveness is bolstered due to the reduced cost of the smaller replacement motor and the substantial efficiency gain.

A completed "Oversized Motor Replacement Analysis" data sheet is given in Figure 13. Motor load, operating efficiency, and losses are determined through measurements and by applying the slip technique. The data sheet walks you through an assessment of annual

Figure 13
Oversized Motor Replacement Analysis

Unscheduled Motor Changeout Analysis

Company HCC Plant _____ Date/Time 1-9-89 0800
 Building _____ Dept. _____ Application Fan
 Motor Shop Number 1943 Phase and HZ 3/60
 Make Louis Allis Frame size 505
 Model/Type _____ Insulation class _____
 Serial number _____ Efficiency rating _____
 Service factor 1.15 NEMA torque type B
 Enclosure type ODP Temperature rise 40°C

A) Full load HP 75
 B) Volts 440/220
 C) Amperes 91/182
 D) Full load speed 1,175
 E) Sync. speed 1,200
2 pole = 3,600, 4 pole = 1,800, 6 pole = 1,200
 F) Full load slip (E-D) 25

Measured Values

G) Average volts 445
 H) Average amperes 75
 J) Average kW 40
 K) Operating speed, RPM 1,188
 L) Full load operating hours 8,000
 M) Average electricity price (\$/kWh) .03

Calculated Values

N) Running slip (E-K) 12
 P) Per cent load (N/F)(100%) 48%
 Q) HP output (A)(P)(100%) 36
 R) kW output (Q)(0.746) 26.3
 S) Eff. per cent (R/J)(100%) 67%
 T) kVA input (G)(H)(1.732)/(1000) 57.8
 U) Power factor (J)/(T)(100%) 69%
 V) kW losses (J-R) 13.1
 W) \$/Year operation (J)(L)(M) \$9,600
 X) \$/Year losses (V)(L)(M) \$3,144
 Y) ¹Annual energy savings due to changeout with a 40 hp
 high-efficiency motor (R)(L)(M)(100/S - 100/EFF) \$2,641
 Z) ²Replacement motor cost 1521 + 500
 Simple payback, years (Z)/(Y) 0.76

¹EFF is the efficiency (%) of a replacement premium efficiency motor at the appropriate load factor.

²Cost is the total cost of purchasing and installing an optimally sized, high-efficiency motor

energy savings and a determination of the simple pay-back for the high-efficiency motor retrofit action.¹⁷

For centrifugal loads, the replacement motor selected should be the next nameplate size above the motor output when operating under fully loaded conditions. It is recommended that voltage, amperage, kW draw, power factor, and slip be metered for a variety of motor operating conditions such that the maximum load point is known with confidence. **The slip technique should not be used for rewind motors or motors operating at other than their design voltage.**

Motors are selected based on startup, normal, or abnormal torque and load characteristics. This motor change

out analysis approach is most useful for continuously operating motors under steady load conditions and for motors driving loads with low startup torque requirements, such as centrifugal fans and pumps where torque is a linear function of speed. The approach should not be used for motors driving conveyors or crushers—where oversizing may be required to account for high startup torque, transient loads, or abnormal operating conditions. **Most energy-efficient motors exhibit approximately the same locked rotor, breakdown, and rated load torque characteristics as their standard-efficiency counterparts.**

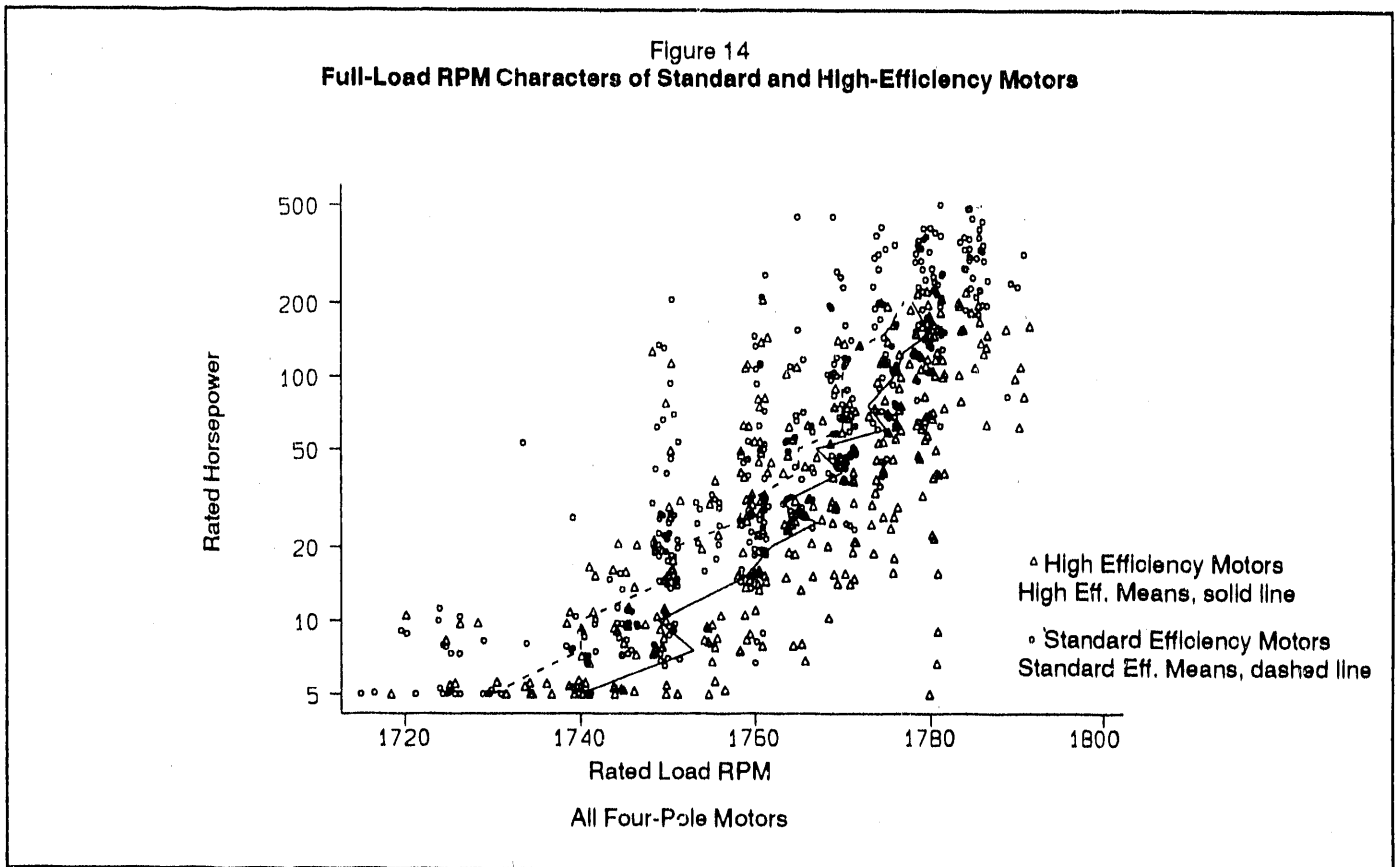
Chapter 6

Speed, Design Voltage, Enclosure, Part-load Efficiency, and Power Factor

Sensitivity of Efficiency Gains to Motor RPM

A motor's rotor must turn slower than the rotating magnetic field in the stator to induce an electrical current in the rotor conductor bars and thus produce torque. When the load on the motor increases, the rotor speed decreases. As the rotating magnetic field cuts the conductor bars at a higher rate, the current in the bars increases, which makes it possible for the motor to withstand the higher loading. Motors with slip greater than 5 percent are specified for high inertia and high torque applications.²⁴

