# 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 |
| EPCA | Energy Policy and Conservation Act |
| hp | Horsepower |
| HVAC | Heating, ventilation, and air conditioning |
| LBNL | Lawrence Berkeley National Laboratory |
| LCC | Life-cycle cost |
| NAICS | North American Industry Classification System |
| NEMA | National Electrical Manufacturers Association |
| NPV | Net present value |
| ODP | Open dripproof |
| OEMs | Original equipment manufacturers |
| quad | One quadrillion ($10^{15}$) British thermal units (Btu) or 293.1 billion kilowatt hours |
| SMMA | Small Motor and Motion Association |

# EXECUTIVE SUMMARY

## Purpose

Under 346(b)(1) of the Energy Policy and Conservation Act (EPCA) (42 U.S.C. 6317(b)(1)) the Department of Energy (DOE or Department) may determine whether energy conservation standards for certain small electric motors would be technologically feasible, economically justified, and would result in significant energy savings. In order to have a basis for a determination, the Department performed this analysis.

## Scope of Motors Analyzed

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 sizes 42, 48 and 56. The horsepower ratings for the two-digit frame series range from 1/4 to 3 horsepower. These motors operate at 60 Hertz and have either a single-phase or a three-phase (polyphase) electrical design. 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.

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. Hence, the analysis covers only these types of small motors. Market research indicates that the annual commercial sales volume of CSIR, CSCR and polyphase small motors meeting the EPCA definition is approximately 4 million units for capacitor start and 1 million units for polyphase designs. These motors are used in a wide variety of commercial and industrial applications, with the largest being pumping equipment and commercial/industrial heating, ventilating, air conditioning equipment rated over 240,000 Btu/h.

## Methodology

The analysis methodology consisted of five major elements: (1) Market research to better understand how small motors are used; (2) engineering analysis to estimate how different design options affect efficiency and cost; (3) life-cycle cost analysis to estimate the costs and benefits to users from increased efficiency in small motors; (4) national energy savings analysis to estimate the potential energy savings on a national scale; and (5) national consumer impacts analysis to estimate potential direct economic costs and benefits that would result from energy efficient small motors. Actual testing of sample motors was conducted. In conducting the engineering and life-cycle cost analyses, the Department utilized two sets of data. The first set derived from

motor testing and design costing conducted by an independent motor industry expert in consultation with a working group comprised of major manufacturers of small motors. The methodology used is similar to methods commonly used by motor manufacturers. The second set of data was submitted by the aforementioned working group.

**Summary of Results**

Energy efficiency-enhancing design options considered in this study have the energy savings potential described below. Differences in estimates of the efficiency and cost increase associated with the options and uncertainty about future shipments and efficiency trends produce a range of estimates for economic impacts for the considered motors.

Capacitor-start, induction-run motors. The analysis based on DOE's motor testing and costing shows potential cumulative energy savings from motor efficiency improvement ranging from 0.6 to one quadrillion British thermal units (quad) of energy over the period 2010 to 2040. The corresponding cumulative economic benefit for consumers, expressed in terms of net present value of benefits (NPV) ranges from $0.4 billion to just over $1 billion.

Analysis based on average data from the NEMA/SMMA working group indicates lower potential energy savings and economic benefits. The highest savings scenario, which in this case refers to the stack change design option, shows energy savings of 0.6 quads with an NPV of 0.1 billion. In the scenario with least savings, the options all have negative NPV.

Polyphase motors. The analysis based on DOE's motor testing and costing shows cumulative energy savings from steel grade changes ranging from a low of 0.15 quad to a high of 0.21 quad. The corresponding cumulative NPV range is from $0.09 billion to $0.27 billion. The design options do not show positive NPV in most cases.

For polyphase motors, DOE did not make estimates of national impacts using the NEMA/SMMA data because the manufacturers' analysis was based on a 1/2 horsepower motor instead of the more typical one horsepower size. Furthermore, the manufacturers' analysis shows some efficiency gains, but with an increase in life-cycle cost, which would lead to a negative NPV.

