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Determination Analysis of Energy Conservation Standards for Small Electric Motors

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ABBREVIATIONS AND ACRONYMS

CSCR	capacitor start-capacitor run
CSIR	capacitor start-induction run
EPAct	Energy Policy Act of 1992
EPCA	Energy Policy and Conservation Act
hp	Horsepower
LBNL	Lawrence Berkeley National Laboratory
LCC	Life-cycle cost
HVAC	Heating, ventilation, and air conditioning
NEMA	National Electrical Manufacturers Association
NPV	Net present value
ODP	Open dripproof
OEMs	Original equipment manufacturers
SMMA	Small Motors and Motion Association

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A number of individuals contributed to this study.

Austin Bonnett performed the engineering cost analysis for LBNL and provided invaluable expertise for the study.

Easton Consultants, led by Gordon Canning, conducted market research on the utilization and shipments of the considered motors by application.

Arthur D. Little, Inc, led by Michael Rivest, assembled data on considered motors from motor manufacturers.

We are grateful for the cooperation of NEMA and SMMA in this study. They organized a working group with representatives of a number of motor manufacturers. This group, coordinated by Robert Wisbey, provided valuable data to the study. In addition, NEMA provided important data on recent industry shipments of various categories of the considered motors.

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At LBNL, Steve Greenberg provided technical expertise on motors. Xiaomin Liu assisted with some of the spreadsheets and prepared some of the figures. Diana Morris and Karen Olson helped with report production.

EXECUTIVE SUMMARY

Section 346(b)(1) of the Energy Policy and Conservation Act (EPCA), 42 U.S.C. 6317(b)(1), directs the Department of Energy (DOE or Department) to determine whether energy conservation standards for certain small electric motors would be technologically feasible, economically justified, and would result in significant energy savings. The purpose of this analysis is to provide a technical and economic basis for the Department's determination.

Under section 340(13)(F) of EPCA, 42 U.S.C. 6311(13)(F), the term "small electric motor" means a National Electrical Manufacturers Association (NEMA) general purpose alternating current single-speed induction motor, built in a two-digit frame number series in accordance with NEMA Standards Publication MG1-1987, "Motors and Generators." The two-digit frame series encompasses NEMA frame series 42, 48 and 56. The horsepower ratings for the two-digit frame series range from 1/4 to 3 hp (hp), operate at 60 Hertz, and could be single-phase or three-phase electrical design (also known as "polyphase").

Typical applications for such small electric motors include pumps, fans and blowers, woodworking machinery, conveyors, air compressors, commercial laundry equipment, service industry machines, food processing machines, farm machinery, machine tools, packaging machinery, and major residential and commercial equipment.

Section 346(b)(3) of EPCA, 42 U.S.C. 6317(b)3 also states that a standard prescribed for small electric motors shall not apply to any small electric motor that is a component of a covered product under section 332(a) of EPCA or covered equipment under section 340. Such covered products and equipment that contain small electric motors include residential air conditioners and heat pumps, furnaces, refrigerators and freezers, clothes washers and dryers, and dishwashers; and commercial package air conditioning and heating equipment, packaged terminal air conditioners and heat pumps, and warm air furnaces.

As a result of the above definition and exclusions, small electric motors covered by EPCA only comprise about 4 percent of the total population of small electric motors. Nevertheless, these motors, which we identify here as "considered small motors," account for a major portion of the energy consumed by the total population of small motors because of their size and use.

NEMA Standards Publication MG1 establishes performance standards, such as torque, for general purpose small electric motors. Among single-phase two-digit frame motors, only capacitor start motors, including both capacitor start-induction run (CSIR) and capacitor start-capacitor run (CSCR), can meet the torque requirements for NEMA general purpose motors. Among three-phase small motors, only non-servo motors can meet the NEMA performance requirements for general purpose motors.

Single-phase motors in two-digit frame sizes range from 1/4 hp through 1 hp. Three-phase motors in a two-digit frame size range from 1/4 hp through 3 hp, although most are 1 hp or less.

A 4-pole small electric motor, which rotates at 1800 rpm, is the most common design for single- and three-phase small motors.

THE MARKET FOR CONSIDERED SMALL MOTORS

The historic trend in annual shipments of considered small motors is not clear. Data from the U.S. Census Bureau show little growth in the 1990s, but these data only include motors produced in the United States. Confidential data on two-digit frame size fractional[1] horsepower motor sales to domestic customers by NEMA member manufacturers, covering the period from 1971 to 2001, show an average annual growth rate of 1.5 percent. Polyphase and capacitor start single-phase motors comprise approximately 20 percent of the motors covered by these data.

A joint NEMA/Small Motor and Motion Association (SMMA) survey of domestic sales in calendar year 2000 of considered small motors estimated sales of 5.4 million units for CSIR and 1.3 million units for polyphase motors. The CSIR motors accounted for approximately 95 percent of total shipments of capacitor start motors. Given the low level of shipments and inherent energy efficiency of CSCR motors, the Department decided to not consider them for further analysis.

Open motors account for 93 percent of total CSIR shipments. The most common size categories (with roughly equal shipments) are 1/3, 1/2, and 3/4 hp, with the average size being 1/2 hp. Enclosed polyphase motors account for two-thirds of total polyphase small motor shipments, reflecting the greater use of such motors in industrial environments. Of these, the largest sales categories are 3/4 and 1 hp, with the average size being 1 hp. For each type and size of considered small motor, there is a range of rated energy efficiencies on the market.

There are between five and ten companies that produce significant quantities of the considered small motors. Approximately two-thirds of the considered small motors are sold to original equipment manufacturers (OEMs), who incorporate them into larger pieces of equipment, such as pumps and HVAC equipment. If the motor wears out, the user will typically replace that motor with the same model, which effectively means that practically all motor purpose decisions are made by the OEMs. For most of the OEM equipment studied in this analysis, energy efficiency is not a high priority to an OEM in the selection of motors. OEMs report that their customers do not request more efficient motors, and are more concerned with first cost than small reductions in operating cost.

The diversity of applications for small motors poses challenges to accurately characterizing typical small motor usage patterns. Based on considerable market research conducted for this study, the estimated typical annual hours of use ranges from 800 hours for air and gas compressors to 5000 hours for industrial/commercial fans and blowers. Many of the values are in the 2000-3000 hours range, and the estimated shipment-weighted average is 2500 hours for

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[1] The term “fractional” generally refers to a motor that is 1 hp or less, depending upon speed and frame size.

both capacitor start and polyphase motors. Motor loading is commonly in the 60-70 percent range.

ENGINEERING ANALYSIS OF DESIGN OPTIONS

The most practical ways to adjust motor performance to achieve increased efficiency for the considered small motors are changing (1) the grade of electrical steel, (2) the stack length, or (3) the flux density by adjusting the effective turns or changing the thickness of the steel. The third option is only done at severe expense to the production process, so we did not analyze it in this study.

We did not analyze optimizing winding design and the quantity of wire used. With respect to winding, although there are optimum flux densities and torque-per-ampere characteristics that will yield the best efficiencies, the gains may be at the expense of other performance characteristics. With respect to wire, increased slot fill and proper end-turn configurations will result in fewer losses, but there are physical limitations as to how much wire can be inserted into a slot automatically. Hand insertion, which is an option in larger motors, is not practical for small motors.

For each product class of small motor, we selected several popular models to analyze the effects of change in the grade of electrical steel and stack length. The analysis only considered the cost changes associated with the active material. These materials include the electrical steel, copper winding and aluminum rotor bar/end ring. The active material costs were calculated based upon typical costs when purchased in volume. Labor and burden were not considered.

This methodology is quite commonly used by the motor industry (with some slight variations) for an initial cost estimate of the impact of design change. It is based on the assumption that labor costs are a very small part of the total cost for motors of this type where extensive automation is employed. If the design change prevents the normal processes from being used, this method is less accurate. Other costs can be broken into fixed burden and variable burden. For this study we assumed that the fixed portion is not affected, and that the variable portion is absorbed by large volume runs and, hence, is not included in the analysis.

In addition to the analysis described above, we asked a working group of motor manufacturers established by NEMA and SMMA to provide comparable data. The results, provided by four manufacturers, show considerable variability. Although details were not given, we believe that each manufacturer used somewhat different methods and assumptions concerning efficiency and cost changes.

LIFE-CYCLE COST ANALYSIS OF DESIGN OPTIONS

To assess the impact on end users of designs that improve motor efficiency, we conducted an analysis that compared the additional up-front cost to the value of electricity savings over the life of a motor. We used a mean lifetime of seven years for capacitor start motors and nine years for polyphase motors. To value electricity savings, we used recent DOE projections of average industrial and commercial electricity prices, and a discount rate of 7 percent based on the weighted average cost of capital for representative end users.

In the case of capacitor start motors, the Lawrence Berkeley National Laboratory (LBNL) analysis shows that improvements to energy efficiency using any steel grade design option have lower life-cycle cost (LCC) than the base motor. However, the NEMA average data for improvements in steel grade design show an increase in LCC for these motors. The LBNL analysis shows that changes in stack length would increase the LCC. The NEMA data show a slight decrease for one design option and an increase for the others.

The difference in the life-cycle cost for the two design options, steel grade and stack length, reflects the situations of different manufacturers. Some are able to improve efficiency at lower cost by changing the grade of steel, while others can do so by changing the stack length.

In the case of polyphase motors, the LBNL analysis shows that all the steel grade options have lower LCC than the base motor, but the NEMA average results show increased LCC. In both the LBNL and NEMA analyses, changes in the stack length design options increase the LCC relative to the base motors.

POTENTIAL NATIONAL ENERGY AND CONSUMER IMPACTS OF ENERGY CONSERVATION STANDARDS FOR SMALL MOTORS

In each product class, we used the average size (1/2 hp for CSIR and 1 hp for polyphase) motor as the basis for the estimation of national impacts. We assumed standards would take effect in 2010, and calculated impacts for motors sold within the 2010-2030 time period. We estimated impacts for two scenarios of average annual growth in shipments from 2010 to 2030 of 1 percent and 1.5 percent. The accounting model calculated total end-use electricity savings in each year with surviving motors (some motors sold in 2030 could operate through 2040). The model used a product retirement function to calculate the number of units of a given vintage which would still be in operation in a given year.

For assessing direct economic impacts on end users, we used the incremental equipment costs for each energy efficiency improvement level in the engineering analysis. We assumed that the current estimated incremental costs would remain the same in the 2010-2030 time period of motor sales.

Creating a base case — what might occur to small motor efficiency in the future in the absence of any standards — is perhaps the most difficult element of the analysis. The perspective of the NEMA/SMMA working group and other motor industry experts we consulted is that the past 20-30 years have seen "very little to moderate" improvement in efficiency. Some gains in energy efficiency to medium (1 through 500 hp) electric motors occurred in the 1970s when electricity prices increased, and consequently there were some spillover improvements to efficiency in small motors. A number of manufacturers have introduced "premium efficiency" small polyphase motors. In the case of capacitor-start motors, there has been some growth in the use of more efficient capacitor-run models, which to some extent had reduced the need to improve the more common induction-run models.

Current expectations for future commercial and industrial electricity prices show a slight declining trend in the long run, which suggests that customer interest in efficiency of small motors may continue to be limited. It seems reasonable that a lower bound case for future efficiency would envision very little improvement, while an upper bound case would envision moderate gains. In the Low Efficiency Improvement base case, the average efficiency of motors sold in the 2010-2030 period is 1/4 point better than the current base case motors. In the Moderate Efficiency Improvement base case, the average efficiency is 1 point better than the current base case motors. In both cases, we assume that there would be gradual efficiency improvement over that period of time.

In the case of capacitor start motors, the cumulative energy savings for options with positive net present value (NPV), based on the LBNL analysis of steel grade change, ranges from a low of 0.6 quad to a high of 1 quad (Figure ES-1). The corresponding cumulative NPV range in dollars is from $0.6 billion to just over $1 billion. None of the stack change options have positive NPV.

Using the NEMA average data, we see positive NPV only in a few instances (Figure ES-2). In the most favorable case (Low Efficiency Improvement base case, High Shipments Growth), there are savings of 0.6 quad with an NPV of just under $0.1 billion (plus 2 stack option).

In the case of polyphase motors, the LBNL analysis shows cumulative energy savings from steel grade change ranging from a low of 0.15 quad to a high of 0.21 quad (Figure ES-3). The corresponding cumulative NPV range in dollars is from $0.09 billion to $0.27 billion. The stack change options generally do not show positive NPV. Use of the NEMA average data would show lower savings than the above.

It seems likely that the potential energy savings and economic impact from energy efficiency improvement for small motors lie somewhere between the LBNL and NEMA/SMMA estimates. Additional technical and market share information would facilitate evaluation of data submitted by individual manufacturers.

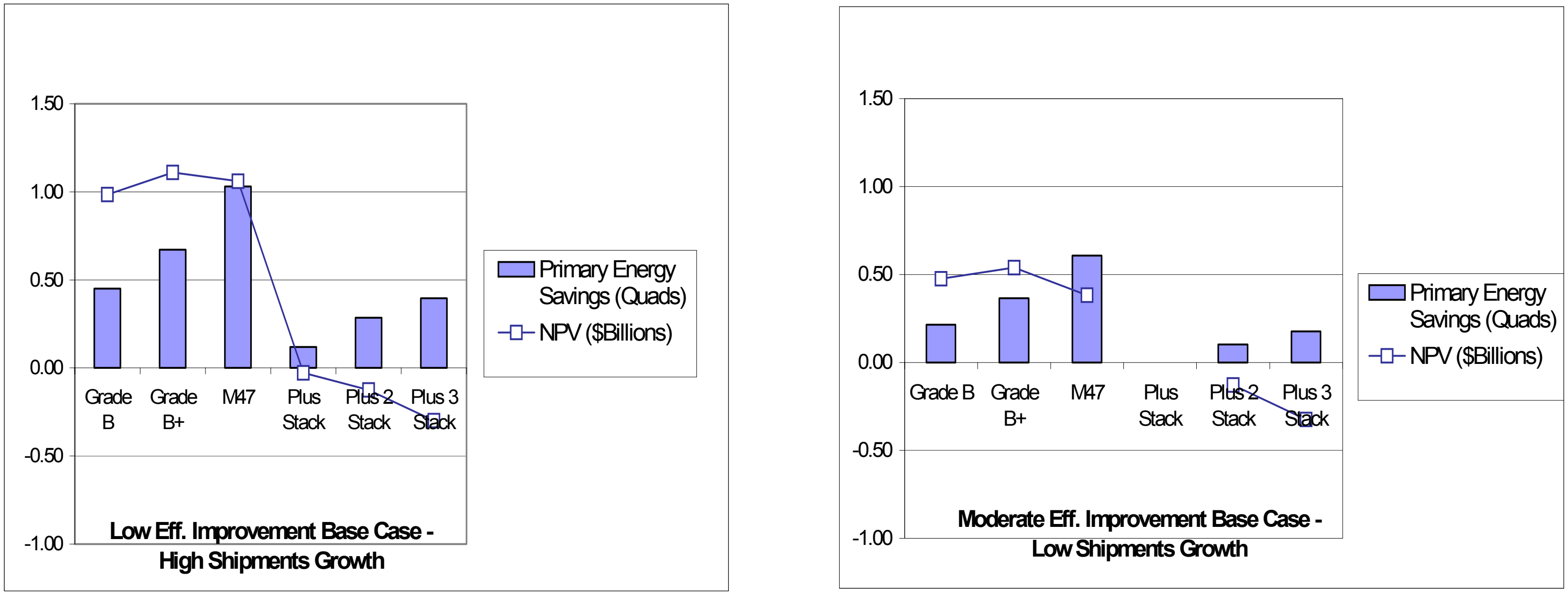


Figure ES-1 Cumulative Primary Energy Savings and Net Present Value of Energy Efficiency Improvement for Capacitor Start Motors, Based on LBNL Engineering Calculations