NEMA Design B motors deliver a starting torque that is 150 percent of full-load or rated torque and run with a slip of 3 to 5 percent at rated load.²⁴ Energy-efficient motors, however, are "stiffer" than equivalently sized standard motors and tend to operate at a slightly higher full-load speed. This characteristic is illustrated in Figure 14, which shows the full-load speed for 1,800 RPM standard and energy-efficient motors of various sizes. On the average, energy-efficient motors rotate only 5 to 10 RPM faster than standard models. The speed range for available motors, however, exceeds 40 to 60 RPM.



Note: The solid lines indicate the mean or average speeds for all standard- and energy-efficient motors for each horsepower size, showing the higher typical RPM for energy-efficient motors.

For centrifugal loads, even a minor change in the motor's full-load speed translates into a significant change in the magnitude of the load and energy consumption. The "Fan" or "Affinity Laws," indicated in Table 15, show that the horsepower loading on a motor varies as the third power (cube) of its rotational speed. In contrast, the quantity of air delivered varies linearly with speed.²⁶

As summarized in Table 16, a relatively minor 20-RPM increase in a motor's rotational speed, from 1,740 to 1,760 RPM, results in a 3.5 percent increase in the load placed upon the motor by the rotating equipment. A 40-RPM speed increase will increase air or fluid flow by only 2.3 percent, but can boost energy consumption by 7 percent, far exceeding any efficiency advantages expected from purchase of a higher efficiency motor. Predicted energy savings will not materialize—in fact, energy consumption will substantially increase. This increase in energy consumption is especially troublesome when the additional air or liquid flow is not needed or useful.

Be aware of the sensitivity of load and energy requirements to rated motor speed. Replacing a standard motor with an energy-efficient motor in a centrifugal pump or fan application can result in increased energy consumption if the energy-efficient motor operates at a higher RPM. **A standard-efficiency motor with a rated full-load speed of 1,750 RPM should be replaced with a high-efficiency unit of like speed in order to capture the full energy conservation benefits associated with a high-efficiency motor retrofit.** Alternatively, you can use sheaves or trim pump impellers so equipment operates at its design conditions.

Table 15
Fan Laws/Affinity Laws

$$\text{Law \#1} \quad \frac{CFM_2}{CFM_1} = \frac{RPM_2}{RPM_1}$$

Quantity (CFM) varies as fan speed (RPM)

$$\text{Law \#2:} \quad \frac{P_2}{P_1} = \frac{(RPM_2)^2}{(RPM_1)^2}$$

Pressure (P) varies as the square of fan speed

$$\text{Law \#3:} \quad \frac{hp_2}{hp_1} = \frac{(RPM_2)^3}{(RPM_1)^3}$$

Horsepower (hp) varies as the cube of fan speed

Table 16
Sensitivity of Load to Motor RPM

$$\frac{(1,760)^3}{(1,740)^3} = 3.5 \text{ percent horsepower increase}$$

$$\frac{(1,780)^3}{(1,740)^3} = 7.0 \text{ percent horsepower increase}$$

Operating Voltage Effects on Motor Performance

Generally, high-voltage motors have lower efficiencies than equivalent medium-voltage motors because increased winding insulation is required for the higher voltage machines. This increase in insulation results in a proportional decrease in available space for copper in the motor slot.²² Consequently, I²R losses increase.

Losses are also incurred when a motor designed to operate on a variety of voltage combinations (for example, 208 - 230/460 volts) is operated with a reduced voltage power supply. Under this condition, the motor will exhibit a lower full-load efficiency, run hotter, slip more, produce less torque, and have a shorter life.²⁷ Efficiency can be improved by simply switching to a higher voltage transformer tap.

If operation at 208 Volts is required, an efficiency gain can be procured by installing an energy-efficient NEMA Design A motor. Efficiency, power factor, temperature rise, and slip are shown in Table 17 for typical open-drip proof 10 hp - 1800 RPM Design B and Design A motors operated at both 230 and 208 volts.^{10,27}

Table 17
Performance Comparison for 10 hp NEMA Design B
Versus Design A Motors at 230 and 208 Volts

Volts	Design B		Design A	
	208	230	208	230
Efficiency, %	80.6	84.4	83.7	85.3
Power Factor, %	85.0	82.7	84.1	78.5
Temp. Rise, deg. C	91.0	72.0	73.0	66.0
Slip, %	5.9	4.1	4.6	3.5