# 1. INTRODUCTION

## 1.1 Background

Under 346(b)(1) of the Energy Policy and Conservation Act (EPCA), 42 U.S.C. 6317(b)(1), the Department of Energy (DOE or Department) may 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 draft analysis is to provide a basis upon which the Department can make its 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 three horsepower. These motors operate at 60 Hertz and have either a single-phase or a 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.

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 four percent of the total population of small electric motors. Nevertheless, these motors, which the Department identifies 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.

## 1.2 Overview of Considered Small Motors

As a result of the above EPCA definition and exclusions, the motors that fall under consideration in this report are a subset of the total population of small electric motors. Further, the term

"general purpose" in the EPCA definition[1] of a small motor is tied to the NEMA Standards Publication MG1-1987 performance requirements that have been established for general purpose motors, such as the minimum levels for breakdown and locked rotor torque for small electric motors presented in MG1-1987 paragraph 12.32.

Among considered, single-phase, two-digit motors, those of shaded pole, permanent split capacitor, and split phase designs 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, the Department considers 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.

For the purposes of this analysis, the considered small electric motors that meet the EPCA 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 percent of total domestic shipments of fractional horsepower motors in 1999 (Figure 1-1).

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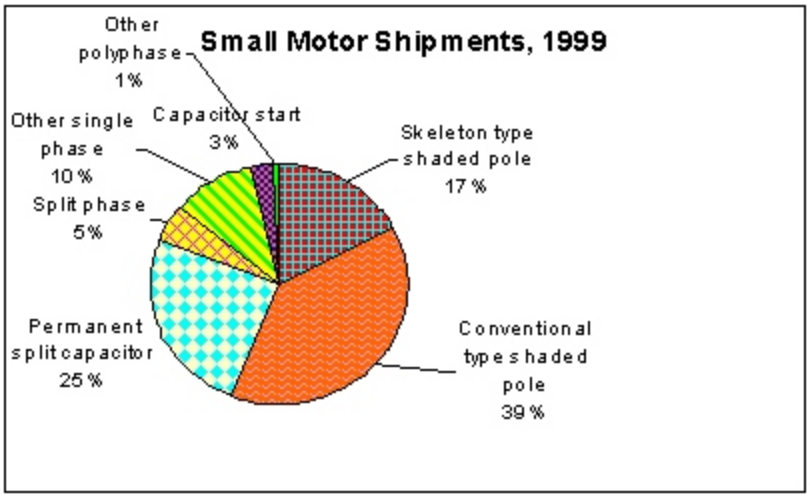
[1] EPCA does not define the term "general purpose motor," although it does define the terms "definite purpose motor" and "special purpose motor." According to EPCA, "definite purpose motor" means "any motor designed in standard ratings with standard operating characteristics or standard mechanical construction for use under service conditions other than ususal or for use on a particular type of application and which cannot be used in most general purpose applications." Section 340(13)(B), (42 U.S.C. 6311 (13)(B)). Likewise, "special purpose motor" means "any motor, other than a general purpose motor or definite purpose motor, which has special operating characteristics or special mechanical construction, or both, designed for a particular application." Id. at (C). Consequently, the term general purpose must be derived by eliminating those definite and special purpose motors and subsequently defined within the context of NEMA performance characteristics that can operate successfully in many different applications.

**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 and Industrial HVAC/Refrigeration Equipment |
| Farm Machinery |
| Conveyors |
| Industrial and 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 and commercial fans and blowers are definite-purpose motors, but a significant number of general-purpose motors are also used. In commercial and 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 five 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 two-pole motor, the pole pitch is half the circle, while for four- or six-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 sturdy and cost-effective construction.

When the stator windings are energized by a three-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 two-pole (or one-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 (one horsepower and below) three-phase induction motors declines rapidly as the load drops below 70 percent of rated load.