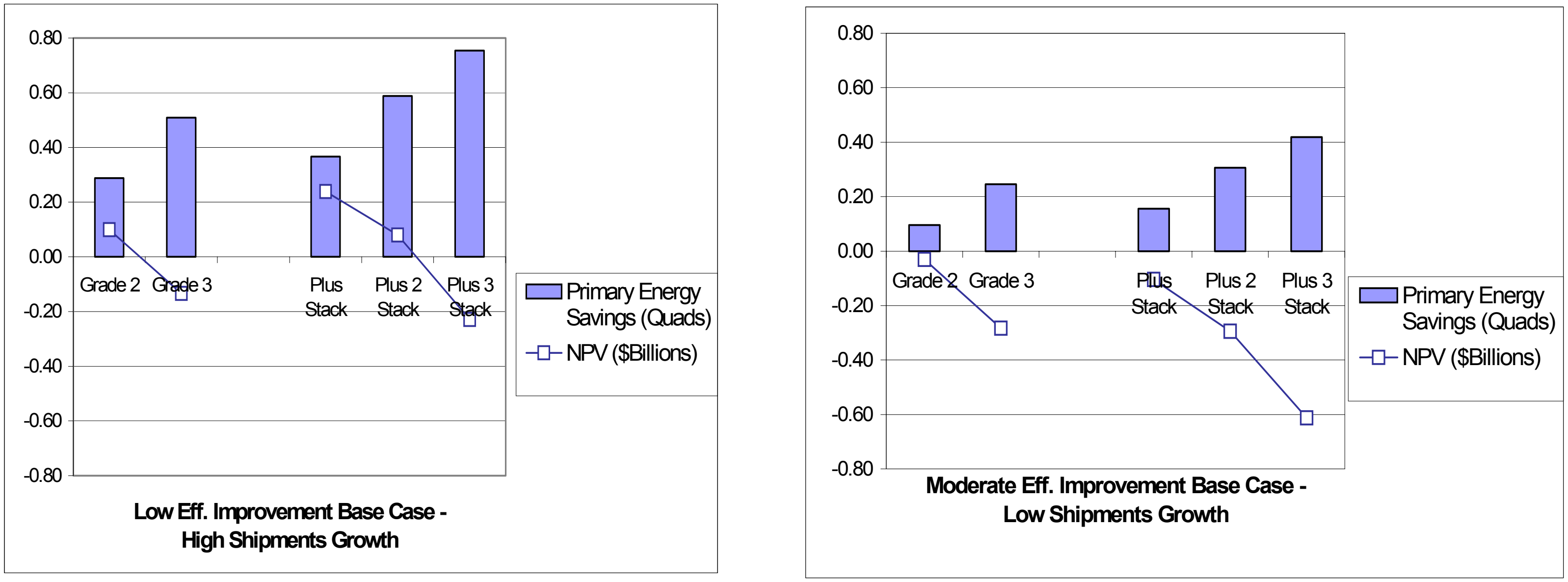


Figure ES-2 Cumulative Primary Energy Savings and Net Present Value of Energy Efficiency Improvement for Capacitor Start Motors, Based on Manufacturer Engineering Calculations

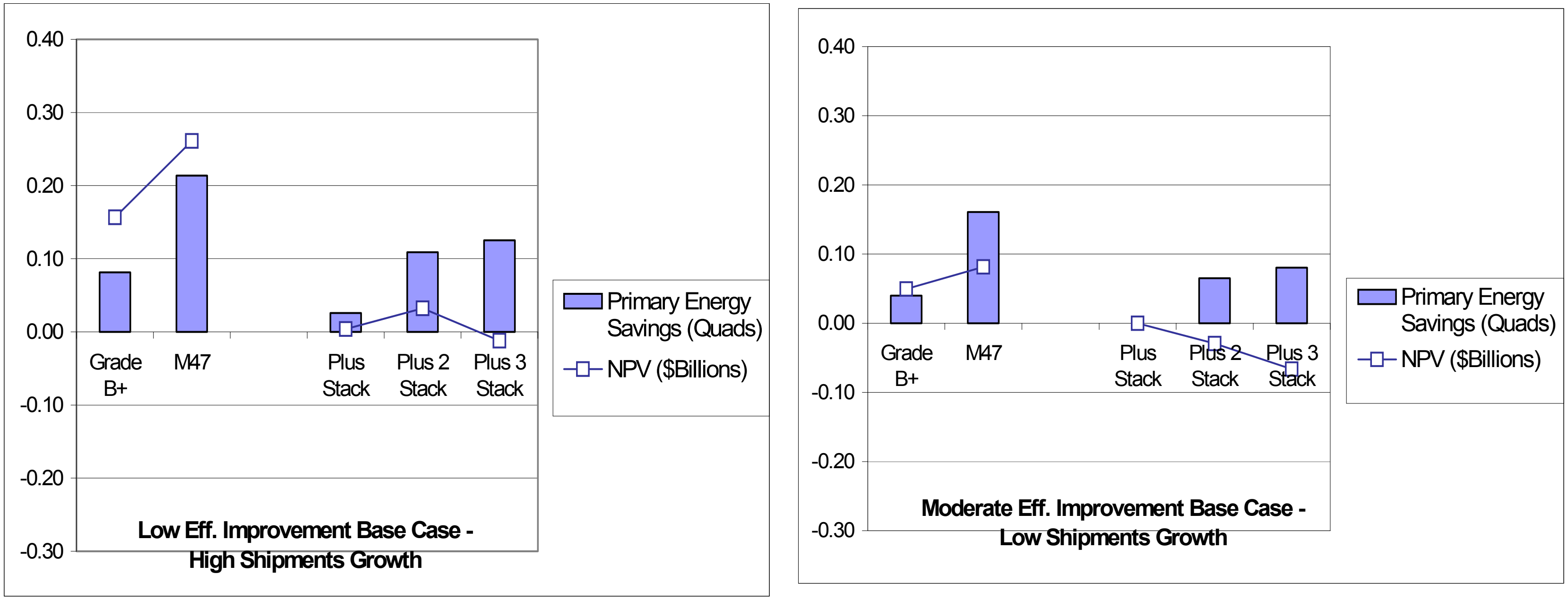


Figure ES-3 Cumulative Primary Energy Savings and Net Present Value of Energy Efficiency Improvement for Small Polyphase Motors, Based on LBNL Engineering Calculations

1. INTRODUCTION

1.1 Background

Subtitle B, Sect. 124, of the Energy Policy Act of 1992, Pub. L. 102-486 (EPAct) contains an amendment to Sect. 346 of the Energy Policy and Conservation Act (EPCA) (42 U.S.C Sect. 6317) that requires the U.S. Department of Energy (DOE) to assess the feasibility of energy conservation standards for small electric motors. The objective of this study was to determine whether energy conservation standards for small electric motors would be technically feasible, be economically justified, and have the potential for significant energy savings.

EPAct defines a “small electric motor” as “a National Electrical Manufacturer Association (NEMA) general purpose alternating current (AC) single-speed induction motor, built in a two-digit frame number series in accordance with NEMA Standards Publication MG1-1987.” This refers mainly to NEMA frame sizes 42, 48, and 56, and includes motors that range in size from 1/4 to 2 hp. It includes single-phase and three-phase (polyphase) motors.

EPAct also states that any standard prescribed for small electric motors shall not apply to any motor that is a component of a covered product under section 332(a) of EPCA or a covered equipment under section 340. Such covered products and equipment that contain small motors include residential air conditioners and heat pumps, furnaces, refrigerators and freezers, clothes washers and dryers, and dishwashers; and commercial package air conditioning and heating equipment, packaged terminal air conditioners and heat pumps, and warm air furnaces.

The result of the above definition and exclusions is that the motors that fall under Sect. 124 of EPAct are a small subset of the total population of fractional horsepower motors (see next section). However, such motors, which we refer to as “considered small motors,” account for a disproportionate share of the energy use by all small motors due to their greater size and utilization compared with other small motors.

1.2 Overview of Considered Small Motors

A key issue in determining exactly which motors fall under Sect. 124 of EPAct is defining what is meant by “general purpose.” EPAct does not define the term “general purpose motor,” thought it does define the terms “definite purpose motor” and “special purpose motor.” However, the NEMA Standards Publication MG1 establishes various performance requirements for general purpose motors. Minimum levels for breakdown and locked rotor torque for general purpose small electric motors are presented in MG1 Part 12.32.

Among single-phase two-digit motors, shaded pole, permanent split capacitor, and split phase motors do not meet the torque requirements of NEMA general purpose motors. Capacitor start motors, including both capacitor start-induction run (CSIR) and capacitor start-capacitor run

(CSCR), can provide the torque requirements for NEMA general purpose motors. Other single-phase motors such as universal, drip-proof, and series AC are designed for definite or special-purpose applications.

The CSCR motor is not interchangeable with the CSIR motor in most cases because of differences in size and starting torque. The addition of a second running capacitor to the motor changes the dimensional envelope of the motor but not the frame size. In this analysis, we consider the CSIR and CSCR motors as separate product classes. Although not interchangeable for all applications, there may be some applications for which the CSCR offers a high efficiency alternative to a CSIR motor.

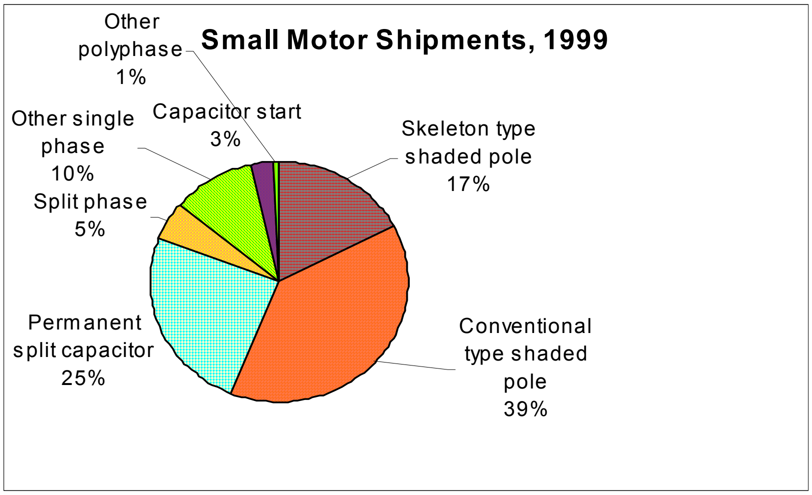
Among polyphase small motors, synchronous stepper motors cannot provide the torque requirements of NEMA general purpose motors, while polyphase servo motors are for definite-purpose applications. Polyphase non-servo motors do meet the NEMA requirements for general purpose motors.

The small electric motors that meet the EPAct definition fall into three product classes:

- Single-phase capacitor start-induction run motors
- Single-phase capacitor start-capacitor run motors
- Polyphase (non-servo) motors

These classes accounted for close to 4% of total domestic shipments of fractional horsepower motors in 1999 (Figure 1-1).

Figure 1-1 Total Domestic Shipments of Fractional Horsepower Motors in 1999



Source: US Census Bureau, Current Industrial Reports, Motors and Generators -- MA335H

Not all capacitor start and polyphase non-servo motors are NEMA general purpose motors. Those in the "definite-purpose" category include many motors used for fans and blowers and specific types of pumps.

1.3 Applications for Considered Small Motors

The applications for considered small motors are listed below.

Table 1-1 Major Applications for Considered Small Motors

Pumps and Pumping Equipment
Commercial & Industrial HVAC/Refrigeration Equipment
Farm Machinery
Conveyors
Industrial & Commercial Fans and Blowers
Machine Tools
Textile Machinery
Woodworking Machinery
Food Products Machinery
Air and Gas Compressors
Packaging Machinery
General Industrial Machinery
Commercial Laundry Machinery
Service Industry Machinery

Many motors used in Pumps and Pumping Equipment and Industrial & Commercial Fans and Blowers are definite-purpose motors, but a significant number of general-purpose motors are also used. In Commercial & Industrial HVAC Equipment, the HVAC equipment that is covered under other EPCA requirements (section 340) is rated at less than 240,000 Btu per hour (cooling capacity). Motors under consideration in this study are used in larger equipment.

1.4 Study Approach

This study consisted of four major components:

- Market research to better understand usage patterns of considered motors;
- Engineering analysis to estimate the impact on efficiency and cost of feasible design options;
- Life-cycle cost analysis to estimate the benefits and costs of efficiency improvement for end users of small motors; and

- National energy savings analysis to estimate the potential national energy savings from efficiency improvement of considered motors.
- National consumer impacts analysis to estimate the potential direct economic costs and benefits resulting from efficiency improvement of considered motors.

The methods and data sources used are discussed in the relevant chapters.

2. GENERAL CHARACTERIZATION OF SMALL ELECTRIC MOTORS

2.1 Three-phase Squirrel Cage Induction Motors

Three-phase squirrel cage induction motors are used as the prime mover for the majority of commercial and industrial sector motor applications requiring over a few horsepower, and in many smaller applications as well.

The typical three-phase induction motor employs a wound stator and a "squirrel cage" rotor. Magnetic force acting between the stator and rotor units produces motor torque. The stator consists of a hollow cylindrical core formed by a stack of thin steel laminations. Insulated copper windings are assembled into slots formed about the inner circumference of the core. Stator winding carries current through one slot and then back though a companion slot located approximately one pole pitch distant from the first. For a 2-pole motor, the pole pitch is half the circle while for 4 or 6 pole machines it is one quarter or one sixth of the circle, respectively.

The rotor unit consists of a laminated steel core press fitted to the steel shaft. Like the stator, the rotor core also has windings set into slots but these are deployed about its outer circumference. Moreover, in the squirrel-cage rotor configuration the rotor windings consist of solid conductor bars that are interconnected at either end with solid-conductor end rings. Absent the laminated steel core this assembly of bars and end rings would look like a “squirrel cage” and hence the nomenclature for this very robust and cost-effective construction.

When the stator windings are energized by a 3-phase electrical source, a radially directed magnetic flux is established in the “air gap” between the rotor and the stator. This flux rotates at a speed determined by the electrical frequency and number of poles given by the stator-winding configuration. For example with 60 Hz excitation and a 2 pole (or 1 pole-pair) winding the flux rotates at a so-called “synchronous” speed of 60 revolutions per second (rps) or 3,600 revolutions per minute (rpm). The flux produced by the energized stator windings envelops the rotor cage bars and due to its motion induces current to flow in these conductors. The interaction of the rotating stator flux and the rotor bar currents develops motor drive torque.

Important characteristics of the three-phase squirrel cage induction motor are simplicity and ruggedness, inherently high starting torque (without the start-assisting devices required for single-phase motors), and the potential to achieve high efficiency. Compared with larger motors, the efficiency of small (1 hp and below) three-phase induction motors declines rapidly as the load drops below 70% of rated load.

Polyphase motors in a two-digit NEMA frame size range from 1/4 hp to 3 hp, though the majority are 1 hp or less. They are available in 2, 4, or 6 pole configurations (corresponding to speeds of 3500, 1750, or 1150 rpm, respectively). A 4-pole configuration is the most common.