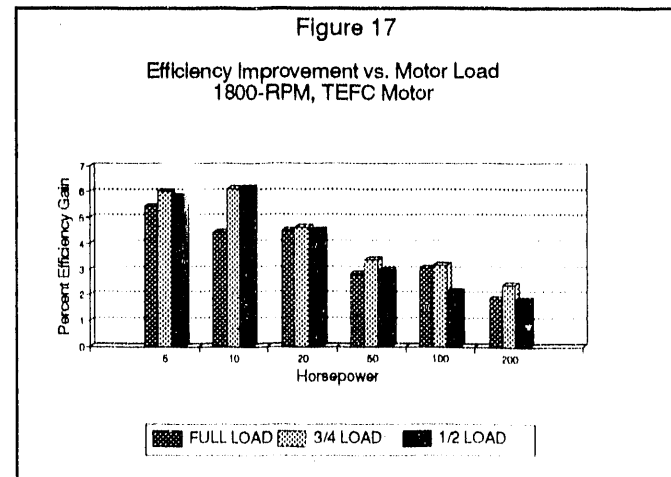
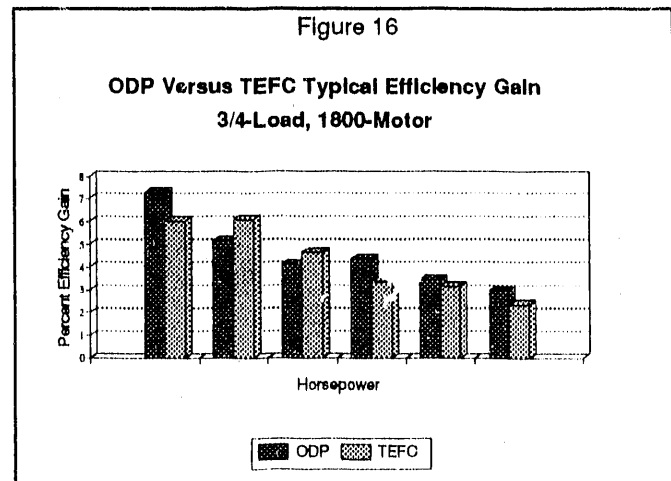
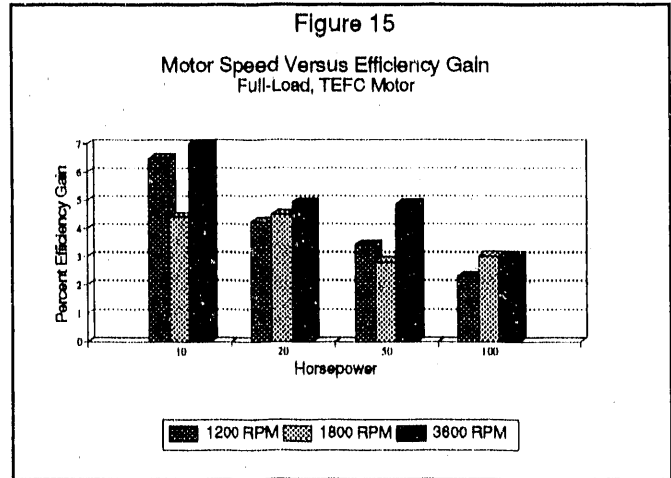
Motor Speed and Enclosure Considerations

Although higher speed motors and motors with open enclosures tend to have slightly higher efficiencies than low-speed or totally-enclosed, fan-cooled units, energy-efficient motors offer significant benefits for all enclosure and speed combinations. In fact, the efficiency improvement associated with premium-efficiency high-speed open motors frequently exceeds that available from 1800 RPM enclosed motors.

Typical motor efficiency gains are illustrated in Figures 15 and 16. Figure 15 shows the efficiency improvement expected from the selection of energy-efficient over standard-efficiency motors with varying nominal speeds. The efficiency gain, and hence the energy and dollar savings benefits, are generally largest for the 3,600-RPM motors. Similarly, Figure 16 indicates that the energy savings associated with 1,800-RPM energy-efficient over standard open motors slightly exceed those available from the high-efficiency over the standard enclosed model.

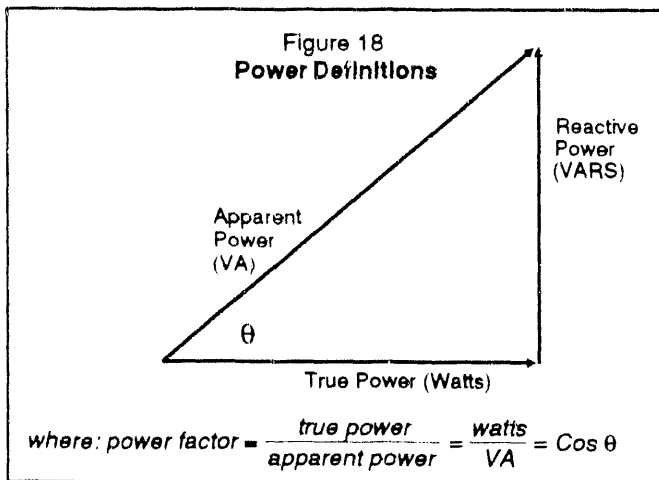
Efficiency Improvements at Part-Load Conditions

Energy-efficient motors perform better than their standard-efficiency counterparts at both full and partially loaded conditions. Typical efficiency gains for 5-, 20-, and 100-hp motors when operating at full, 3/4-, and 1/2-load are given in Figure 17. Efficiency improvements from use of a premium-efficiency motor actually increase slightly under half-loaded conditions. While the overall energy conservation benefits are less for partially versus fully-loaded motors, the percentage of savings remains relatively constant. To obtain full-, 3/4-, and 1/2-load efficiencies and power factor information, consult WSEO's Electric Motor Database.



Power Factor Improvement

An induction motor requires both active and reactive power to operate. The active or true power, measured in kW, is consumed and produces work or heat. The reactive power, expressed in kVARs, is stored and discharged in the inductive or capacitive elements of the circuit, and establishes the magnetic field within the motor that causes it to rotate.^{2,10} The total power or apparent power is the product of the total voltage and total current in an AC circuit and is expressed in KVA. The total power is also the vector sum of the active and reactive power components. Power factor is the ratio of the active to the total power, (Figure 18).



The electric utility must supply both active and reactive power loads. A low or "unsatisfactory" power factor is caused by the use of inductive (magnetic) devices and can indicate a possible low system electrical operating efficiency. Induction motors are generally the principal cause of low power factor because there are so many in use and they are not fully loaded.²⁸

When motors operate near their rated load, the power factor is high, but for lightly loaded motors the power factor drops significantly. This effect is partially offset as the total current is less at reduced load. Thus, the lower power factor does not necessarily increase the peak KVA demand because of the reduction in load. Many utilities, however, levy a penalty or surcharge if a facility's power factor drops below 95 or 90 percent.

In addition to increased electrical billings, a low power factor may lower your plant's voltage, increase electrical distribution system line losses, and reduce the system's capacity to deliver electrical energy. While motor full- and part-load power factor characteristics are important, they are not as significant as nominal efficiency. When selecting a motor, conventional wisdom is to purchase efficiency and correct for power factor.¹⁰

Low power factors can be corrected by installing external capacitors at the main plant service or at individual pieces of equipment. Power factor can also be improved and the cost of external correction reduced by minimizing operation of idling or lightly loaded motors and by avoiding operation of equipment above its rated voltage.

Power factors can usually be improved through replacement of standard- with premium-efficiency motors. Power factors vary tremendously, however, based on motor design and load conditions. While some energy-efficient motor models offer power factor improvements of 2 to 5 percent, others have lower power factors than typical equivalent standard motors. Even high power factor motors are affected significantly by variations in load. A motor must be operated near its rated loading in order to realize the benefits of a high power factor design.