Polyphase motors in a two-digit NEMA frame size range from 1/4 horsepower to three horsepower, though the majority are one horsepower or less. They are available in two-, four-, or six-pole configurations (corresponding to speeds of 3500, 1750, or 1150 rpm, respectively). A four-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 three-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 contains 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 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 Motor -- This configuration is the least costly. The start winding has a higher resistance-to-reactance ratio than the main winding, which is 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 three to five 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 horsepower to one horsepower and are available in two-, four-, or six-pole configurations. A four-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 zero to one. 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 a higher grade of steel for the magnetic components; improving the mechanical components and design (winding, bearings, and fan); and improving the 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 cannot ignore interaction among different motor losses in the process of optimizing. The $I^2R$ (the expression of heat loss in watts where I is measured current and R is resistance) of the rotor is a key loss, as are windage, friction and stray losses. 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 five percent to about 24 percent (EPRI, 1987).

## REFERENCES

Electric Power Research Institute, 1987. *Optimization of Induction Motor Efficiency, Vol. 2: Single-Phase Induction Motors*. EPRI EL-2152.

# 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 interpolating the data, the average annual growth rate is 1.5 percent. The three-phase and capacitor-start motors being analyzed make up only around 20 percent 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 approximately 95 percent 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 percent of total CSIR shipments. The most important size categories (with roughly equal shares) are 1/3, 1/2, and 3/4 horsepower. The average size is 1/2 horsepower. 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 one horsepower. The average size is one horsepower. Four-pole motors account for two-thirds of the total.

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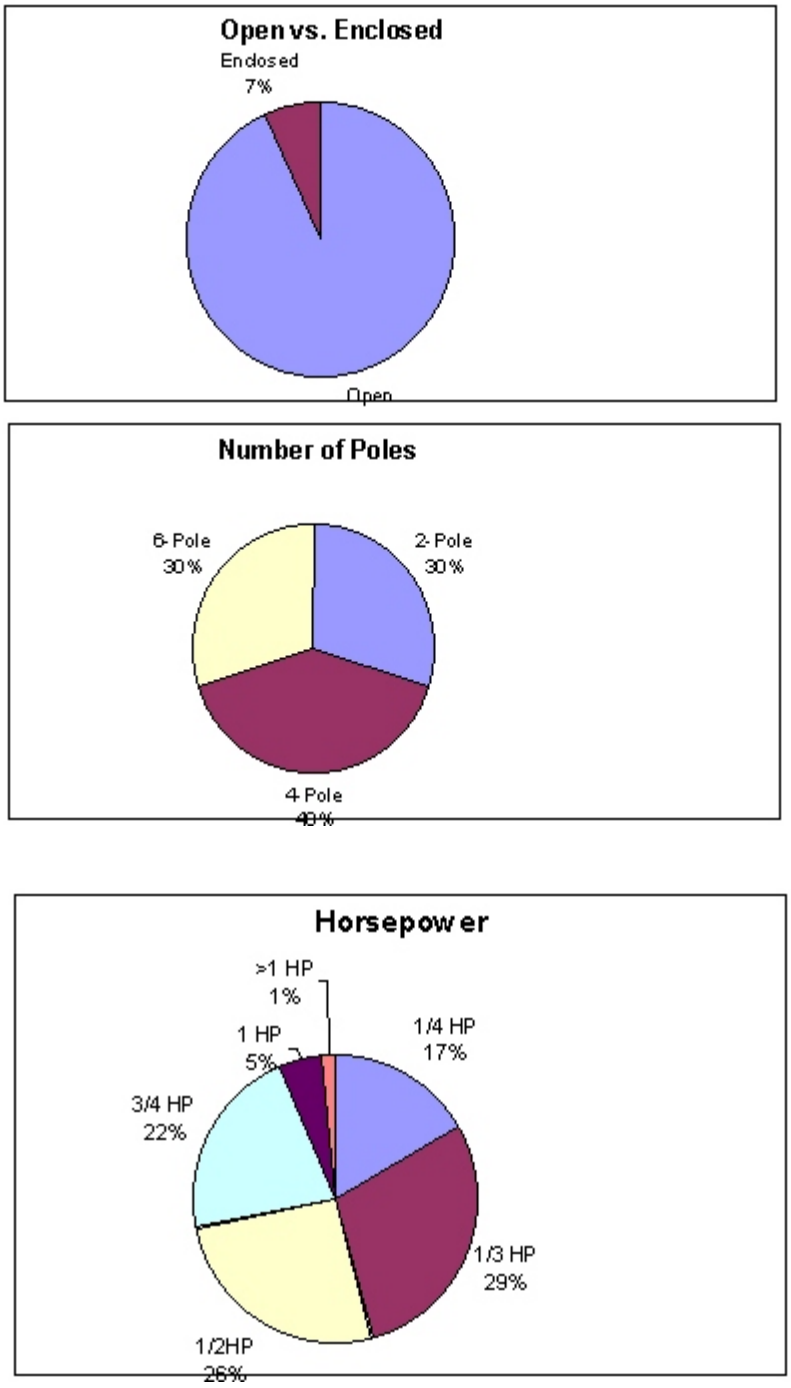
[2] US Census Bureau, Current Industrial Reports, Motors and Generators -- MA335H. The Department has included all single-phase motors, one horsepower and over, with capacitor-start motors.