2.2 Single-phase Squirrel Cage Induction Motors

The basic principal of operation of a single-phase squirrel-cage induction motor is similar to a 3-phase induction motor. A rotating magnetic field is easily established with three-phase excitation of motor windings as described in the preceding subsection. In a single-phase induction motor two counter-rotating fields are produced which develop equal and opposite rotor torque components when the motor is at standstill. However, if means are provided to urge rotation in one direction or the other, net torque will be developed to sustain the rotation and drive the attached load. While the electromagnetic torque acting on the rotor of a three-phase motor is relatively smooth and free from pulsating disturbances, this is not the case in the single-phase motor. In this instance, the torque may pulsate from zero to a maximum value at twice the power line frequency—e.g., 120 Hz. In most applications, this is of little consequence as the inertia of the motor and the driven load act to smooth out the torque pulsations.

The basic construction of the single-phase induction motor includes a rotor and stator; each built up of a stack of electromagnetic grade steel laminations as previously described for the three-phase motor. The "squirrel cage" rotor has a series of aluminum bars cast lengthwise into the rotor laminations. These bars are connected with rings located at each end of the stack. The stator laminations contain a series of slots for the windings that are aluminum or copper wire. Two sets of windings are provided, at a 90°-phase difference. The “main” or “run” winding operates directly from line current, and stays always energized as long as the motor is running.

Single phase motors are categorized according to the way the “start and run,” “secondary”, or “auxiliary” winding is utilized for starting the motor and then running it at normal speed. Widely used single-phase motor categories are:

- The Split-Phase or Resistance Start/Induction Run Motor -- This configuration is the lowest cost. The start winding has a higher resistance-to-reactance ratio than the main winding achieved by using a relatively small diameter wire. This reduces both the amount and the cost of the copper in the start winding and the space taken up in the stator slots by this winding.
- The Capacitor Start/Induction Run (CSIR) Motor -- This configuration is a relatively low efficiency motor that provides higher starting torque than the split-phase motor.
- The Permanent Split Capacitor (PSC) Motor -- This configuration has a high potential efficiency depending on the design.
- The Capacitor Start/Capacitor Run (CSCR) Motor -- This is an efficient run configuration with a large capacitance at start-up providing a large starting torque. The start capacitance is typically 3 - 5 times the size of the run capacitor, but can be packaged compactly, because continuous operation (and the resulting heat dissipation) is not a consideration.

Split phase and CSIR motors use the secondary winding for starting only; the capacitor start version provides higher starting torque. The secondary winding uses a much smaller diameter wire energized for a limited time without overheating and automatically disconnected after start up by a centrifugal switch. In PSC and CSCR motors, the secondary winding continues operating when the motor is running. The capacitor in series with this winding shifts the phase of the input voltage approximately 90°, so the two windings together create a rotating magnetic field. The benefits achieved by PSC and CSCR motors are the suppression of torque pulsations and the improved utilization of both the windings and the iron in the motor. These benefits increase the efficiency and the power factor of the motor, but at an added cost associated with the capacitor.

Single-phase motors in a two-digit NEMA frame size range from 1/4 hp to 1 hp and are available in 2, 4, or 6 pole configurations. A 4-pole configuration is the most common.

2.3 Energy Efficiency: Basic Considerations

The application of a motor to do work creates energy losses that are both external and internal to the motor. Losses that are external to the motor are influenced by the power factor of the motor. The power factor is the ratio of real power to apparent power, and ranges from 0 to 1. The real power (measured in watts) is used to create the useful work (and waste heat) of the motor. Reactive power (measured in volt-amps reactive) is used to create the magnetic field needed for the motor to operate, but it does not contribute to the mechanical power generated by the motor.

Internal energy losses are usually categorized as conductive, magnetic, mechanical, and stray. All of these energy losses appear as heat in the motor. Losses are strongly dependent on design and quality control of motor components.

The conventional methods for reducing losses include increasing the amount of active material (e.g., the diameter of wire conductors); substituting higher grade of steel for the magnetic components; improving mechanical components and design (winding, bearings, and fan); and improving quality control of components and assembly. These methods may increase either the motor cost or size if no other changes in the motor are made.

The precise impacts on motor cost and efficiency will depend on how the designer makes trade-offs between added performance from improved materials or design and maintenance of the motor performance. A designer can not ignore interaction among different motor losses in the process of optimizing. The I^2R of the rotor is a key loss, as is the windage and friction and the stray loss. Options that may reduce the stray loss can increase the core loss; those that can reduce the windage loss may increase the I^2R loss; those that may reduce the slip loss may increase the core loss.

Often a measure that enhances efficiency improves motor performance such that other cost-saving changes can be made to offset the cost of the efficiency improvement. An example of this is the use of more expensive high permeability steel in place of iron. This leads to higher efficiency, smaller motor size, and improved torque, and also allows the volume of copper used in the motor to be reduced while maintaining performance.

Various component additions to a single-phase motor are known to improve the efficiency while increasing the cost and usually changing the motor's dimensions. Adding an auxiliary winding with a capacitor, adding an auxiliary winding with a starting capacitor and switch, or adding an auxiliary winding with starting capacitor, switch, and running capacitor to a single-phase motor can reduce energy losses, increase torque, and improve the power factor. The additional winding may be continuously energized as in the CSCR motor, or disconnected with a centrifugal switch as is often done in the CSIR motor. The CSCR motor has a switch added in series with the starting capacitor and adds a second running capacitor in parallel to the starting capacitor that is not switched out of the circuit after starting. The auxiliary winding and running capacitor of the CSCR motor contribute to motor output, allowing it to approach the efficiency of a polyphase motor. The efficiency increase of the CSCR motor over the CSIR motor ranges from about 5% to about 24% (EPRI, 1987).

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3. THE MARKET FOR CONSIDERED SMALL MOTORS

3.1 Annual Shipments

The historic trend in annual shipments of considered small motors is uncertain. Data from the U.S. Census Bureau[2] show little growth in the 1990s, but these data only include motors produced in the U.S.

NEMA provided confidential data on two-digit frame size fractional horsepower motor sales to domestic customers by NEMA manufacturers, covering the period from 1971 to 2001. After smoothing the data, the average annual growth rate is 1.5%. Unfortunately, the three-phase and capacitor start motors being analyzed make up only around 20% of the motors covered by these data.

A joint NEMA/SMMA survey of U.S. sales of considered small motors in 2000 estimated values of 5.4 and 1.3 million for capacitor start-induction run (CSIR) and polyphase motors, respectively. CSIR motors accounted for approx. 95% of total shipments of capacitor start motors.

3.2 Features of Considered Small Motors

The basic features of considered small motors sold in 2000 (according to the NEMA/SMMA survey) are shown in Figures 3-1 and 3-2.

Open motors account for 93% of total CSIR shipments. The most important size categories (with roughly equal shares) are 1/3, 1/2, and 3/4 hp. The average size is 1/2 hp. Four-pole motors account for a somewhat higher share than two- and six-pole motors.[3]

For polyphase motors, enclosed motors account for two-thirds of total shipments, reflecting the greater use of such motors in industrial environments. The largest sales categories are 3/4 and 1 hp. The average size is 1 hp. Four-pole motors account for two-thirds of the total.

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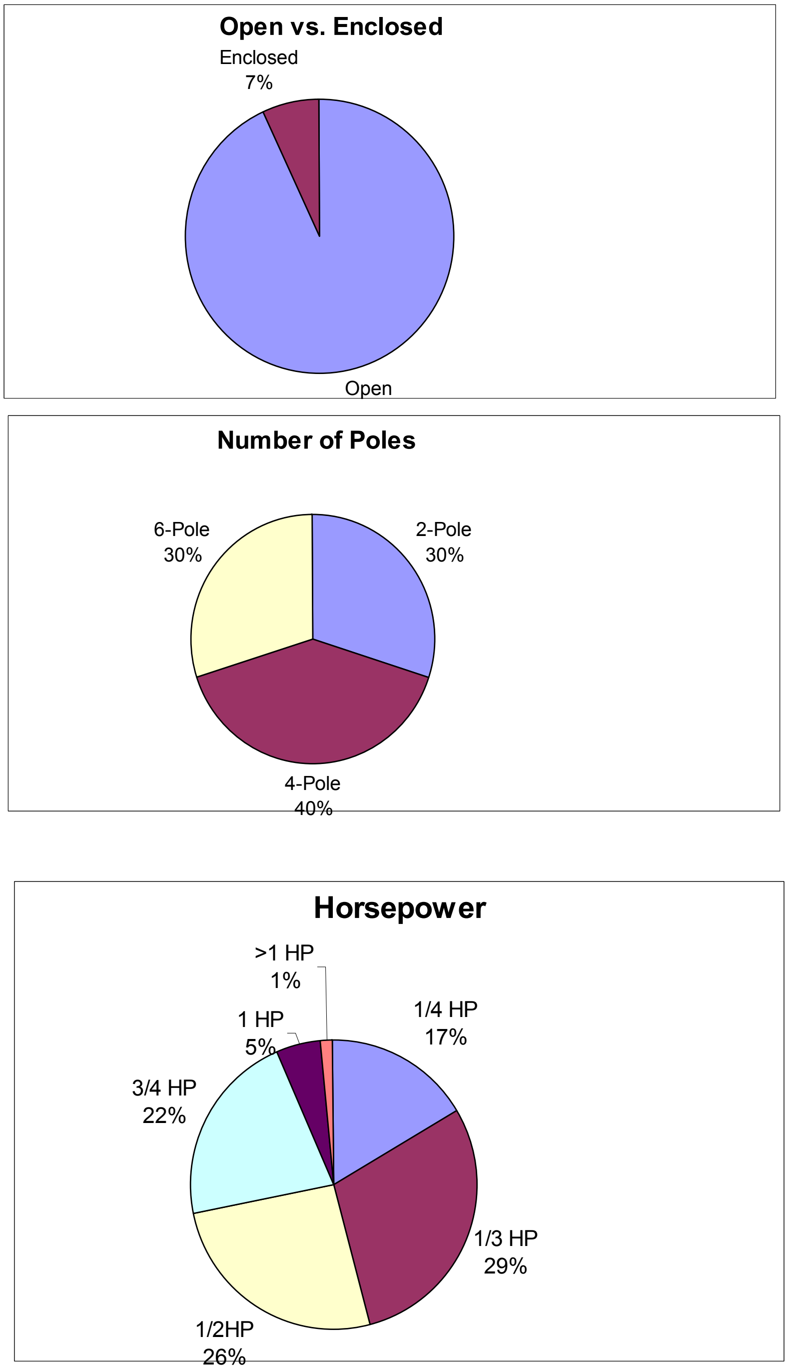
[2] US Census Bureau, Current Industrial Reports, Motors and Generators -- MA335H. We have included all single-phase motors, 1 hp and over, with capacitor start motors.

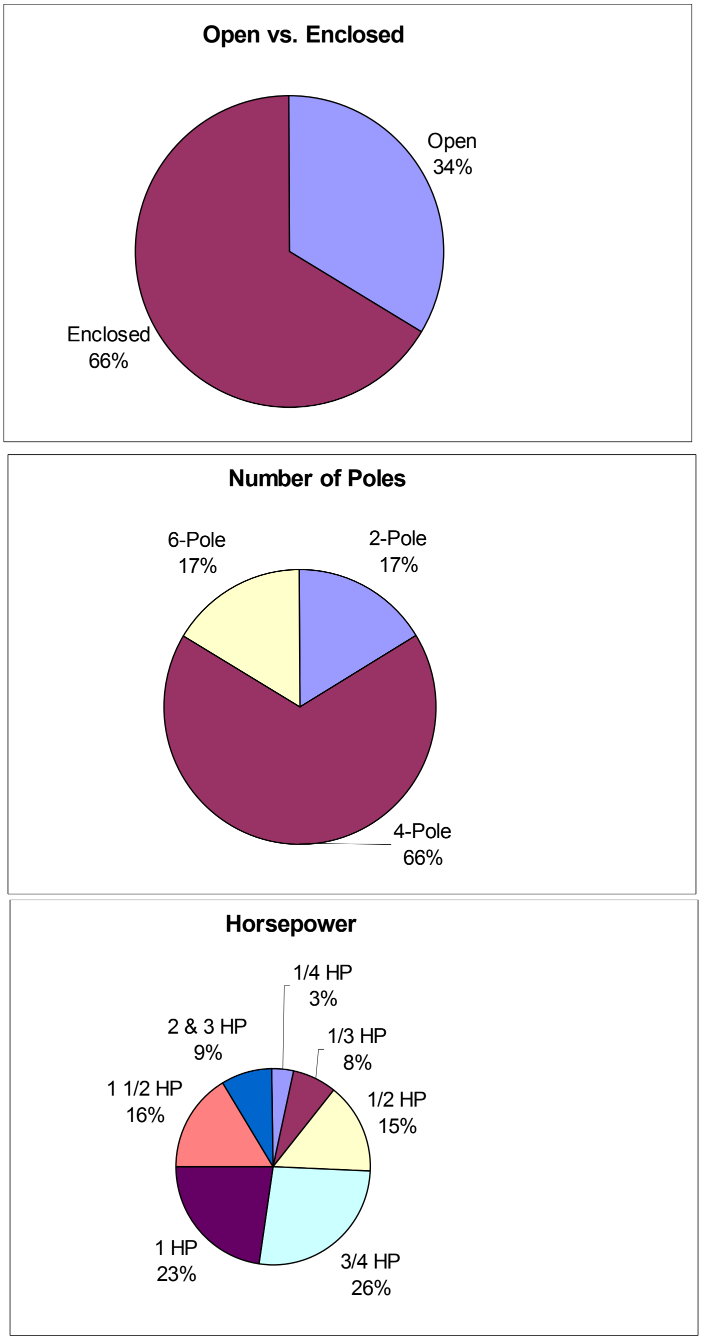
[3] The shares of 2- and 6-pole motors are estimated values, as complete data were lacking.

Figure 3-1 Capacitor Start-IR Motors – Shipments in 2000



Source: NEMA/SMMA survey

Figure 3-2 Small 3-Phase Motors – Shipments in 2000



Source: NEMA/SMMA survey

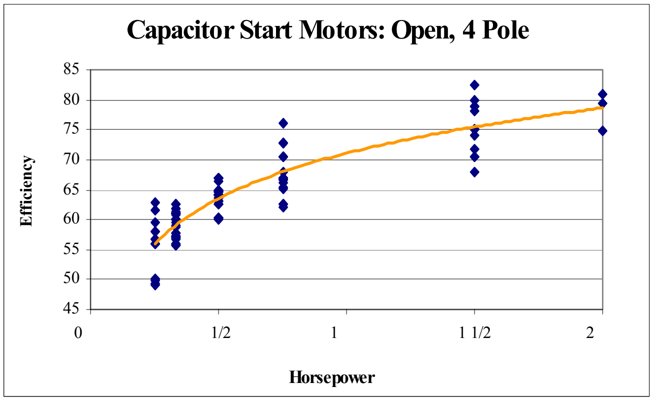
3.3 Range of Energy Efficiencies

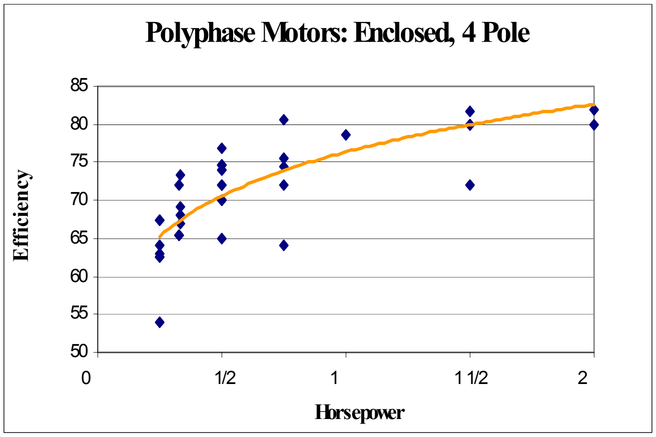
We assembled data from manufacturer catalogs on the listed nominal full-load efficiency and other features of over 700 different models (A.D. Little, 2001). While these data provide an approximate picture of the spread of efficiencies on the market, two caveats bear mention. First, the reported efficiencies are not precisely comparable among different manufacturers, since they are not all based on the same test procedure. Second, many of the models likely have a low sales volume, so looking at the spread of the data may not give an accurate portrait of what is actually being sold.