Chapter 7

Motor Operation Under Abnormal Conditions

Motors must be properly selected according to known service conditions. Usual service conditions, defined in NEMA Standards Publication MG1-1987, *Motors and Generators*, include:²⁹

1. Exposure to an ambient temperature between 0°C and 40°C
2. Installation in areas or enclosures that do not seriously interfere with the ventilation of the machine
3. Operation within a tolerance of ± 10 percent of rated voltage
4. Operation from a sine wave of voltage source (not to exceed 10 percent deviation factor)
5. Operation within a tolerance of ± 5 percent of rated frequency
6. Operation with a voltage unbalance of 1 percent or less

Operation under unusual service conditions may result in efficiency losses and the consumption of additional energy. Both standard and energy-efficient motors can have their efficiency and useful life reduced by a poorly maintained electrical system.² Monitoring voltage is important for maintaining high-efficiency operation and correcting potential problems before failures occur. Preventative maintenance personnel should periodically measure and log the voltage at a motor's terminals while the machine is fully loaded.

Over Voltage

As the voltage is increased, the magnetizing current increases by an exponential function. At some point, depending upon design of the motor, saturation of the core iron will increase and overheating will occur.²² At about 10 to 15 percent over voltage both efficiency and

power factor significantly decrease while the full-load slip decreases². The starting current, starting torque, and breakdown torque all significantly increase with over voltage conditions.¹⁵

A voltage that is at the high end of tolerance limits frequently indicates that a transformer tap has been moved in the wrong direction. This causes overheating with the VAR current larger than if the voltage was maintained within acceptable limits. An overload relay will not recognize this over-voltage situation and, if the voltage is more than 10 percent high, the motor can overheat. Over voltage operation with VAR currents above acceptable limits for extended periods of time may accelerate deterioration of a motor's insulation.²⁴

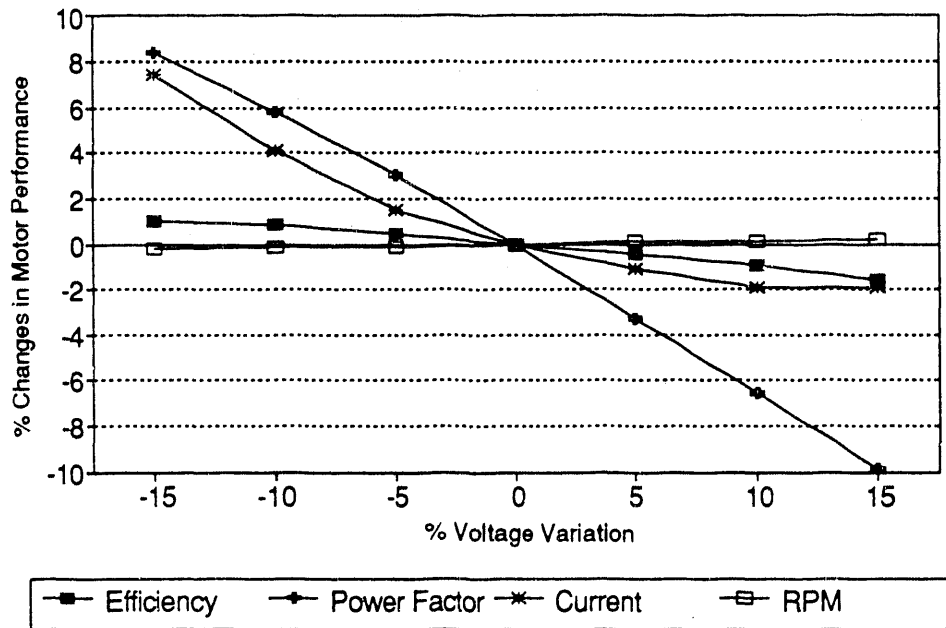
Under Voltage

If a motor is operated at reduced voltage, even within the allowable 10 percent limit, the motor will draw increased current to produce the torque requirements imposed by the load.¹⁸ This causes an increase in both stator and rotor I^2R losses. Low voltages can also prevent the motor from developing an adequate starting torque. The effects on motor efficiency, power factor, RPM, and current from operating outside nominal design voltage are indicated in Figure 19.¹⁴

Reduced operating efficiency because of low voltages at the motor terminals is generally due to excessive voltage drops in the supply system.² If the motor is at the end of a long feeder, reconfiguration may be necessary. The system voltage can also be modified by:

- Adjusting the transformer tap settings
- Installing automatic tap-changing equipment if system loads vary considerably over the course of a day
- Installing power factor correction capacitors that raise the system voltage while correcting for power factor

Figure 19
Voltage Variation
Effect on Motor Performance



Voltage Imbalance

A voltage imbalance occurs when there are unequal voltages on the lines to a polyphase induction motor. This imbalance in phase voltages also causes the line currents to be out of balance. The unbalanced currents tend to overheat one and possibly two phase windings. This results in a dramatic increase in motor losses and heat generation, which both decrease the efficiency of the motor and shorten its life.²⁴ A voltage unbalance of only 3.5 percent can increase motor losses by approximately 20 percent.²⁹

Unbalanced voltages can also cause torque pulsations and increased vibration of the motor. Imbalances over 5 percent indicate a serious problem. Per NEMA MG1-14.35, a voltage imbalance of 2.5 percent would require a derate factor of 0.925 to be applied to the motor rating. To avoid derating, voltage imbalance must be less than 1 percent. The NEMA derating factors apply to all motors. There is no distinction between standard and energy-efficient motors when selecting a derate factor for operation under voltage unbalance conditions.

Common causes of voltage unbalance include:^{2,24}

- Unbalanced transformer bank supplying a three-phase load that is too large for the bank
- Unevenly distributed single-phase loads on the same power system
- Unidentified single-phase to ground faults
- An open circuit on the distribution system primary

The following steps will ensure proper system balancing.²

- Check your electrical system single-line diagram to verify that single-phase loads are uniformly distributed
- Regularly monitor voltages on all phases to verify that a minimum variation exists.
- Install required ground fault indicators
- Perform annual thermographic inspections

Load Shedding

Energy and power savings can be obtained directly by shutting off idling motors to eliminate no-load losses.¹ This action also greatly improves the overall system power factor, which in turn improves system efficiency. Typical no-load or idling power factors are in the 10 to 20 percent range. Load shedding is most effective for slower speed (1,800 RPM and less) motors used in low-inertia applications.¹⁰ While it is possible to save energy by de-energizing the motor and re-starting it when required, excessive starting, especially without soft-starting capacity, can cause overheating and increased motor failures.

Consideration must be given to thermal starting capability and the life expectancy of both motor and starting equipment.¹⁰ Motors 200 hp and below can only tolerate about 20 seconds of maximum acceleration time with each start. Motors should not exceed more than 150 start seconds per day.² Starting limitations for motors over 200 hp should be obtained from the manufacturer. Maximum number of starts per hour and

minimum off-time guidelines for 1800 RPM Design B motors of various sizes are given in Table 18.²⁹

Table 18
**Allowable Number of Starts and
 Minimum Time Between Starts**
 (For 1800 RPM Design B Motors)

Motor Size, hp	Maximum Number of Starts per Hour ¹	Minimum Off Time (Seconds)
5	16.3	42
10	12.5	46
25	8.8	58
50	6.8	72
100	5.2	110

¹This table is extracted from NEMA Standards Publications No. MG10 *Energy Management Guide for Selection and Use of Polyphase Motors*. NEMA has prepared a comprehensive load shedding table for 3600, 1800, and 1200 RPM motors in the 1- to 250-hp size range. NEMA also presents a methodology for minimizing winding stresses by adjusting the number of allowable starts per hour to account for load inertia.