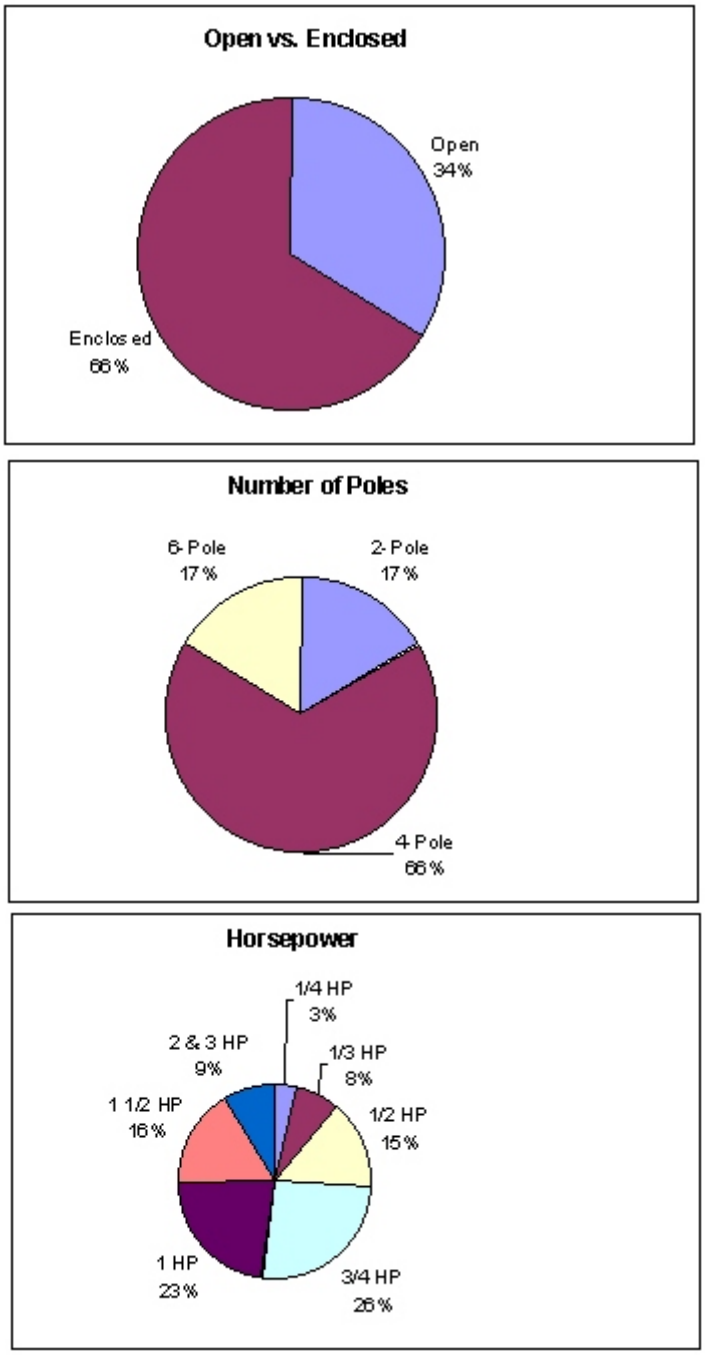
[3] The shares of two- and six-pole motors are estimated values, as complete data were lacking.