Figure 3-3 shows the full-load efficiency vs. the nominal horsepower of capacitor start and three-phase motors in a popular design. Generally speaking, larger motors have higher efficiency than smaller motors in a given class. For open, 4-pole capacitor start motors, the efficiency range is greater for 3/4 hp motors than for 1/3 and 1/2 hp motors. Some of the highest-efficiency motors in the >1 hp sizes are capacitor start-capacitor run motors. For three-phase motors, there is also a significant range in efficiency.

The range of efficiencies for a given type and size is likely due in part to different methods of testing among the manufacturers. Differences in specific features also play a role.

Figure 3-3 Listed Efficiency (full load) of Small Motor Models





Source: A.D. Little (2001)

3.4 Market Structure and Actors

Based on expert judgement, we estimate the sales channels for considered small motors as follows:

Motor Manufacturers → Original Equipment Manufacturers (OEMs)	40%
Motor Manufacturers → Distributors → OEMs	25%
Motor Manufacturers → Distributors → End Users	35%

The latter are motors sold to end users as replacements or spares.

A high percentage of considered small motors sold in the U.S. are domestically manufactured. In addition to imported stand-alone motors, some considered small motors are imported as components of equipment built in other countries. The magnitude of such imports is difficult to determine.

Table 3-1 lists the manufacturers that produce most of the considered small motors in the U.S.

Table 3-1 Leading Manufacturers of Considered Small Motors Sold in the U.S.

Manufacturer	Brand
A.O. Smith	
Baldor Electric	
Emerson Motors	Dayton, US Motors
GE	
Regal-Beloit	Leeson, Lincoln, Marathon
Rockwell Automation	Reliance
TECO-Westinghouse	
Toshiba	
WEG Electric Motor Corp.	

There are dozens of OEMs that incorporate considered small motors in industrial, agricultural, and commercial equipment. These range in size from large to small companies.

The users of equipment containing considered small motors primarily consist of firms that have the applications listed in Table 3-2. The large diversity of applications poses challenges with respect to accurately characterizing typical motor usage patterns. To determine how considered small motors are used, we conducted considerable research, including review of trade literature and interviews with manufacturers that produce the equipment into which small motors are built (Easton Consultants, 2001). See Appendix A for description of the information gathering process.

The estimated typical annual hours of use ranges from 800 hours for air and gas compressors to 5000 hours for industrial/commercial fans and blowers. Many of the values are in the 2000-3000 range.

Table 3-2 Average Utilization Characteristics for General Purpose Small Motors by Type of Application

Application	Hours/ year	Motor loading (% of rated)
Farm Machinery	1000	70%
Conveyors	3000	50%
Machine Tools	2000	60%
Textile Machinery	3000	70%
Woodworking Machinery	2000	35%
Food Machinery	3000	60%
Pumps and Pumping Equipment	3000	65%
Air and Gas Compressors	800	85%
Industrial/Commercial Fans and Blowers	5000	80%
Packaging Machinery	3000	60%
General Industrial Machinery	2000	n/a
Commercial Laundry Machinery	2000	60%
Commercial and Industrial HVAC/Refrigeration Equipment	2500	60%
Service Industry Macinery	1500	n/a

Source: Easton Consultants (2001)

We also investigated typical motor loading practices. The motor loading is commonly in the 60-70% range, though it is higher in two cases.

To assess the relative importance of different application categories, we estimated the magnitude of annual shipments of considered small motors to each group (see Appendix B for method.) Motors used in pumps & pumping equipment and in commercial & industrial HVAC/refrigeration equipment each account for approximately 30% of total shipments for capacitor start motors. No other category accounts for more than 10%. Motors used in pumps & pumping equipment are the largest category for polyphase motors, followed by commercial & industrial HVAC/Refrigation equipment and conveyors.

Table 3-3 Estimated Annual Shipments of General Purpose Small Motors by Type of Application

Application	**Cap. Start**		**Polyphase**	
	'000	**%**	**'000**	**%**
Farm Machinery	457	8.1	33	2.5
Conveyors	497	8.8	207	16.0
Machine Tools	81	1.4	81	6.2
Textile Machinery	18	0.3	13	1.0
Woodworking Machinery	101	1.8	34	2.6
Food Machinery	90	1.6	90	7.0
Pumps & Pumping Equip.	1723	30.4	364	28.1
Air and Gas Compressors	338	6.0	101	7.8
Industrial/Commercial Fans & Blowers	248	4.4	62	4.8
Packaging Machinery	12	0.2	11	0.8
General Industrial Machinery	101	1.8	38	2.9
Commercial Laundry Machinery	104	1.8	9	0.7
Commercial & Industrial HVAC/Refrig Equip.	1770	31.2	239	18.4
Service Industry Machinery	125	2.2	16	1.2
TOTAL	**5664**	**100**	**1297**	**100**

Source: Easton Consultants (2001)

3.5 Motor Purchasing

An end user will almost always replace a worn-out motor with the same model, which means that the motor purchase decision is effectively made by the OEMs, and not by the actors who use the motors and pay for the electricity to run them.

The price paid for a motor depends on the type of purchaser and the volume purchased. Our research indicates typical ranges as follows:

Channel	Purchase price (% of list)
Motor Manufacturers → OEMs	37-40
Motor Mfrs → Distributors → OEMs	46-48
Motor Mfrs → Distributors → End Users	65-75

Our interviews with OEMs inquired about their attitudes towards motor energy efficiency. Most of the OEMs took a view of motor efficiency that can be summarized as follows:

1. Efficiency is not a high priority in selection of motors for most of the equipment studied. The respondents characteristically stated that they have not given much attention to motor efficiency in this size range primarily because their customers do not request more efficient motors, and are more concerned with first cost than small reductions in operating cost.
2. Somewhat more interest in energy efficiency was shown in some industrial categories -- conveyors, food products machinery, industrial pumps, and packaging equipment -- than others. Relatively more interest in energy efficiency in general was expressed in these industries where hours of operation are longer and the end-user customer is a more sophisticated cost-sensitive operator. These categories in total represented about 40% of two digit motors. (The response from the HVAC category was mixed with some OEM respondents quite interested in greater efficiency, others not.)
3. In several instances some interest was shown in total motor system efficiency, particularly adjustable speed drives. There is wide recognition that energy can be saved with the installation of adjustable-speed drives and other devices to control motor systems, and considerable interest was shown, particularly in HVAC fans and industrial pumps.

Many of the product designers noted that there are few premium-efficient two-digit motors available. They stated that even if an OEM wanted to use a more efficient motor it would be difficult because motor manufacturers offer very few premium-efficient motors in these frame sizes. In the case of several manufacturers of single-phase motors, the CSCR motors are designated “premium efficient” in contrast to CSIR motors. However, the former are not always physically interchangeable with a CSIR motor.

REFERENCES

Arthur D. Little, 2001. Small motor database (Prepared for this study).

Easton Consultants, 2001. Analysis of considered motors use by principal machinery categories (Prepared for this study).

4. ENGINEERING ANALYSIS OF DESIGN OPTIONS TO IMPROVE EFFICIENCY OF CONSIDERED SMALL MOTORS

4.1 Approach

The most practical ways to adjust motor performance to achieve increased efficiency for the considered small motors are: (1) change the grade of electrical steel, (2) change the stack length, (3) change the flux density by adjusting the effective turns or changing the thickness of the steel. The latter option is only done at severe expense to the production process, so we did not analyze it in this study.

We did not analyze optimizing of winding and wire. With respect to winding, although there are optimum flux densities and torque per amp characteristics that will yield the best efficiencies, the gains may be at the expense of other performance characteristics. With respect to wire, increased slot fill and proper end turn configurations will yield less I^2R losses, but there are limitations as to how much wire can be inserted automatically. Hand insertion, which is an option in larger motors, is not practical for fractional motors.

For each product class, we selected several popular models to analyze. We engaged a recently retired engineering executive from the motor industry (Austin Bonnett) to conduct the analysis. The testing of the sample motors was done with the dynamic reaction torque procedure with a controlled acceleration cycle using a d.c. drive motor. In three seconds 2000 data points were collected that characterized the motor performance. Loss segregation was then achieved through computer modeling and correlation. The influence of temperature was not included in this evaluation.

We conducted separate analyses of change in the grade of electrical steel and change in the stack length. The electrical steel options considered are shown in Table 4-1 (see section below for discussion of the motor manufacturers' analysis). For stack change, the options considered involve incremental increases of 0.25 inch with respect to the sample motors.

Note: In this chapter, the term "Capacitor Start" refers to capacitor start motors with induction run.

Table 4-1 Electrical Steel Options Considered

Grade	Type*	Maximum Loss (watts/lb @15kg, 60 hz)	Thickness (inch)
LBNL Analysis			
Grade A	Cold rolled	4.51	0.031
Grade B	Cold rolled	4.15	0.031
Grade A+	Cold rolled	4.04	0.025
Grade B+	Cold rolled	2.78	0.022
M47	Semi-processed electrical	1.53	0.019
Manufacturers' Analysis			
Grade 1	Cold rolled		0.026-0.031
Grade 2	Cold rolled		0.022-0.025
Grade 3	Semi-processed electrical		0.018-0.022

* Semi-processed steel with full anneal after punching

The efficiency change for each design package was calculated using the traditional motor performance program based on equivalent circuit analysis, which is used by most motor manufacturers. The model used for this program does not take into account the losses associated with motor heating. Hence, the stator and rotor are assumed to be at ambient temperature. The I^2R losses are understated due to a lower resistance being used in the calculations. The effect could be overstatement of motor efficiency in the 0.25-0.75 load range. However, the relationship among various design options will be accurate.

Costing Changes in Design

Our analysis only considered the active material cost changes. These materials include the electrical steel, copper winding and aluminum rotor bar/end ring. The active material costs were calculated based upon typical costs when purchased in volume. No other materials were included. Labor and burden were ignored. The impact on set-up time and the introduction of new part numbers were also not considered.

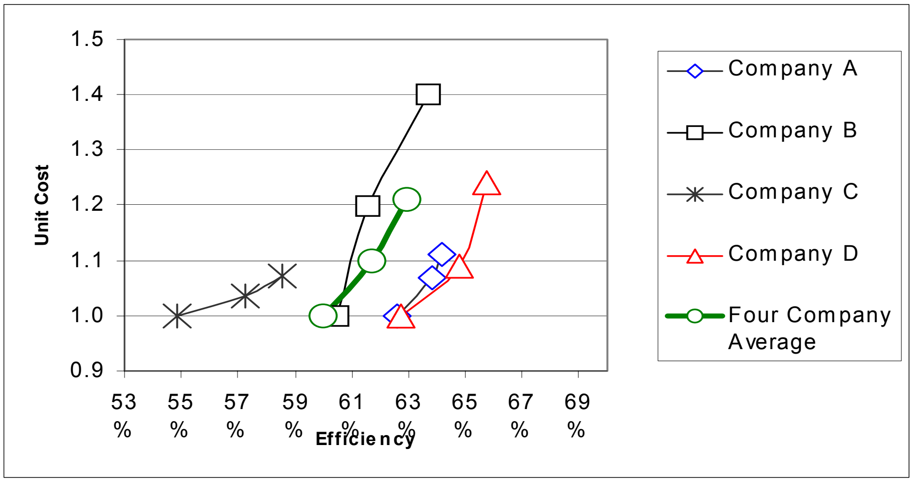
The Base motor in each case was given a "per-unit" (PU) cost of 1. All active material changes are related to the PU cost of 1. If a change in electrical steel represented a 10% change in the total active material cost, for example, the PU number would be 1.10 for the new design.

This methodology is quite commonly used by the motor industry (with some slight variations) for an initial cost estimate of the impact of design changes. It is based on the assumption that labor costs are a very small part of the total cost for motors of this type where extensive automation is employed. Of course, if the design change prevents the normal processes from being used, this method is less accurate. Other costs can be broken into fixed burden and variable burden. For this study it is assumed that the fixed portion is not effected, and that the variable portion is absorbed based on large volume runs, and hence is not included in the analysis.

Analysis Submitted by Motor Manufacturers

In addition to the analysis described above, we asked a working group of motor manufacturers established by NEMA and SMMA to provide comparable data. The results, provided by four manufacturers, show considerable variability (Figure 4-1). Each manufacturer selected a typical motor to use as the "base motor." We believe that each manufacturer used somewhat different methods and assumptions concerning efficiency and cost changes. Furthermore, the precise steel grades considered varied, so the data are presented in terms of Grades 1, 2, and 3 (see Table 4-1).

Figure 4-1 Increase in Efficiency and Cost from Steel Grade Change, Capacitor Start 1/2 hp, NEMA Data*



* Cost for Companies A, B and D includes capital for new production tooling

For steel grade options, the "NEMA" data in the tables below refer to the average values of the four submissions. For stack change options, the NEMA/SMMA working group provided data that they considered most typical.

4.2 Efficiency and Cost Impacts of Design Options

The tables below present the results of the analyses of steel grade and stack length change. All calculations assume operation at 70% of rated load.

Capacitor Start Motors: Steel Grade Options

The 4K motor has relatively low efficiency, so the design options yield proportionately more efficiency gain than for the more typical 6K motor. The NEMA average data show much less efficiency gain than does the LBNL analysis.

Capacitor Start LBNL #4K, 1/2 hp, 4-pole, ODP

	Grade A	**Grade B**	**Grade B$^+$**	**M47**
P.U. Cost	**1.00**	1.03	1.08	1.25
Input (Watts)	492	462	447	438
Outpot (Watts)	265	265	265	265
Loss (Watts)	227	197	182	173
Efficiency	**53.9%**	57.4%	59.3%	60.5%

Capacitor Start LBNL #6K, 1/2 hp, 4-pole, ODP

	Grade A	**Grade B**	**Grade B$^+$**	**M47**
P.U. Cost	**1.00**	1.03	1.10	1.25
Input (Watts)	417	399	391	378
Output (Watts)	261	261	261	261
Loss (Watts)	156	138	130	117
Efficiency	62.6%	65.4%	66.8%	69.0%

Capacitor Start NEMA, 1/2 hp, 4-pole, ODP

	Grade 1	**Grade 2**	**Grade 3**
P.U. Cost	1.00	1.10	1.21
Input (Watts)	435	423	415
Efficiency	60.0%	61.7%	62.9%

Capacitor Start Motors: Stack Change Options

The stack change options yield less efficiency gain (for the LBNL 6K and NEMA motors) than do the steel grade options. The NEMA/SMMA analysis shows somewhat greater efficiency gain from stack change than does LBNL's analysis of the 6K motor.