Chapter 8

Motor Selection Considerations

Overall motor performance is related to the following parameters:¹⁰

- Acceleration capabilities
- Breakdown torque
- Efficiency
- Enclosure type
- Heating
- Inrush current
- Insulation class
- Power factor
- Service factor
- Sound level
- Speed
- Start torque

A good motor specification should define performance requirements and describe the environment within which the motor operates. As the purchaser, you should avoid writing design-based specifications that would require modification of standard components such as the frame, bearing, design, rotor design, or insulation class.²

Specification contents should include:

- Motor horsepower and service factors
- Temperature rise and insulation class
- Maximum starting current
- Minimum stall time
- Power factor range
- Efficiency requirement and test standard to be used
- Load inertia and expected number of starts

Environmental information should include:

- Abrasive or non-abrasive
- Altitude
- Ambient temperature
- Hazardous or non-hazardous
- Humidity level

You should specify special equipment requirements such as thermal protection, space heaters (to prevent moisture condensation), and whether standard or non-standard conduit boxes are required.

Motor Enclosures

Many types of motor enclosures are available, including:¹⁶

Open. An enclosure with ventilating openings that permit passage of external cooling air over and around the motor windings. This design is now seldom used.

Open Drip-Proof (ODP). An open motor in which ventilation openings prevent liquid or solids from entering the machine at any angle less than 15 degrees from the vertical.

Guarded. An open motor in which all ventilating openings are limited to specified size and shape. This protects fingers or rods from accidental contact with rotating or electrical parts.

Splash-Proof. An open motor in which ventilation openings prevent liquid or solids from entering the machine at any angle less than 100 degrees from the vertical.

Totally-Enclosed. A motor enclosed to prevent the free exchange of air between the inside and outside of the case, but not airtight.

Totally-Enclosed Nonventilated (TENV). A totally-enclosed motor that is not equipped for cooling by means external to the enclosed parts.

Totally-Enclosed Fan-Cooled (TEFC). A totally-enclosed motor with a fan to blow cooling air across the external frame. They are commonly used in dusty, dirty, and corrosive atmospheres.

Encapsulated. An open motor in which the windings are covered with a heavy coating of material to provide protection from moisture, dirt, and abrasion.

Explosion-Proof. A totally-enclosed motor designed and built to withstand an explosion of gas or vapor within it, and to prevent ignition of gas or vapor surrounding the machine by sparks, flashes, or explosions that may occur within the machine casing.

Motor Insulation Systems

The most common cause of motor failure is internal heat production and increased operating temperatures due to high currents or contamination. An insulation system is comprised of insulating materials for conductors and the structural parts of a motor.^{16,30} Since motor failures occur due to thermal degradation of insulating materials, motors that run hotter tend to have shorter operating lives. A typical rule of thumb is that the service life expectancy of a motor is reduced by one-half for each 10°C increase in operating temperature.

NEMA has established standards for insulation design, temperature rating, and motor thermal capacity.²⁹ Four classes of insulation have been designated, each with an allowable operating temperature. These insulation systems, designated classes A, B, F, and H, vary with respect to design and selection of material and bonding agent thermal range. A Class A insulation system is one which is shown by experience or test to have a suitable operating life when operated at 105°C. A Class B system shows acceptable thermal endurance when operated at 130°C; a Class F insulation system can be operated at 155°C, while a Class H system can be operated at a limiting temperature of 180°C.¹⁶ Class B and F systems are most commonly used.

Service Factor

The maximum allowable temperature rise during operation for a motor varies with respect to insulation class and the motor's service factor. The service factor refers to the motor's ability to continuously deliver horsepower beyond its nameplate rating under specified conditions. Most motors are rated with a 1.0 or 1.15 service factor. A 10-hp motor operating under rated conditions with a 1.15 service factor should be able to continuously deliver 11.5 horsepower without exceeding the NEMA allowable temperature rise for its insulation system.²⁹ NEMA allows an ambient temperature of 40°C (104°F) when specifying "usual service conditions."

If the ambient temperature exceeds 40°C, the motor service factor must be reduced or a higher horsepower motor is required. As the oversized motor will be underloaded, the operating temperature rise is less and overheating will be reduced.¹⁶

NEMA temperature standards for motors with Class B and F insulation and a 1.0 or 1.15 service factor are given in Table 19.² Note that a motor equipped with Class F insulation, but operating within Class B temperature limitations, is operating far below its maximum operating limitations. It is thus running "cooler" relative to its thermal capability.²⁹ Premium- or energy-efficient motors are typically equipped with Class F insulation and rated with a 1.15 service factor.

Table 19
Temperature Limitations for Insulation Classes

Service Factor	Insulation Temperature	Class B	Class F
1.0/1.15	Ambient Temperature	40°C/104°F	40°C/104°F
1.0	Allowable Temperature Rise	80°C/176°F	105°C/221°F
1.0	Operating Temperature Limitation	120°C/248°F	145°C/293°F
1.15	Allowable Temperature Rise	90°C/194°F	115°C/239°F
1.15	Operating Temperature Limitation	130°C/266°F	155°C/311°F

Motor Speed, Slip, and Torque Characteristics

When selecting the proper motor speed, consider the original equipment cost and the requirements of the driven system. Generally, large high-speed standard or energy-efficient motors have improved efficiency and power factor characteristics.

Load, torque, and horsepower requirements determine the type and size of motor required for a particular application. Torque is a measure of the rotational force that a motor can produce. As the physical size of a motor is proportional to its torque capability, high-torque motors are larger and cost more.²

Induction motors are standardized according to their torque characteristics (Design A, B, C, and D).² Torque is in turn characterized by starting or locked-rotor torque, which is the minimum torque produced by the motor at rated voltage and frequency at all angular

positions of the rotor; pull-up torque, which is the minimum torque developed by the motor during acceleration; and breakdown torque, which is the maximum torque that the motor can supply before stalling. A re-torque that the motor can supply before stalling. A representative speed-torque curve for a Design B induction motor is shown in Figure 20.¹⁶

The motor design selected must have adequate torque capability to start a load and accelerate it to full speed. NEMA Design B motors can be used with constant speed centrifugal fans, pumps and blowers, unloaded compressors, some conveyors, and cutting machine tools.¹⁶ Most induction motors are Design B, with Design A being the second most common.² While NEMA limits for locked rotor torque for Design A and B motors are the same, some manufacturers design their motors to different criteria. Frequently, Design A motors have higher starting current and start-up torque characteristics. Speed-torque characteristics for polyphase motors are given in Table 20.²⁹