**Figure 3-1 Capacitor-Start, Induction-Run Motors – Shipments in 2000**




Source: NEMA/SMMA survey

**Figure 3-2 Small Polyphase Motors – Shipments in 2000**




Source: NEMA/SMMA survey

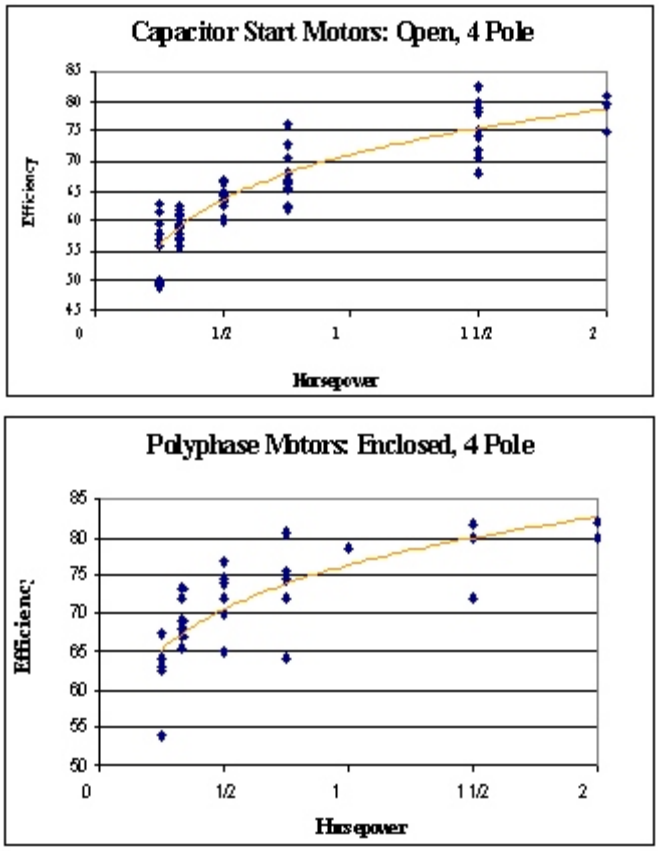
## 3.3 Range of Energy Efficiencies

The Department assembled data from manufacturers' 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 versus 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, four-pole capacitor-start motors, the efficiency range is greater for 3/4 horsepower motors than for 1/3 and 1/2 horsepower motors. Some of the highest-efficiency motors larger than one horsepower 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

The Department estimates the distribution 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 | A.O. Smith, MagneTek, |
| Baldor Electric | Baldor Electric Co. |
| Emerson Motors | Emerson, U.S. Motors |
| General Electric | GE Motors |
| Regal-Beloit | Lincoln Motors, Marathon Electric |
| Rockwell Automation | Reliance Electric |
| TECO Electric and Machinery Co. Ltd. | TECO, TECO-Westinghouse Motor Company |
| Toshiba International Corporation | Toshiba International Corporation |
| WEG Electric Motor Corp. | WEG |

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, the Department 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 Machinery | 1500 | n/a |

Source: Easton Consultants (2001)

The Department also investigated typical motor loading practices. The motor loading is commonly in the 60-70 percent range, though it is higher in two cases, and lower in two cases.

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

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

| Application | Capacitor-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 and Pumping Equipment | 1723 | 30.4 | 364 | 28.1 |
| Air and Gas Compressors | 338 | 6.0 | 101 | 7.8 |
| Industrial/Commercial Fans and 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 and 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 percent of two-digit motors. (The response from the HVAC category was mixed, with some OEM respondents quite interested in greater efficiency, and 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, 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).

# 1. 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; and (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 the Department did not analyze it in this study.

The Department did not analyze optimizing of winding and wire. 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 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, the Department selected several popular models to analyze. The Department engaged a recently retired engineering executive from the motor industry (Austin Bonnett) to conduct the analysis. The testing of the sample motors followed industry practice for these motor types. It used 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 is not included in this type of testing because obtaining accurate results for this size of motor is problematic and this factor is not significant.

The Department 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 changes, 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 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***

The Department's 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 are normally affected by the design changes considered. Labor and burden were not considered because the cost of labor is minor and the burden is spread over a large number of manufacturing activities. The impact on set-up time and the introduction of new part numbers were also not considered because such costs are uncertain and likely small.