Capacitor Start LBNL #4K, 1/2 hp, 4-pole, ODP

	Base	**Plus stack**	**Plus 2 stack**	**Plus 3 stack**
P.U. Cost	**1.00**	1.09	1.19	1.29
Input (Watts)	492	458	441	429
Output	265	266	266	266
Loss (Watts)	227	192	175	163
Efficiency	**53.9%**	58.1%	60.3%	62.0%

Capacitor Start LBNL #6K, 1/2 hp, 4-pole, ODP

	Base	Plus stack	Plus 2 stack	Plus 3 stack
P.U. Cost	**1.00**	1.07	1.15	1.22
Input (Watts)	417	411	405	4012
Output (Watts)	261	261	261	261
Loss (Watts)	156	150	144	140
Efficiency	62.6%	63.5%	64.4%	65.1%

Capacitor Start NEMA, 1/2 hp, 4-pole, ODP

	Base	Plus stack	Plus 2 stack	Plus 3 stack
P.U. Cost	**1.00**	1.10	1.20	1.30
Input (Watts)	421	406	398	392
Efficiency	62.0%	64.3%	65.5%	66.5%

Polyphase Motors: Steel Grade Options

In LBNL's analyses, the lowest-loss option (M47) yields an efficiency gain of approximately five points. The NEMA average shows an increase of four points from the base motor to Grade 3.

Polyphase LBNL #3N, 1/2 hp, 4-pole, ODP

	Grade A	Grade B	Grade B^+	M47
P.U. Cost	**1.00**	1.03	1.7	1.15
Input (Watts)	361	352	347	338
Output (Watts)	267	267	267	267
Loss (Watts)	94	85	80	71
Efficiency	74.0%	75.8%	76.9%	79.0%

Polyphase LBNL #2N, 1/2 hp, 4-pole, ODP

	Grade A	Grade B	Grade B^+	M47
P.U. Cost	0.93	0.96	**1.00**	1.14
Input (Watts)	381	368	363	353
Output (Watts)	266	266	267	267
Loss (Watts)	115	102	96	86
Efficiency	70.1%	72.3%	73.5%	75.6%

Polyphase NEMA, 1/2 hp, 4-pole, ODP

	Grade 1	**Grade 2**	**Grade 3**
P.U. Cost	1.00	1.10	1.20
Input (Watts)	383	369	362
Efficiency	68.1	70.7	72.1

Polyphase LBNL #3N, 1 hp, 4-pole, ODP

	Grade A+	**Grade B$^+$**	**M47**
P.U. Cost	**1.0**	1.04	1.20
Input (Watts)	699	682	658
Output (Watts)	534	534	534
Loss (Watts)	165	148	124
Efficiency	76.4%	78.3%	81.2%

Note: Grade B yields same efficiency as Grade A+

Polyphase Motors: Stack Change Options

The efficiency gain from stack change is less than for steel grade options. For the “plus stack” option, the LBNL and NEMA analyses agree reasonably well.

Polyphase LBNL #3N, 1/2 hp, 4-pole, ODP

	Base	**Plus stack**	**Plus 2 stack**	**Plus 3 stack**
P.U. Cost	1.00	1.10	1.17	1.23
Input (Watts)	361	359	354	355
Output (Watts)	267	268	266	268
Loss (Watts)	94	91	88	87
Efficiency	74.0%	74.7%	75.1%	75.5%

Polyphase LBNL #2N, 1/2 hp, 4-pole, ODP

	Base	**Plus stack**	**Plus 2 stack**	**Plus 3 stack**
P.U. Cost	1.00	1.08	1.23	1.37
Input (Watts)	363	358	347	340
Output (Watts)	267	267	266	266
Loss (Watts)	96	91	88	87
Efficiency	73.5%	74.6%	76.6%	78.2%

Polyphase NEMA, 1/2 hp, 4-pole, ODP

	Base	Plus stack	Plus 2 stack	Plus 3 stack
P.U. Cost	1.00	1.08	1.16	1.24
Input (Watts)	361	357	353	352
Efficiency	72.2%	73.1%	73.9%	74.1%

Polyphase LBNL #3N, 1 hp, 4-pole, ODP

	Base	**Plus stack**	**Plus 2 stack**	**Plus 3 stack**
P.U. Cost	1.00	1.06	1.1	1.24
Input (Watts)	699	692	677	674
Output (Watts)	534	534	534	534
Loss (Watts)	165	158	143	140
Efficiency	76.4%	77.2%	78.9%	79.2%

4.3 Issues to Consider

Changing to a lower-loss grade of steel may involve a change in thickness. The major disadvantage of altering the thickness is that it usually requires new lamination punching dies, since these are usually optimized for a finite thickness. Standardizing on one die can cause excessive burr and slugs to stick in the dies. Most manufacturers only use one gage of steel for a particular diameter of stator.

Changing the stack length could cause the active material of the motor to exceed the mechanical package that houses the stator and rotor, hence affecting the motor interchangeability for some applications. If the motor frame is longer due to the increase in stack length, the motor may not fit on the application. If the stack is too long for a given frame, it might restrict the ventilation through the motor.

5. LIFE-CYCLE COST ANALYSIS OF DESIGN OPTIONS TO IMPROVE EFFICIENCY OF SMALL MOTORS

5.1 Method and Data

To assess the life-cycle cost to end users of designs that improve motor efficiency, we conducted an analysis that compares the additional up-front cost to the value of electricity savings. The life-cycle cost analysis compares the cost to the discounted value of electricity savings over the life of the motor. The simple payback analysis calculates the amount of time required for the electricity savings to match the incremental cost.

The analysis requires several inputs:

1. Typical utilization in terms of hours and loading
2. Typical price for the base motors (allows us to express the percentage change in per unit cost in dollar terms)
3. Typical motor lifetime;
4. Discount rate (to express the present value of future money savings)

We discuss these variables below.

Motor Utilization

The estimates of average annual hours of use, loading, and shipments for each application category (see Chapter 3) yield weighted-average values as follows:

Annual hours of use: 2500 (for both capacitor start and polyphase)
Average loading (% of rating): 70%

Price for the Base Motors

We calculated average purchase prices for the prototype motors using the following assumptions:

Channel	Distribution of sales	Purchase price (% of list)
Motor Manufacturers → OEMs	40%	38
Motor Mfrs → Distributors → OEMs	25%	47
Motor Mfrs → Distributors → End Users	35%	70

The resulting weighted average price is 51% of list. We applied this value for each motor analyzed. For the motors analyzed by LBNL, we took the list price from the 2001/02 Grainger catalog. For the data submitted by the NEMA/SMMA working group, we estimated list prices based on data in the Grainger catalog.

We assume that the full incremental cost of higher-efficiency motors is passed on to equipment buyers by the OEMs without additional markup.

Motor Lifetime

The typical lifetime of small motors in the field is not well determined. Studies at one manufacturer show that small motors have an "L10" life (defined as the point where 10% of test population has failed) under typical operating conditions of around 25,000 hours ("typical" assumes no start/stop or excessive vibration, 75° C bearing temperatures, normal mineral oil based bearing lubricants, and regular sized lubricant reservoirs).[4] For an average utilization of 2500 hours per year, that would yield a 10-year L10 life.

The life of a motor depends on a variety of factors in the service conditions of the application. These include environment (largely temperature), loading of the motor, and speed of rotation. The studies cited above have shown that bearing failure is by far the most critical factor in motor failure. In turn, the main reason for bearing failure is failure of the lubricant, mainly due to heat generation.

The three-phase integral motor in mostly three digit sizes has an average life of 11 or 12 years. While these motors have grease fittings on the bearings (per industry standards), all two-digit motors have permanently sealed bearings. This means the life of the two-digit motor is no longer than the breakdown point of the lubricant, and as a result the life of the two-digit will likely be less than the three-digit. Motor industry experts consulted suggest that the average life for two-digit motors is at most 10 years, depending of course on the usage and physical environment.

We received some input on motor lifetime from OEMs. A complicating factor is that in some cases the potential lifetime of the motor may be greater than that of the equipment. Thus, the actual motor lifetime is limited by the lifetime of the equipment. Similarly, replacement motors,

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[4] Personal communication from John Platz, FASCO Motors, Dec. 13, 2001.

which account for about one third of the market for the considered motors, may have a shorter average lifetime than motors installed in original equipment if the equipment fails sooner than anticipated.

The NEMA/SMMA small motor efficiency task force agreed with an estimated average life of 5 to 10 years for fractional motors, with the average being closer to 10 years for three-phase and to 5 years for single-phase motors. The studies mentioned earlier did not find a major difference between small single and three-phase motors, however.

Based on the above considerations, we elected to use a mean lifetime of seven years for capacitor start motors and nine years for polyphase motors.

Electricity Price

Based on expert judgement, we estimate that approximately three-fourths of capacitor start motors are used by utility customers on a commercial tariff, while most users of small polyphase motors are on an industrial tariff. We based commercial and industrial electricity prices on the average of the 2010 and 2020 forecasts from EIA's *Annual Energy Outlook 2001.* For capacitor start motors, we derived an average price giving a 0.75 weighting to the commercial price. For polyphase motors, we increased the industrial price slightly to reflect our belief that use of these motors is weighted toward smaller facilities, which would pay a higher tariff than large industrial customers.

Motor Type	Price used in the analysis (cents/kWh)
Capacitor start	5.6
Polyphase	4.0

Discount Rate

Economists recommend that the discount rate applied to relatively broad categories of investment should be set equal to the opportunity cost of the capital used to finance investments of equivalent risk. In some cases, the opportunity cost of capital is the expected return to a company stock. However, many firms use the company cost of capital as a general discount rate. The company cost of capital is a weighted average of the expected return on the company's stock and the interest rate that it pays for debt.

This approach is correct as long as the capital investment in question is typical for the company as a whole. It can be misleading, however, if the capital investment has more or much less non-diversifiable risk than the company as a whole. In general, the appropriate discount rate to evaluate low risk investments should be lower than the discount rate used to evaluate higher risk investments. In particular, the discount rate used to evaluate electricity efficiency investments, which have low risk, may be quite a bit lower than the rate used to evaluate other investments by the firm.

We assume that the ultimate investors in motor efficiency improvement are the end users of the equipment. For the small motors considered herein, the end users are broadly distributed across manufacturing and commercial sectors of the economy.

A list of companies was chosen to represent buyers of small motors (see Appendix C for details). The cost of debt, cost of equity, debt share, equity share and beta (market risk) value for these companies was obtained from the Damodaran financial data base. These data were then used to calculate the weighted average cost of capital for each company.

The weighted average cost of capital for the representative companies, after deducting for expected inflation, ranges from 4% to 11%. The average cost of capital for the companies is 6.0%. The standard deviation of the cost of capital is 1.4%.

Based on the above, we used a discount rate of 6% for assessing efficiency improvement as a typical investment.

5.2 Results for Capacitor Start-Induction Run Motor Options

Key results of the financial analysis are presented in the tables and figures below. We only present results for the most typical motors. Note that the base motors are different in the LBNL and NEMA/SMMA cases. This difference is not of much importance, however, since it is the relative change for each motor that is of most interest.

In the LBNL analysis, the steel grade options all have lower LCC than the base motor. Results using the NEMA average data show an increase in LCC, however.

The LBNL analysis shows the stack length options increasing the LCC. The NEMA results show a slight decrease for the first option, but then increase.

The difference in results for the two design options reflects the varying situation of different manufacturers. Some are able to improve efficiency at lower cost using change of steel grade, while others can do so better using stack change.

Table 5.1 Impacts of Efficiency Improvement on Typical End User, Capacitor Start 1/2 hp, LBNL Data

	Steel Grade				Stack Change		
	Grade A (Base)	**Grade B**	**Grade B+**	**M47**	**Plus Stack**	**Plus 2 Stack**	**Plus 3 Stack**
Motor Price–Buyer	$91	$94	$100	$114	$97	$105	$111
Annual Operating Cost	$58	$55	$54	$52	$57	$56	$56
Life-Cycle Cost (7% DR)	$414	$403	$403	$407	$416	$418	$422
Change in LCC (WRT Base)		-$11.21	-$11.02	-$7.43	$1.73	$4.37	$7.65
Percent Change in LCC		-2.7%	-2.7%	-1.8%	0.4%	1.1%	$1.8%
Payback Period (years)		1.1	2.5	4.2	7.7	8.2	9.0

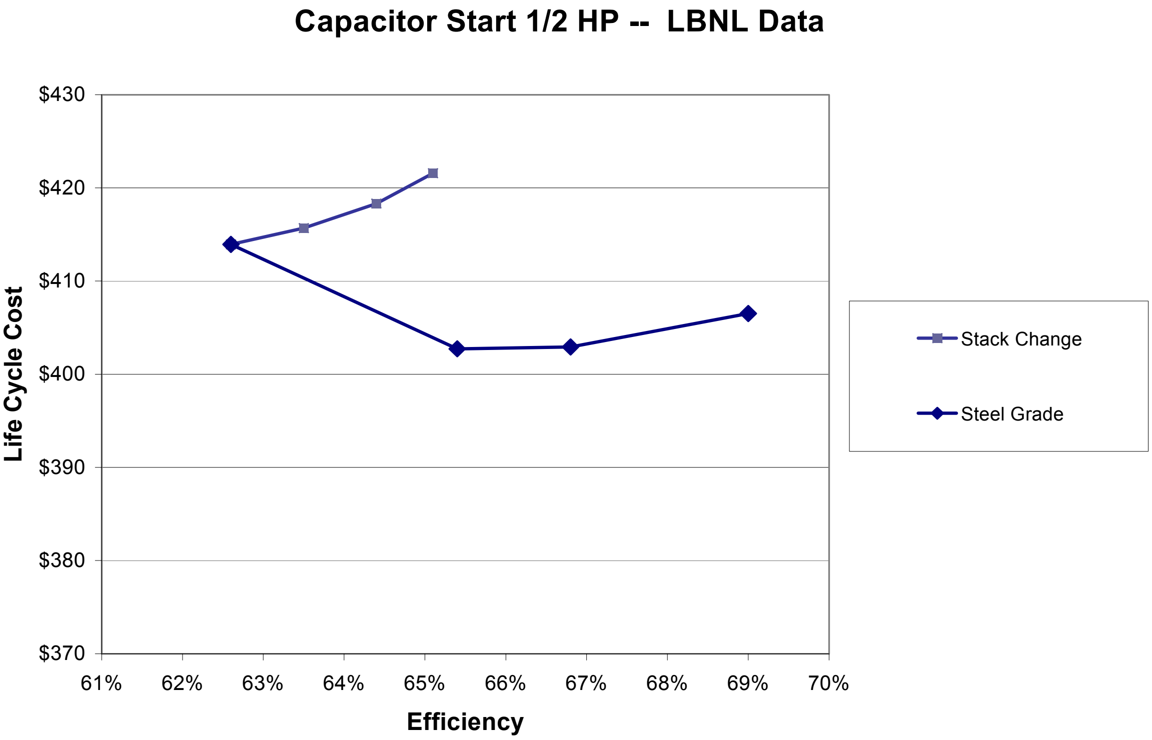
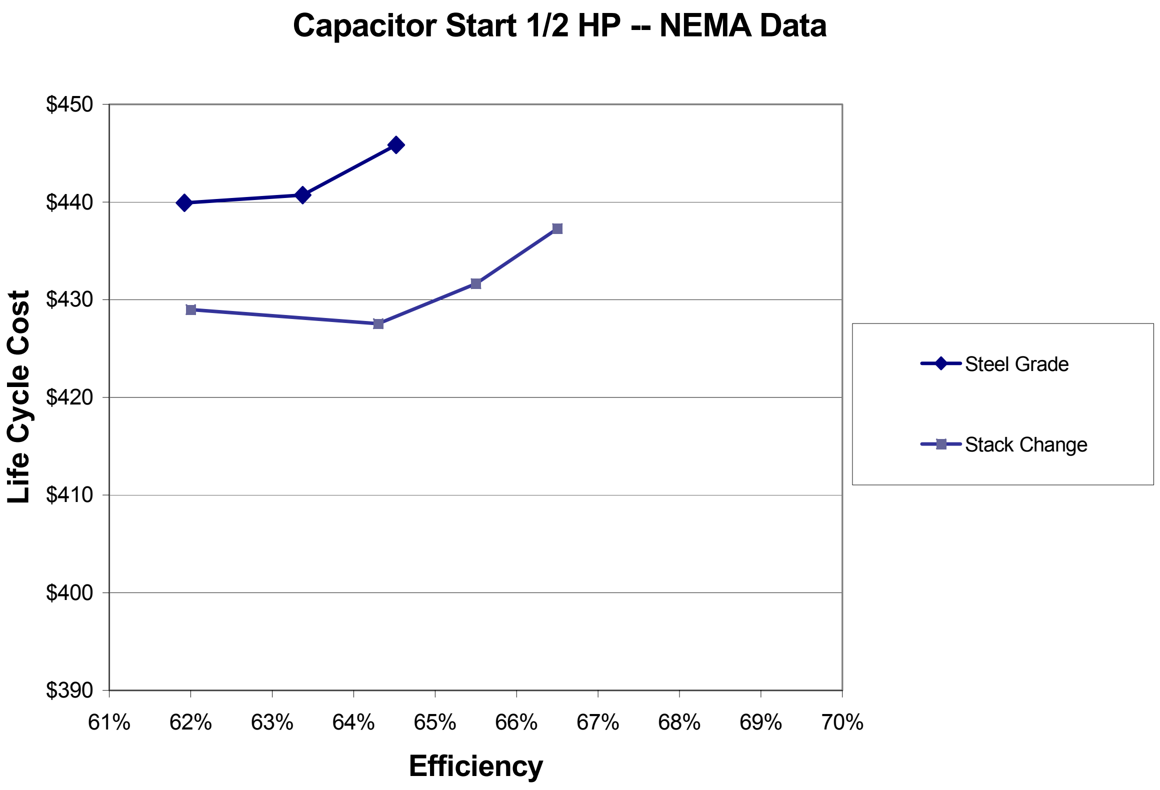