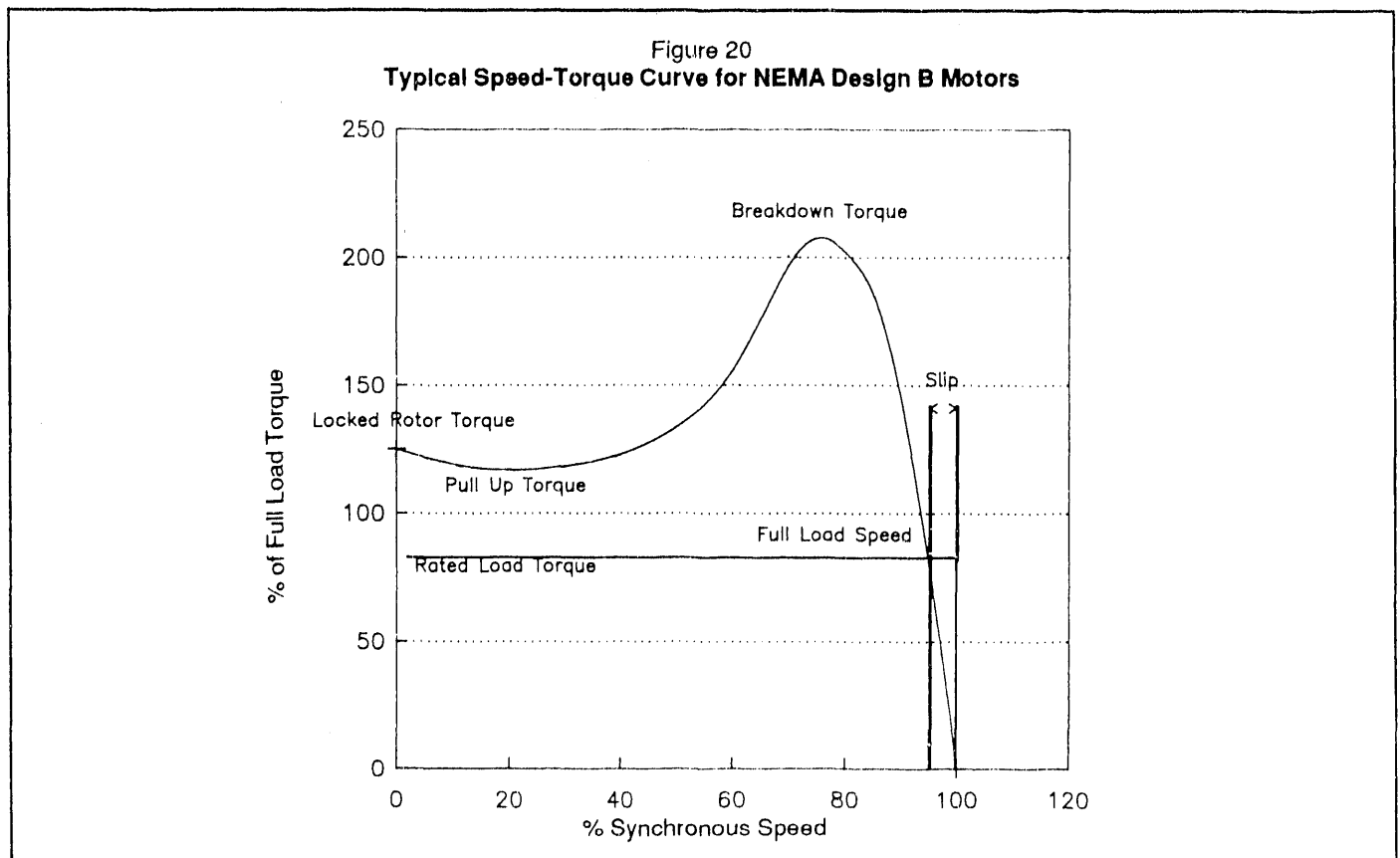


Table 20
NEMA Torque Characteristics for Medium Polyphase Induction Motors¹

NEMA Design	Starting Current (% Rated Load Current)	Locked Rotor Torque (% Rated Load Torque)	Breakdown Torque (% Rated Load Torque)	Percent Slip
B ²	600 - 700	70 - 275	175 - 300	1 - 5
C	600 - 700	200 - 250	190 - 225	5
D	600 - 700	275	275	5 - 8

¹NEMA Standards Publication for Motors and Generators MG1-1978 classifies motors as medium or large. 3600 or 1800 RPM motors rated up to 500 hp are defined as medium motors. The rating declines to 350 and 250 hp for 1200 and 900 RPM motors, respectively.

²Design A motor have characteristics similar to those for Design B motors except that starting currents are higher.

Chapter 9

Additional Benefits of Energy-Efficient Motors

Energy-efficient motors are mounted in the same frame as corresponding standard-efficiency T-frame motors. They fully conform with NEMA inrush current, starting, and breakdown torque standards. Conventional NEMA controls and protection can be applied.¹¹

Energy-efficient motors typically operate cooler than their standard efficiency counterparts.²⁰ Lower operating temperatures translate into increased motor, insulation, and bearing life. The result is fewer winding failures, increased bearing life, longer periods between scheduled maintenance actions, and fewer forced outages.

Accelerated life testing, by subjecting the motor to repeated stalls and other abuse, indicates that energy-efficient motors should have a longer life expectancy than standard-efficiency designs.²⁰ Besides this increased capacity to withstand stalling and overloads, energy-efficient motors should run quieter and operate with lower no-load losses.

Besides reducing operating costs and extending winding and bearing service lives, additional benefits typically associated with using energy-efficient motors include:¹¹

- The ability to operate in higher ambient temperatures
- A service factor of 1.15
- Fewer failures under conditions of impaired ventilation
- Less sensitivity to abnormal operating conditions, such as under and over voltage or phase unbalance
- More tolerance to poorer voltage and current waveshapes
- A slightly higher power factor in the 100 hp and lower size range, which reduces distribution system losses

These benefits however, depend on many factors. Based on manufacturer design practices, energy-efficient motors may have higher or lower power factors than their standard-efficiency counterparts. Both energy-efficient and standard motors should be derated the same amount under conditions of voltage unbalance. Generally, the perception exists that standard and energy-efficient motors operate at different temperatures and there is more temperature margin available in the energy-efficient motor before reaching NEMA operating temperature limits.

Chapter 10

Starting Your Motor Improvement Program

Begin your motor improvement program by screening to select the best candidates for immediate retrofit or future replacement with energy-efficient units. Complete an Electric Motor Data Sheet for each motor used in excess of 2,000 hours per year. Examine rewind history, motor age, and application.²⁰ A recording wattmeter may be useful for analyzing varying loads over a representative period of time.