Table 5.2 Impacts of Efficiency Improvement on Typical End User, Capacitor Start 1/2 hp, NEMA Data

	Steel Grade*			**Stack Change****			
	Grade 1 (Base)	**Grade 2**	**Grade 3**	**Base**	**Plus Stack**	**Plus 2 Stack**	**Plus 3 Stack**
Motor Price—Buyer***	$103	$113	$125	$103	$113	$123	$134
Annual Operating Cost	$60	$59	$58	$58	$56	$55	$54
Life cycle Cost (7% DR)	$440	$441	$446	$429	$428	$432	$437
Change in LCC (WRT Base)		$0.80	$5.93		-$1.42	$2.67	$8.32
Percent Change in LCC		0.2%	1.3%		-0.3%	0.6%	1.9%
Payback Period (years)		6.1	7.7		4.9	6.5	

* Data are average of four manufacturers
** Data reflect typical costs and performance
*** Estimated by LBNL



5.3 Results for Polyphase Motor Options

Key results of the financial analysis for the most typical motors are presented in the tables below. We only present results for the most typical motors. Note that the base motors are different in the LBNL and NEMA/SMMA analyses.

In the LBNL analysis, the steel grade options all have lower LCC than the base motor. The NEMA average results show an increase in LCC, however. In both analyses, the stack length options increase the LCC relative to the base motors.

Table 5.3 Impacts of Efficiency Improvement on Typical End User, Polyphase 1 hp, LBNL Data

	Steel Grade			**Stack Change**		
	Grade A+ (Base)	**Grade B+**	**M47**	**Plus Stack**	**Plus 2 Stack**	**Plus 3 Stack**
Motor Price–Buyer	$105	$109	$126	$111	$124	$130
Annual Operating Cost	$71	$69	$66	$70	$68	$68
Life cycle Cost (7% DR)	$585	$578	$578	$587	$589	$593
Change in LCC (WRT Base)		-$7.49	-$7.19	$1.49	$3.77	$8.01
Percent Change in LCC		-1.3%	-1.2%	0.3%	0.6%	1.4%
Payback Period (years)		2.4	5.1	8.9	8.5	

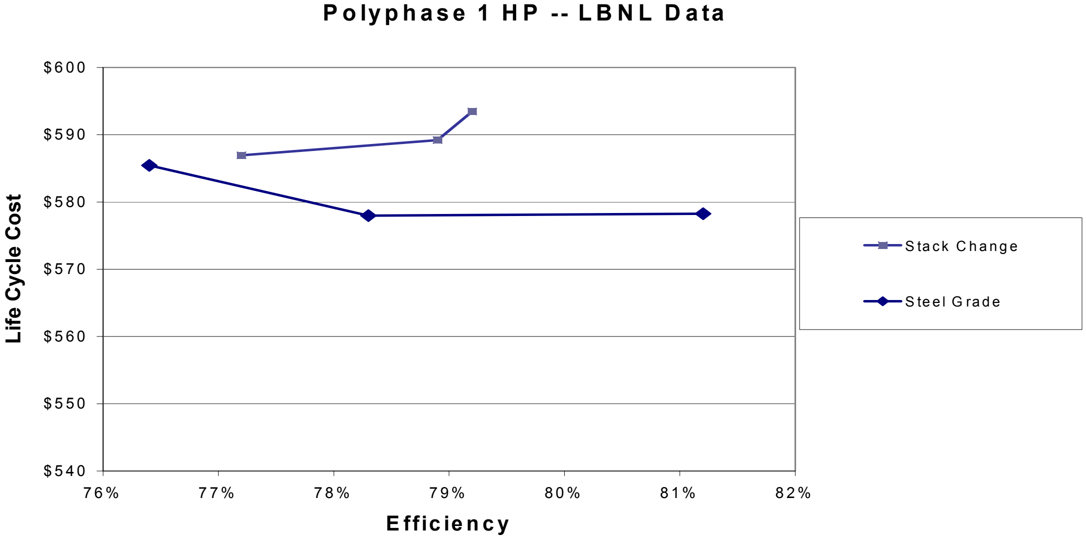


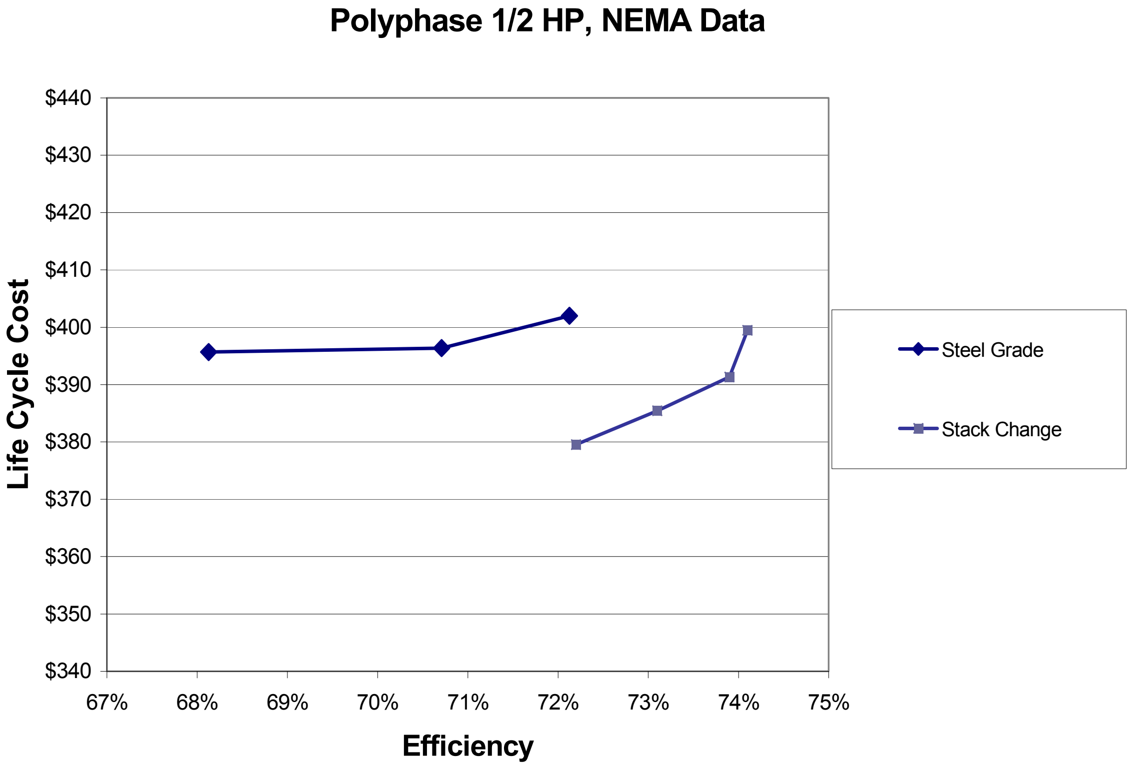
Table 5.4 Impacts of Efficiency Improvement on Typical End User, Polyphase 1/2 hp, NEMA Data

	Steel Grade*			Stack Change**			
	Grade 1 (Base)	**Grade 2**	**Grade 3**	**Base**	**Plus Stack**	**Plus 2 Stack**	**Plus 3 Stack**
Motor Price—Buyer***	110.6	121.7	132.7	111.0	119.9	128.8	137.6
Annual Operating Cost	$38.7	$37.3	$36.6	$36.5	$36.1	$35.7	$35.6
Life cycle Cost (7% DR)	$396	$396	$402	$380	$385	$391	$399
Change in LCC (WRT Base)		$0.65	$6.32		$5.90	$11.81	$19.95
Percent Change in LCC		0.2%	1.6%		1.6%	3.1%	5.3%
Payback Period (years)		7.8	10.3		22.0	22.0	

* Data are average of four manufacturers

** Data reflect typical costs and performance

*** Estimated by LBNL



6. POTENTIAL NATIONAL ENERGY AND CONSUMER IMPACTS OF ENERGY CONSERVATION STANDARDS FOR SMALL MOTORS

6.1 Method

In each product class, we used the average size motor as the basis for the estimation of national impacts:

Capacitor start motors	1/2 hp
Polyphase motors	1 hp

We used the results of the LBNL and manufacturers' engineering analyses (Chapter 4) as the basis for national energy savings estimates. For polyphase motors, however, we only used the LBNL results, as the manufacturers' analysis was based on a 1/2 hp motor. (The manufacturers' analysis shows some efficiency gains, but with an increase in life-cycle cost.) For each design option, the estimated savings are relative to the Base Case.

We believe that the motors analyzed (open drip-proof, four-pole) serve as reasonable proxies for enclosed motors and two- and six-pole motors. We would expect, however, that an analysis that developed separate estimates for four, two, and six-pole motors would show somewhat different results, as would one that made discrete estimates for different hp ratings.

A simplifying assumption in the calculation is that each level of energy efficiency improvement reflects an average attained by all new motors sold in each considered year. Thus, if a standard were set at a specific level of energy efficiency improvement, the savings attributable to the standard are a function of the difference in efficiency relative to the Base Case motor.

We assume standards take effect in 2010. We calculate impacts for motors sold in the 2010-2030 period.

The accounting model calculates total end-use electricity savings in each year with surviving motors (some of the motors sold in 2030 operate through 2040). The model uses a product retirement function to calculate the number of units in a given vintage that are still in operation in a given year. The retirement function assumes that individual motor lifetime is normally distributed around the mean lifetime.

We calculated primary energy savings associated with end-use electricity savings using data from EIA's *Annual Energy Outlook 2001*. These data yield an average multiplier for end-use electricity to primary energy (power plant consumption) for each year for 2010-2020. We extrapolated the 2010-2020 trend for the 2021-2040 period.

For assessing direct economic impacts on end users, we used the incremental equipment costs for each energy efficiency improvement level presented in Chapter 5. We assumed that the current estimated incremental costs remain the same in the 2010-2030 period of motor sales. In addition, we assume that electricity prices remain at the projected 2010-2020 average through 2040.

We discounted future costs and benefits using a rate of 7%, in keeping with "Guidelines and Discount Rates for Benefit-Cost Analysis of Federal Programs" issued by the Office of Management and Budget in 1992 (Circular No. A-94, Revised). This rate approximates the marginal pretax rate of return on an average investment in the private sector in recent years.

Projection of Future Shipments

As discussed in Chapter 3, the past growth in annual shipments of the considered motors (including imported motors) is not known, but NEMA did provide confidential data on two-digit frame size fractional horsepower motor sales to domestic customers by NEMA manufacturers, covering the period from 1971 to 2001. After smoothing the data, the average annual growth rate is 1.5%. Although the motors being analyzed make up only around 20% of the motors covered by these data, as an approximation it may be reasonable to assume that growth in sales of the considered motors was similar to that of all fractional motors.

Several factors suggest that the growth in future sales may be slower than in the past. At a basic level, U.S. economic growth is expected to be slightly slower than that in the 1970-2000 period. Second, continuation of the current trend toward greater use of definite-purpose small motors would mean that sales of the general-purpose motors considered in this analysis would increase more slowly. Finally, foreign manufacturers of end-use equipment incorporating considered small motors may have lower production costs sufficient to gain market share at the expense of U.S.-based manufacturers, which would reduce U.S. domestic demand for small motors.

Based on the above considerations, we estimated impacts for two scenarios of average annual growth in shipments in the 2010-2030 period: one with 1% and the other with 1.5%.

Base Case Efficiencies

Judging what might occur to small motor efficiency in the future in the absence of any standards is perhaps the most difficult element of our analysis. Apart from the usual problem of estimating future market behavior, we have only limited knowledge regarding the past trend in efficiency. The perspective of the NEMA/SMMA working group and other motor industry experts we consulted is that the past 20-30 years have seen "very little to moderate" improvement in efficiency. Some gains occurred in the 1970s as electricity prices rose, and there has also been some spillover into small motors from efficiency improvement in integral horsepower motors. A number of manufacturers have introduced "premium efficiency" small polyphase motors. In the case of capacitor-start motors, there has been some growth in use of more efficient capacitor-run models, which to some extent had lessened the need to improve the more common induction-run models.

Current expectations for future commercial and industrial electricity prices show a slight declining trend in the long run. While customer interest in efficiency of small motors may continue to be limited, manufacturers may use performance (which includes efficiency) as a selling point to gain advantage in a competitive market. In sum, it seems reasonable that a lower bound case for future efficiency would envision very little improvement, while an upper bound case would envision moderate gains.

We expressed the above qualitative cases into actual numbers as follows. In the Low Efficiency Improvement base case, the average efficiency of motors sold in the 2010-2030 period is ¼ point better than the current base case motors (e.g., 62.25% compared to 62%). In the Moderate Efficiency Improvement base case, the average efficiency is 1 point better than the current base case motors. In both cases, we assume that there would be gradual change over the period.

6.2 Estimates of Potential Energy and Consumer Impacts

Capacitor Start Motors

For options with positive NPV, the cumulative energy savings, based on the LBNL analysis of steel grade change, range from a low of 0.6 quad to a high of 1 quad (Figure 6-1). The corresponding cumulative NPV range is $0.6 billion to just over $1 billion. None of the stack change options have positive NPV.

Using the NEMA average data, we see positive NPV only in a few instances (Figure 6-2). In the most favorable case (Low Efficiency Improvement base case, High Shipments Growth), there are savings of 0.6 quad with an NPV of just under $0.1 billion (plus 2 stack option).

Polyphase Motors

The LBNL analysis shows cumulative energy savings from steel grade change ranging from a low of 0.15 quad to a high of 0.21 quad (Figure 6-3). The corresponding cumulative NPV range is $0.09 billion to $0.27 billion. The stack change options generally do not show positive NPV.

Use of the NEMA average data for 1/2 hp motors would show lower savings than the above.

Figure 6-1 Capacitor Start Motors, National Energy and Consumer Impacts, LBNL Analysis

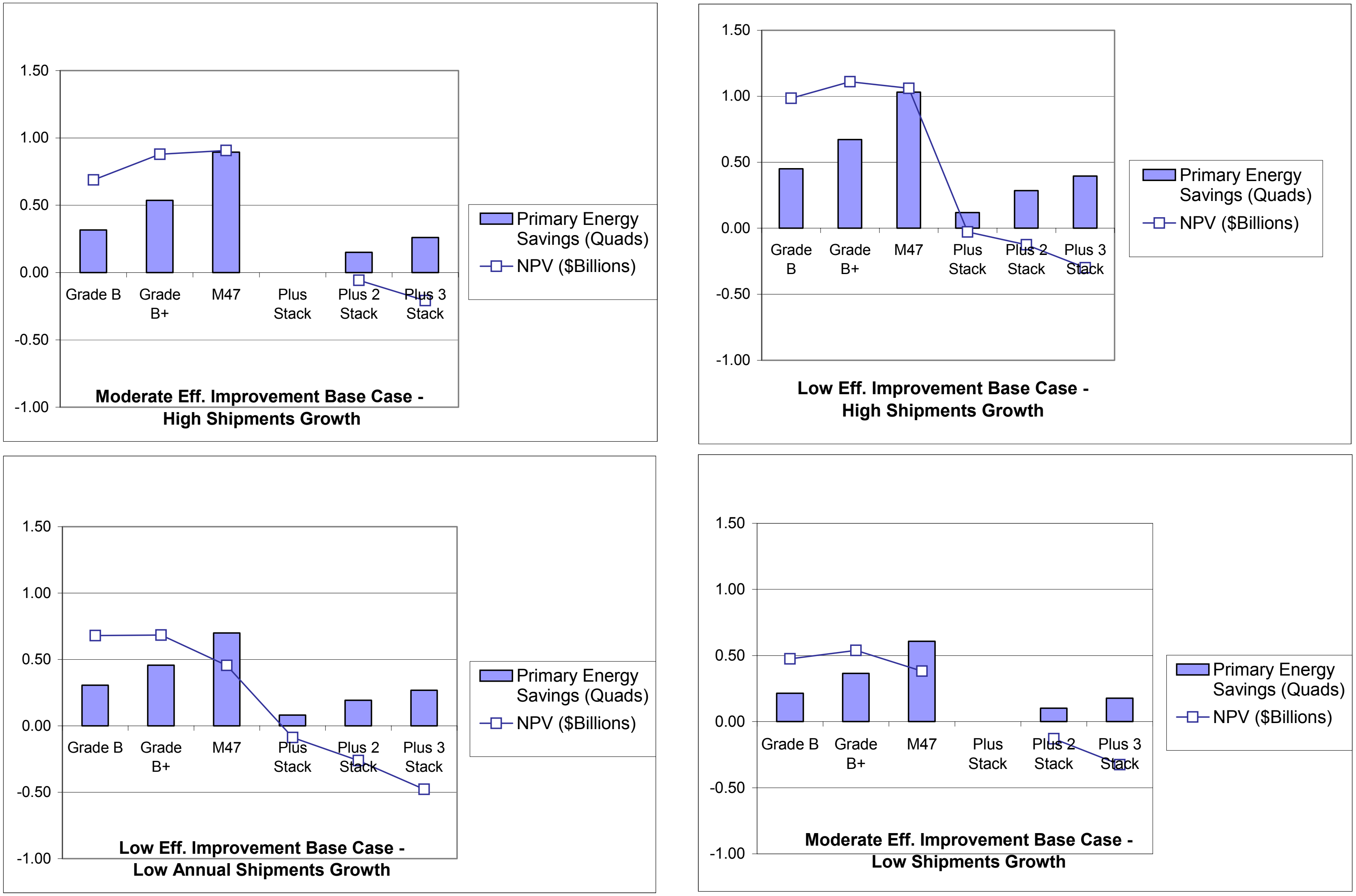
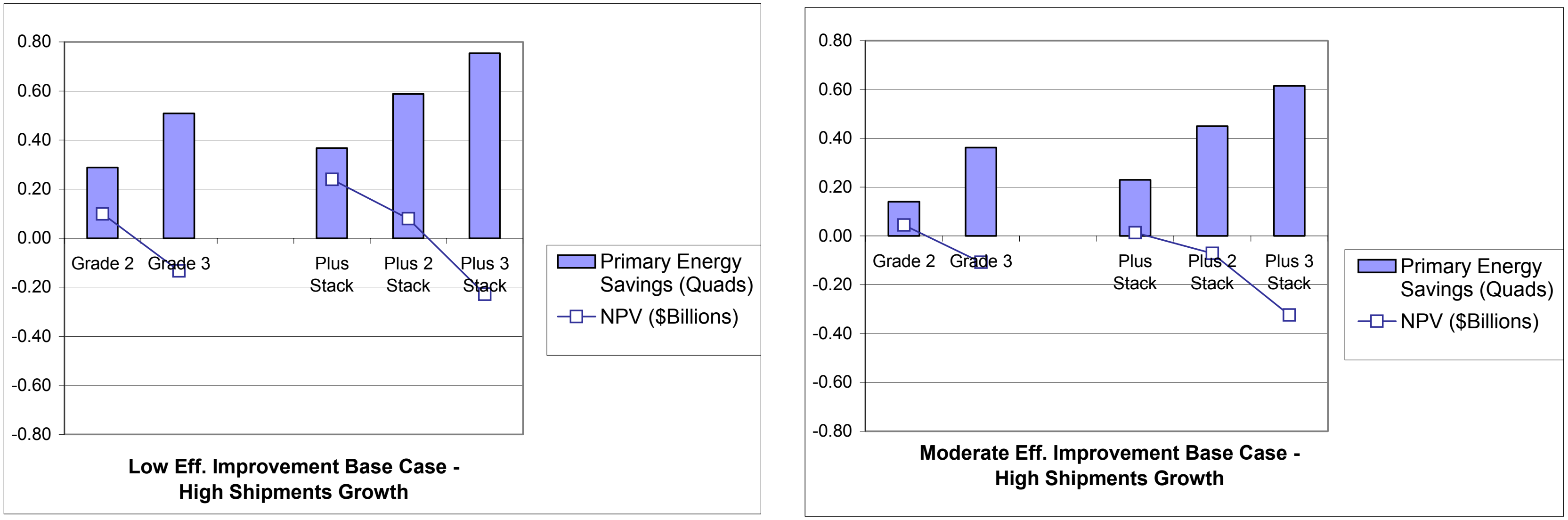
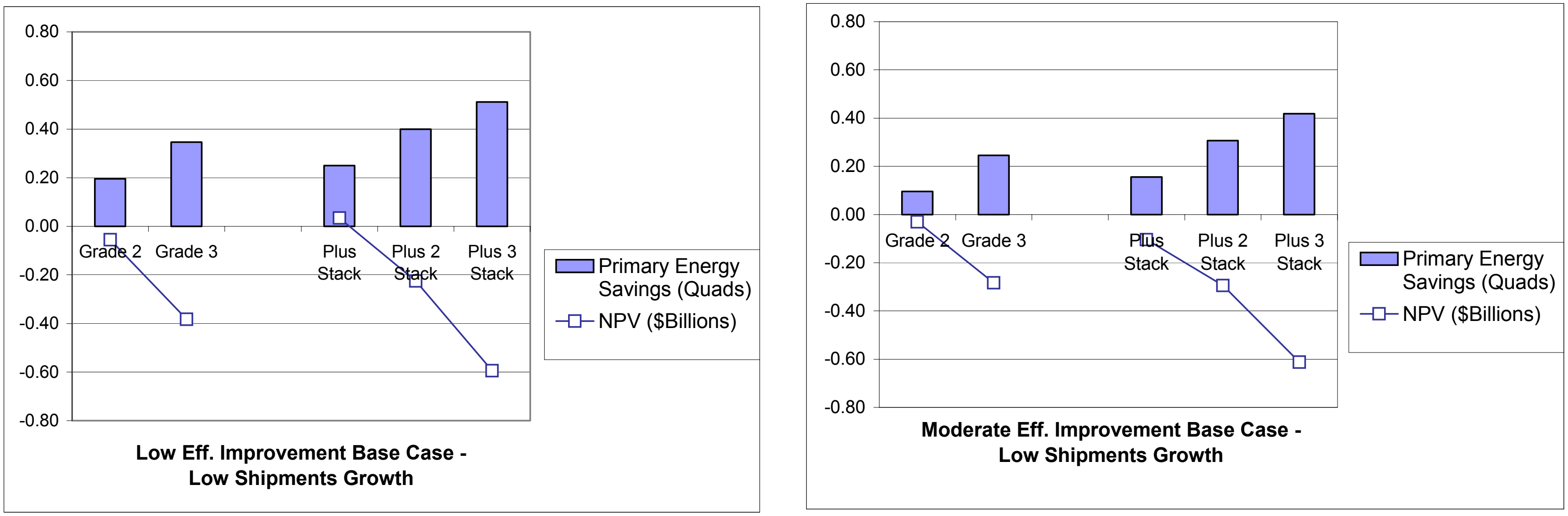


Figure 6-2 Capacitor Start Motors, National Energy and Consumer Impacts, NEMA Data



Low Eff. Improvement Base Case - High Shipments Growth

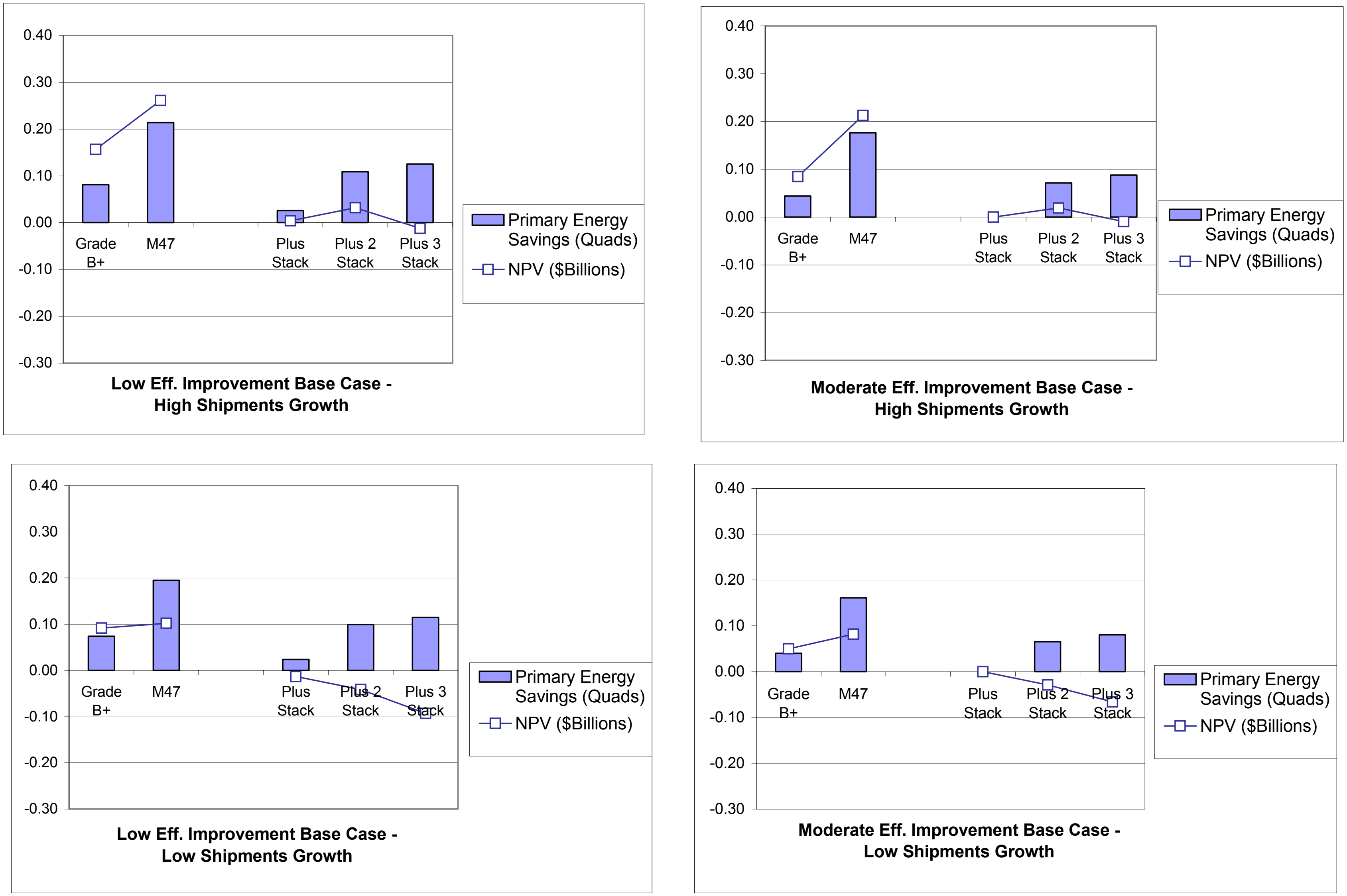
Moderate Eff. Improvement Base Case - High Shipments Growth



Low Eff. Improvement Base Case - Low Shipments Growth

Moderate Eff. Improvement Base Case - Low Shipments Growth

Figure 6-3 Polyphase Motors, National Energy and Consumer Impacts, LBNL Analysis



7. CONCLUSION

The objective of this study was to determine whether energy conservation standards for small electric motors would be technically feasible, be economically justified, and have the potential for significant energy savings.

Standards established at levels that correspond with the efficiency-enhancing design options considered in this study would be technically feasible. Because of differences between LBNL and motor manufacturers with respect to estimates of the efficiency and cost increase associated with the options, it is difficult to accurately determine whether or not standards would be economically justified, and have the potential for significant energy savings.

The best case for positive economic impact and significant energy savings can be made for capacitor start-induction run motors. The analysis of design options conducted by LBNL shows potential cumulative energy savings from steel grade change ranging from from 0.6 to 1 quad. The corresponding cumulative NPV range is $0.6 billion to just over $1 billion. However, the average data provided by the NEMA/SMMA working group indicate lower potential energy savings and positive economic impacts. The best cost-effective case shows energy savings of 0.6 quads, while in the worst case the options are not cost-effective.

The LBNL and NEMA/SMMA data are in reasonably close agreement with respect to the stack change design option. Projected impacts with the NEMA/SMMA data are actually more favorable than with the LBNL data, though the cumulative savings are low.