Check with the local utility and the Bonneville Power Administration regarding the availability of financial incentives such as high-efficiency electric motor rebates or commercial/industrial sector energy conservation programs, technical assistance, billing credit offers, or competitive bidding solicitations.

If financial incentives are available, it may be cost-effective to complete a "group" conversion of eligible motors rather than wait for operable standard-efficiency motors to fail. A disadvantage of waiting until failure to replace motors is that energy-efficient units might not be readily available. Also, once a motor fails, it is no longer possible to check whether the motor is properly matched to the load.²³ Too often, immediate replacement needs outweigh energy management objec-

tives and a failed standard-efficiency motor is replaced by a standard efficiency spare. Immediate replacement locks in future energy savings at today's capital cost.²⁰

Replacement of an operable standard-efficiency motor may also be wise from a preventative maintenance standpoint. Some would argue that "...the most efficient motor is one that runs consistently...thus reducing downtime to an absolute minimum."³⁰ Replacement of aged standard-efficiency motors with new, more reliable energy-efficient units should provide secondary economic benefits through prevention of unexpected failures and increased productivity.

Downtime costs can be substantial. Estimates of typical downtime costs for various industries are summarized in Table 21.³⁰

Table 21
Estimated Downtime Costs for Selected Industries

Forest Industries	\$7,000/hour
Food Processing	\$30,000/hour
Petroleum & Chemical	\$87,000/hour
Metal Casting	\$100,000/hour
Automotive	\$200,000/hour

A Motor Changeout Case Study

The Twin City Foods plant in Prosser prepares and packages potatoes grown in southeastern Washington. Potatoes are washed, sliced, cooked, frozen, and packaged. Monthly electricity costs vary seasonally from \$50,000 to over \$100,000. Electric requirements are predominantly for motors and lighting.

In 1988, major lighting and motor efficiency changes were implemented under an energy conservation grant through the Bonneville Power Administration's Energy Savings Plan. As part of this program, 81 motors were replaced with energy-efficient units. Installed cost of the motor changeout was \$47,953. BPA contributed \$35,593, leaving a company share of \$12,360.

All the replaced motors are in the freezer tunnels where packaged foods are frozen for shipping. Food moves through the tunnels on conveyors. Motors drive the

conveyors and large evaporator fans that circulate cold air. Many of the motors were quite old and plant management was considering either high-efficiency rewinds or replacement with new energy-efficient motors. The BPA program provided the incentive to get new motors. The 81 motors purchased included:

Number	hp	RPM
56	10	1800
20	15	1800
3	20	1800
2	30	1200

The replacement motors were specified by the senior electrician based on review of product literature and exchange of information with other industrial users. All motors were replaced with others of identical horsepower, but the newer motors had higher service factors.

Case Study, continued

This was not by intent; newer motors typically have service factors of 1.15 compared to the 1.0 typical of older motors.

These motors operate in demanding circumstances. Utilization is nearly 100 percent during the peak season from mid July until early November. For the remainder of the year it is about 70 percent. Temperatures vary from -35°F to ambient and relative humidity is high enough that condensate sometimes forms and gets into the motors.

All replaced motors were totally enclosed. All new motors were open drip proof. The motor supplier advised the company that open drip-proof enclosures are now preferred for freezer tunnels because of their ability to drain any moisture that might condense or drain into the motors.

Changing the motors presented certain challenges, but these were anticipated. The new motors are smaller and in some cases had smaller shafts. Some of the old motors were coupled with arrangements involving drilling and tapping the shafts. This necessitated purchasing

special mounting hardware along with the motors. Some of the purchased mounting hardware had to be further modified in-house before installation could be completed. No production time was lost because the changes took place in normal down time during the slower season.

The company is satisfied with the new motors. Their failure rate is low and has been comparable to the failure rate with the standard motors before the replacement. Nearly all failures of the old and new motors have been burnouts presumed to be caused by moisture.

The company has noted a significant reduction in utility bills since the changeover. However, it is impossible to separate the effects of the motor changeout from normal production variations and other improvements (lighting and power factor management) that were accomplished at the same time. No before and after testing of motors was performed. This would have been difficult not only because precise recording of power output is difficult but because load can vary. For example, the larger motors drive fans with manually variable inlet guide vanes that affect power draw.

Chapter 11

Energy-Efficient Motors:

Twenty Questions and Answers

To help you assess the viability of energy-efficient motors for your operation, here are answers to typical technical, and financial questions. These questions are adapted from B.C. Hydro's Power Smart Publication entitled *High-Efficiency Motors*.

1. **What is an energy-efficient motor?**
An energy-efficient motor produces the same shaft output power (hp), but uses less electrical input power (kW) than a standard-efficiency motor. Energy-efficient motors must have nominal full-load efficiencies that exceed the minimum NEMA standards given in Table 2.
2. **How is an energy-efficient motor different than a standard motor?**
Energy-efficient motors are manufactured using the same frame as a standard T-frame motor, but have:
 - Higher quality and thinner steel laminations in the stator
 - More copper in the windings
 - Smaller air gap between the rotor and stator
 - Reduced fan losses
 - Closer machining tolerances
3. **Are all new motors energy-efficient motors?**
No, you generally have to ask for them.
4. **Where can I buy a energy-efficient motor?**
Energy-efficient motors can be purchased directly from most motor distributors. They can also be specified in any equipment package you may be ordering.
5. **Are energy-efficient single-phase motors available?**
Although energy-efficient single-phase motors are not common, a few manufacturers are beginning to produce them.
6. **Do energy-efficient motors require more maintenance?**
No. Energy-efficient motors are equally as reliable as standard motors and have the same maintenance requirements.
7. **What hp, speed, and voltage ranges are available?**
Energy-efficient motors are available for most motor sizes 1 hp and up at speeds of 3600, 1800, 1200, and 900 RPM and three-phase voltages of 208, 230, 460, 575, and higher.
8. **Can a energy-efficient motor replace my present U- or T-frame motor?**
Yes. Since T-frame energy-efficient motors generally use the same frame casting as a standard motor, standard T-frame to high-efficiency T-frame should be a straight replacement. An adapter or transition base is required for a U-frame to energy-efficient T-frame replacement. In addition, some manufacturers now make energy-efficient U-frame motors. Talk to motor dealers for specifics.
9. **Should I rewind my standard efficiency motor or purchase an energy-efficient motor?**
An energy-efficiency motor will result in lower energy costs when compared with a rewind motor. Its cost effectiveness will depend on the hours operated, motor efficiencies, utility rates, and the difference in cost between the rewind and the energy-efficient motor. (Guidelines for energy-efficient motor purchase versus rewinds are given in Table 14.)
10. **Can a standard motor be rewound as an energy-efficient motor?**
It is possible for a standard motor to have what is commonly called a "high-efficiency rewind." This rewind procedure can slightly increase the efficiency of a standard motor above its initial level. However, the efficiency would still be lower than that of a new energy-efficient motor because of its

unique physical characteristics. Energy-efficient motors can also be rewound.

11. What is the efficiency of a energy-efficient motor at different load points?

The efficiency of any motor varies with such factors as size, speed, and loading. As indicated in Figure 17, energy-efficient motors offer performance improvements over standard efficiency motors under full, partial, and unloaded conditions.

12. Do energy-efficient motors maintain the same percentage edge over standard motors when the load range drops from full load?

Yes. Most manufacturers are designing their energy-efficient motors to provide peak efficiency at 75 percent to 100 percent load. As shown in Figures 11 and 17, efficiency stays fairly constant from full down to 50 percent load, but the power factor drops significantly.

13. How reliable are energy-efficient motors?

Energy efficient motors are as reliable as regular or standard-efficiency motors. In some cases, they have a longer life because of lower motor operating temperatures.

14. What is the power factor of an energy-efficient motor?

Power factors vary tremendously depending on motor loading and manufacturer. While some energy-efficient motor models offer power factor improvements of 2 to 5 percent, others have lower power factors than their standard motor counterparts. On the average, a power factor improvement of less than 1 percent is expected.

15. I have heard different types of efficiencies quoted. What are they?

The following motor efficiency definitions are used: Quoted, Nominal, Average, Expected, Calculated, Minimum, Guaranteed, and Apparent. The most commonly used are Nominal and Minimum, defined as:

- Nominal Efficiency is the average measured efficiency of a large number of motors of the same design.
- Minimum Efficiency is the value appearing at the end of the bell curve plotted from the measurement of a large number of motors.

16. What are NEMA MG1, IEC 34.2, and JEC 37?

These are motor efficiency test or product standards:

- NEMA MG1, based upon the IEEE Standard 112 Method B motor efficiency testing methodology, is the most commonly used North American standard.
- CSA C390-M1985 is a Canadian-developed standard that is more rigorous than other test standards.
- IEC 34.2 is the European motor test standard.
- JEC 37 is the Japanese motor test standard.

17. Can I compare motor efficiencies using nameplate data?

Per NEMA MG1-12.54.2 the efficiency of Design A and Design B motors in the 1- to 125-hp range for frames in accordance with MG 13 shall be marked on the motor nameplate. As nameplate nominal efficiencies are rounded values, you should always obtain efficiency values from the motor manufacturer.

18. Is the service factor any different from that of a standard motor?

The service factor for many energy-efficient motors is at least 1.15 and can be as high as 1.30 to 1.40.

19. How much do energy-efficient motors cost?

Generally, they cost 15 to 30 percent more than standard motors, depending on the specific motor, manufacturer, and market competition. It may, however, be possible to negotiate a lower price premium when purchasing a large quantity of energy-efficient motors.

20. What is the payback period for selecting a energy-efficient versus a standard efficiency motor?

The payback period varies according to the purchase scenario under consideration, cost difference, hours of operation, electrical rates, motor loading, and difference in motor efficiencies. For new purchase decisions, the simple payback on the incremental cost of a continuously operated energy-efficient motor can be recovered through energy savings in less than 2 years.

Chapter 12

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Appendix A

Induction Motor Test Data Sheet

Unscheduled Motor Changeout Analysis

Company _____ Plant _____ Date/Time _____

Building _____ Dept. _____ Application _____

Motor Shop Number _____ Phase and HZ _____

Make _____ Frame size _____

Model/Type _____ Insulation class _____

Serial number _____ Efficiency rating _____

Service factor _____ NEMA torque type _____

Enclosure type _____ Temperature rise _____

A) Full load HP _____

B) Volts _____

C) Amperes _____

D) Full load speed _____

E) Sync. speed _____

2 pole = 3,600, 4 pole = 1,800, 6 pole = 1,200

F) Full load slip (E-D) _____

Measured Values

G) Average volts _____

H) Average amperes _____

J) Average kW _____

K) Operating speed, RPM _____

L) Full load operating hours _____

M) Average electricity price (\$/kWh) _____

Calculated Values

N) Running slip (E-K) _____

P) Per cent load (N/F)(100%) _____

Q) HP output (A)(P)(100%) _____

R) kW output (Q)(0.746) _____

S) Eff. per cent (R/J)(100%) _____

T) kVA input (G)(H)(1.732)/(1000) _____

U) Power factor (J)/(T)(100%) _____

V) kW losses (J-R) _____

W) \$/Year operation (J)(L)(M) _____

X) \$/Year losses (V)(L)(M) _____

Y) ¹Annual energy savings due to changeout with a _____ hp high-efficiency motor (R)(L)(M)(100/S - 100/EFF) _____

Z) ²Replacement motor cost _____

Simple payback, years (Z)/(Y) _____

¹EFF is the efficiency (%) of a replacement premium efficiency motor at the appropriate load factor.

²Cost is the total cost of purchasing and installing an optimally sized, high-efficiency motor

Appendix B

Motor Manufacturer Representatives

Baldor Electric Motors
Tillinghast Sales
503/225-0755
Portland, OR

Delco Electric
Reed Electric
503/223-8191
Portland, OR

Grainger (Dayton Motors)
800/323-0620

Lincoln Electric
Oregon Representative
503/228-8858
OR

Lincoln Electric
Western Washington Rep.
206/767-4743
Seattle, WA

Marathon Electric
N.W. Field Sales Office
714/956-7111
Los Angeles, CA

Reliance Electric
Washington/Idaho Office
509/535-4950
Spokane, WA

Siemens
Oregon Sales Office
503/635-6700
Portland, OR

Siemens Energy
Washington Sales Office
206/828-6600
Seattle, WA

Delco Electric
K&N Electric
509/838-8000
Spokane, WA

General Electric
Western Region Sales Office
714/939-6931
Orange, CA

Leeson Electric
N.W. Regional Rep.
206/395-1195
Kent, WA

Lincoln Electric
Washington/Idaho Rep.
509/448-6484
Spokane, WA

MagneTek/Century Electric
Evan Wiggs, District Sales
206/574-1455

Reliance Electric
Oregon Office
503/659-3906
Portland, OR

Reliance Electric
Western Washington Office
206/454-1565
Seattle, WA

Siemens Energy
Washington/Idaho Office
509/325-2582
Spokane, WA

Sterling Electric
S.L. Yunker Co.
503/252-5483
Portland, OR

Teco American Inc.
Electric Motor TEK, Inc.
503/620-2768
Portland, OR

Toshiba
Pat Rogers
206/693-8639

U.S. Motors
Bob Zopf, N.W. Representative
206/896-8220
Vancouver, WA

END

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