For steel grade change, however, the data are not in good agreement. We were not able to analyze the reasons for the differences between the LBNL and NEMA/SMMA data, as the NEMA/SMMA working group did not wish to share details of the calculations performed by the four companies that submitted data. At the request of the group, we used the average values for the four companies, though we have concerns that some of the data may not be representative of typical motors on the market. The NEMA/SMMA working group felt, however, that it would be inappropriate to exclude any of the submissions.

Based on the limited information available, we believe that the best estimate of potential impacts would lie somewhere between the LBNL and NEMA/SMMA results. Better resolution of the uncertainty would require both more information from the NEMA/SMMA group and good estimates of the market shares of the major manufacturers for the considered motors. The former would help us evaluate the individual data submissions by the companies, while the latter would allow us to better weight the data according to the market share of each manufacturer.

APPENDIX A INFORMATION COLLECTION PROCESS ON USE OF SMALL MOTORS

Small motors are used in a variety of equipment. Easton Consultants identified 14 NAICA categories (industries) and over 45 categories of equipment that use small motors as defined. These include such diverse types of equipment as farm milking machines, industrial pumps, packaging machines, and machine tools.

The information collected for each category included the following three types:

Type 1 – Usage information

- Horsepower range
- Average horsepower
- Average hours of use
- Qualitative information on specific applications (e.g. ambient conditions)
- Estimate of typical motor loading
- Other application specific information.

Type 2 – Motor selection information

- Information on motor purchasing practices and procedures by OEMs who use considered motors in their products.
- The degree to which changes in motor size related to improved efficiency may be incompatible with equipment designs used by OEMs.
- The degree to which motor efficiency is a significant consideration for OEMs
- Other selection related information.

Type 3 – Quantitative (shipments) information

- Annual shipments of each considered motor type (cap-start and polyphase) for each NAICA category.

We used an information collection process that followed a sequence of steps moving from general sources to specific as needed. We proceeded step-by-step for each of the 14 categories as follows:

- **Step 1 –In-house expertise.** We started with our expertise on each of the categories from past projects. We assembled this information as the starting point.
- **Step 2 --Industry associations**. We contacted the association or associations servicing each of the categories for general information on the industry, important players, industry characteristics and trends, and motor use.
- **Step 3 --Industry literature search.** We conducted a review of the relevant trade magazines and reports available publicly for relevant motor-related information on motor selection and use.

- **Step 4 --Company information review**. We explored the information available on one or two leading motor-using company web sites (particularly product specifications), requesting specs from the sales department where not available on the web.
- **Step 5 --Expert assistance**. We worked with a former director of market research of a motor manufacturer who has extensive industry background to extend our expertise. His inputs and review were added to our information.
- **Step 6 --Direct motor-using company informal discussion**. After the above sources had been fully utilized we conducted a series of informal phone conversations with equipment designers and engineers in each of the sectors. These were informal, were designed to collect the specific information needed, and varied for each NAICA category depending on the specifics of what was needed for that category.

  In these interviews we discussed:
  - Types of motors used in the particular equipment to identify the approximate proportion of all motors that are considered motors
  - Sizes of motors used
  - Typical hours of operation of the motors
  - Motor loading against its rated horsepower
  - Role of energy efficiency in the decision and the rationale
  - Health of the industry
  - Technical changes expected that would affect motor use
  - Typical life of the motor in this equipment's service
  - Other related subjects

APPENDIX B METHOD FOR ESTIMATING CONSIDERED SMALL MOTORS SHIPMENTS BY INDUSTRY SECTOR

As part of the effort to support the LBNL project, "Development of Application Information for General Purpose Small Electric Motors Considered for Efficiency Standards", Easton Consultants conducted an analysis to estimate the shipments of considered small motors to each of 14 industry segments.

There is no single source that provides a measurement of the shipments of considered motors in the principal industries of use. As a result we had to rely on a variety of sources of information, each one of which provided only a piece of the puzzle. By integrating all of those available and then applying judgment, we have developed a reliable "first cut" estimate. The cornerstone to the estimates was first hand research with a number of manufacturers of small motor-using equipment.

The data sources used included the following:

1. Discussion with four to ten equipment OEMs (product designers, engineers) in each of the small-motor using equipment industries.
2. Survey of the small motors manufacturers conducted by NEMA to measure the total shipments of considered motors.
3. The Census of Manufacturers (1997), which measures equipment shipments and certain component usage by each of the principal small motor using industries
4. Industry associations that cover the principal small motor using industries.
5. Catalogs of equipment using small motors.
6. Expert counsel from an individual who was formerly a market research manager with a leading motor manufacturer.
7. Past Easton projects on small motor use, particularly the 1995 project conducted for LBNL.

In the chart below we have defined the role of each source of information in making the estimates.

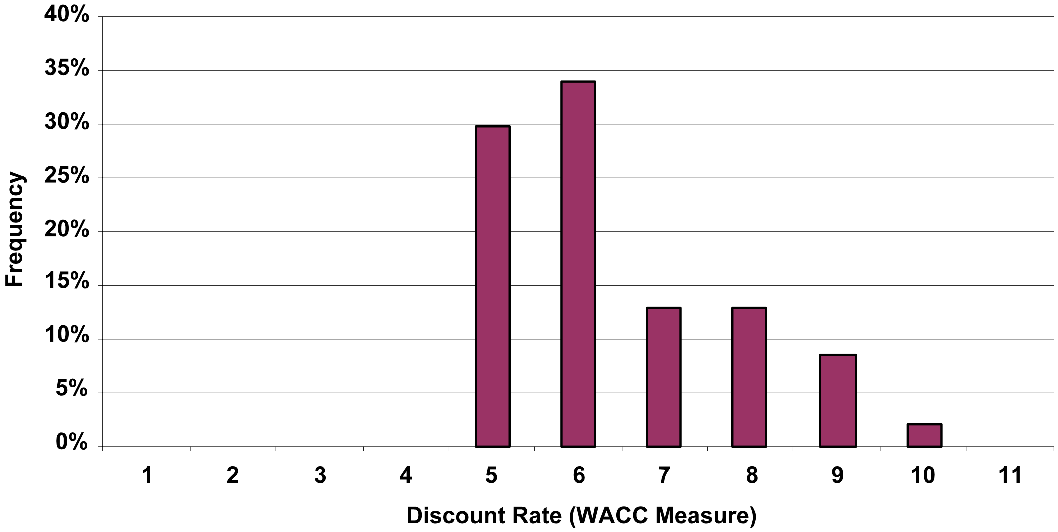
Information Source	**Description**	**Principal Value**	**Limitations**	**Importance of Source**
OEM Interviews	Discussions with manufacturers of small motor using equipment	First hand inputs from engineers and designers who make the motor selection decisions in the user industries	The sample of OEMs was necessarily a small sample of the many companies using small motors.	Very High
NEMA Survey	Survey of principal small motors manufacturers	Provided a reliable measure of the total number of considered small motor shipments by size and type	Did not provide any information on the equipment in which the motors are used	High
Census of Manufacturers (1997)	Survey of U.S. Manufacturers	(1) Shipments of motor using equipment	Difficult in most cases to match equipment definitions with motor type	Low
		(2) Shipments of small motors to each industry	Data given for all shipments; considered motors not broken out.	High
Industry Associations	Organizations supporting industrial sectors	Information on sector structure (e.g. major companies), trends, economic health,	Most information could not be tied directly to motor use	Low
Equipment catalogs	Equipment descriptions for sales purposes	Often explicit as to the type and size of motors used	Most catalogs do not provide motor use information; only a few were useful	Low
Expert counsel	Review by an experienced market research head formerly with a motor manufacturer	“Reality check” on estimates	Motor manufacturers do not have good information on where small motors are used	Medium
Past Easton Reports	Easton files on small motor use from past projects	A variety of information, esp. from the 1995 report on small motors	Information generally dated	Medium

APPENDIX C. SMALL MOTORS DISCOUNT RATE CALCULATIONS

A list of companies was chosen to represent buyers of considered small motors. The cost of debt, cost of equity, debt share, equity share and beta (market risk) value for these companies was obtained from the Damodaran web site financial data base (Table C-1).[1] These data were then used to calculate the weighted average cost of capital for each company. The weighted average cost of capital of companies is a common measure of the discount rate appropriate for evaluating typical company investments.

The weighted average cost of capital for the list of representative companies ranges from 4% to 11% (Figure 1). The average cost of capital, after deducting for expected inflation, is 6.0%. The standard deviation of the cost of capital is 1.4%.

Figure 1. Distribution of Discount Rates for the Small Motors Analysis



The sample of companies included for this analysis included heavy manufacturing (43%), large commercial (retail, grocery and real estate) (40%) and water agency and agricultural companies (17%).

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[1] Aswath Damodaran web site. This site is hosted at New York University Stern Business School. The site includes a data base with financial information covering over 7,000 companies representing different economic sectors of the economy. http://www.stern.nyu.edu/~adamodar/New_Home_Page/data.html

Table C-1. Cost of Capital of Representative Firms Purchasing Small Motors

Company Name	**Industry Name**	**Company Beta (1)**	**Cost Equity (2)**	**We (3)**	**Cost Debt (4)**	**Wd (5)**	**WACC (6)**	**WACC-no inflation (7)**
Manufacturing Firms								
Ivanhoe Energy Inc	Petroleum (Producing)	0.7	9.35%	100%	9.00%	0.22%	9.35%	6.9%
Caledonia Mining Corpor	Metals & Mining (Div.)	0.35	7.43%	100%	9.00%	0.00%	7.43%	5.0%
Kaiser Alum.	Metals & Mining (Div.)	0.95	10.73%	11%	8.00%	88.52%	8.31%	5.9%
Coeur d'Alene Mines	Gold/Silver Mining	0.50	8.25%	15%	9.00%	84.76%	8.89%	6.4%
Hecla Mining	Gold/Silver Mining	0.40	7.70%	51%	9.00%	49.01%	8.34%	5.9%
Brigham Exploration Co	Petroleum (Producing)	1.00	11.00%	36%	9.00%	63.76%	9.72%	7.3%
Enbridge Inc.	Petroleum (Producing)	0.55	8.53%	52%	6.00%	48.13%	7.31%	4.9%
Exploration Co	Petroleum (Producing)	0.80	9.90%	97%	9.00%	3.18%	9.87%	7.4%
Intrawest Corporation	Homebuilding	0.75	9.63%	53%	5.72%	46.61%	7.81%	5.4%
ConAgra Foods	Food Processing	0.70	9.35%	65%	4.02%	34.73%	7.50%	5.1%
Kellogg	Food Processing	0.60	8.80%	86%	4.44%	14.50%	8.17%	5.7%
Boise Cascade	Paper & Forest Product	1.20	12.10%	50%	3.55%	49.92%	7.83%	5.4%
Louisiana-Pacific	Paper & Forest Product	1.00	11.00%	41%	4.89%	59.26%	7.38%	5.0%
Dow Chemical	Chemical (Basic)	1.00	11.00%	83%	4.27%	17.47%	9.82%	7.4%
ChemFirst Inc.	Chemical (Diversified)	0.80	9.90%	87%	3.91%	12.83%	9.13%	6.7%
Goodyear Tire	Tire & Rubber	1.15	11.83%	52%	5.33%	48.31%	8.69%	6.2%
Bayou Steel	Steel (General)	0.75	9.63%	4%	7.00%	96.28%	7.10%	4.7%
Thomas & Betts	Electrical Equipment	1.10	11.55%	64%	7.00%	35.54%	9.93%	7.5%
Overseas Shipholding	Maritime	0.80	9.90%	48%	4.53%	51.95%	7.11%	4.7%
Northwest Airlines 'A'	Air Transport	1.35	12.93%	26%	4.71%	74.14%	6.83%	4.4%
Commercial Firms								
Costco Wholesale	Retail Store	1.30	12.65%	95%	4.20%	5.03%	12.22%	9.7%
Kmart Corp.	Retail Store	1.15	11.83%	46%	5.35%	54.47%	8.30%	5.9%
Neiman Marcus	Retail Store	1.25	12.38%	86%	4.34%	14.47%	11.21%	8.7%
Penney (J.C.)	Retail Store	1.10	11.55%	55%	5.47%	45.28%	8.80%	6.4%
Target Corp.	Retail Store	1.30	12.65%	84%	4.00%	15.75%	11.29%	8.8%
Wal-Mart Stores	Retail Store	1.15	11.83%	92%	4.13%	7.93%	11.21%	8.7%
Toys 'R' Us	Retail (Special Lines)	1.20	12.10%	71%	5.70%	29.29%	10.23%	7.7%
Safeway Inc.	Grocery	0.75	9.63%	76%	3.80%	23.68%	8.25%	5.8%
Smart & Final	Grocery	0.80	9.90%	69%	4.00%	31.21%	8.06%	5.6%
Village Super Market 'A'	Grocery	0.55	8.53%	61%	4.01%	38.84%	6.77%	4.4%
Whole Foods Market	Grocery	1.10	11.55%	89%	4.43%	11.40%	10.74%	8.2%
Winn-Dixie Stores	Grocery	0.75	9.63%	73%	4.92%	26.82%	8.36%	5.9%
Security Cap Group Inc	R.E.I.T.	0.50	8.25%	99%	4.72%	0.98%	8.22%	5.8%
Rouse Co.	R.E.I.T.	0.65	9.08%	39%	5.96%	60.94%	7.18%	4.8%
Bedford Ppty Invs	R.E.I.T.	0.55	8.53%	56%	5.75%	44.19%	7.30%	4.9%
HMG Courtland Prop	R.E.I.T.	0.40	7.70%	44%	8.00%	56.21%	7.87%	5.4%
Health Care Property	R.E.I.T.	0.55	8.53%	61%	5.75%	38.89%	7.45%	5.0%
Bedford Ppty Invs	R.E.I.T.	0.55	8.53%	56%	5.75%	44.19%	7.30%	4.9%
Catellus Development	R.E.I.T.	0.90	10.45%	62%	3.58%	38.40%	7.81%	5.4%
Agricultural Firms								
ML Macadamia Orchards LI	Food Processing	0.6	8.80%	82%	6.25%	17.59%	8.35%	5.9%
Sylvan Inc.	Food Processing	0.5	8.25%	61%	5.04%	39.05%	7.00%	4.6%
Tejon Ranch Co.	Food Processing	0.8	9.90%	89%	6.50%	11.33%	9.51%	7.1%
Chiquita Brands Int'l	Food Processing	0.4	7.70%	3%	9.00%	96.66%	8.96%	6.5%
Water Utilities								
Amer. Water Works	Water Utility	0.5	8.25%	60%	3.93%	40.49%	6.50%	4.1%
California Water	Water Utility	0.6	8.80%	66%	3.61%	34.43%	7.01%	4.6%
Middlesex Water	Water Utility	0.45	7.98%	66%	4.18%	33.51%	6.70%	4.3%
Southwest Water	Water Utility	0.45	7.98%	72%	4.09%	28.20%	6.88%	4.5%
Group Averages		0.79	9.9%	62.4%	5.6%	37.6%	8.4%	6.0%

Source:

1. Damodaran data base. Covariance between company return and stock market return.
2. Risk free bond rate (5.5%) plus company beta times the expected return on common stocks minus the risk free bond rate (5.5%).
3. Damodaran data base. Proportion of equity in company financial position.
4. Damodaran data base. After tax interest paid on debt.
5. Damodaran data base. Proportion of debt in company financial position.
6. WACC. Cost of equity times the proportion of equity (We) plus the cost of debt times the proportion of debt (Wd).
7. Inflation rate is 2.3%.