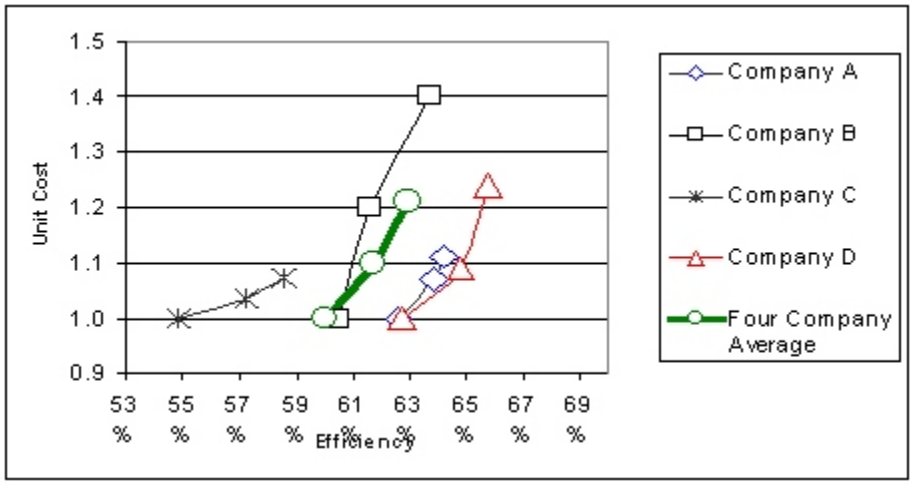
The Base motor in each case was given a "per-unit" (PU) cost of one. All active material changes are related to the PU cost of one. If a change in electrical steel represented a 10 percent change in the total active material cost, for example, the PU number would be 1.10 for the new design.

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 and variable. The fixed costs normally do not change, and 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, the Department 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." The Department believes 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 horsepower, 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 it 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 percent of the 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 horsepower, 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 horsepower, 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 horsepower, 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 horsepower, 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 horsepower, 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 horsepower, 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 horsepower, 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 horsepower, 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 horsepower, 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 horsepower, 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 changes is less than that for the steel grade options. For the "plus stack" option, the LBNL and NEMA analyses agree reasonably well.

**Polyphase LBNL #3N, 1/2 horsepower, 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 horsepower, 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 horsepower, 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 horsepower, 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 Discussion

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, because 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 gauge 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.

## 2. 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, the Department 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; and
4. Discount rate (to express the present value of future money savings).

The Department discusses 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 (percent of rating): 70%

***Price for the Base Motors***

The Department 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 percent of list. The Department applied this value for each motor analyzed. For the motors analyzed, the Department used model-specific list prices given in the 2001/02 Grainger catalog (Grainger, 2001). For the motors analyzed by the NEMA/SMMA working group, the Department estimated list prices based on representative motors in the Grainger catalog.[4]

The Department assumes 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 percent 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).5 For an average utilization of 2500 hours per year, that would yield a ten-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 shorter than that of the three-digit. Motor industry experts consulted suggest that the average life for two-digit motors is at most ten years, depending of course on the usage and physical environment.

The Department 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, 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 five to ten years for fractional motors, with the average being closer to ten years for three-phase and to five 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, the Department elected to use a mean lifetime of seven years for capacitor-start motors and nine years for polyphase motors.

***Electricity Price***

The Department estimates that, based on the market research done by Easton Consultants, 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. The Department 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, the Department derived an average price giving a 0.75 weighting to the commercial price. For polyphase motors, the Department increased the industrial price slightly to reflect its 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.

The Department assumes 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 four percent to 11 percent. The average cost of capital for the companies is 6.0 percent. The standard deviation of the cost of capital is 1.4 percent.

Based on the above, the Department used a discount rate of six percent 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. The Department only presents 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 a change of steel grade, while others can do so better using a stack change.

**Table 5-1 Impacts of Efficiency Improvement on Typical End User, Capacitor-Start, 1/2 horsepower, 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 |

*Data refer to a specific typical motor
**Based on actual motor price in Grainger catalog.

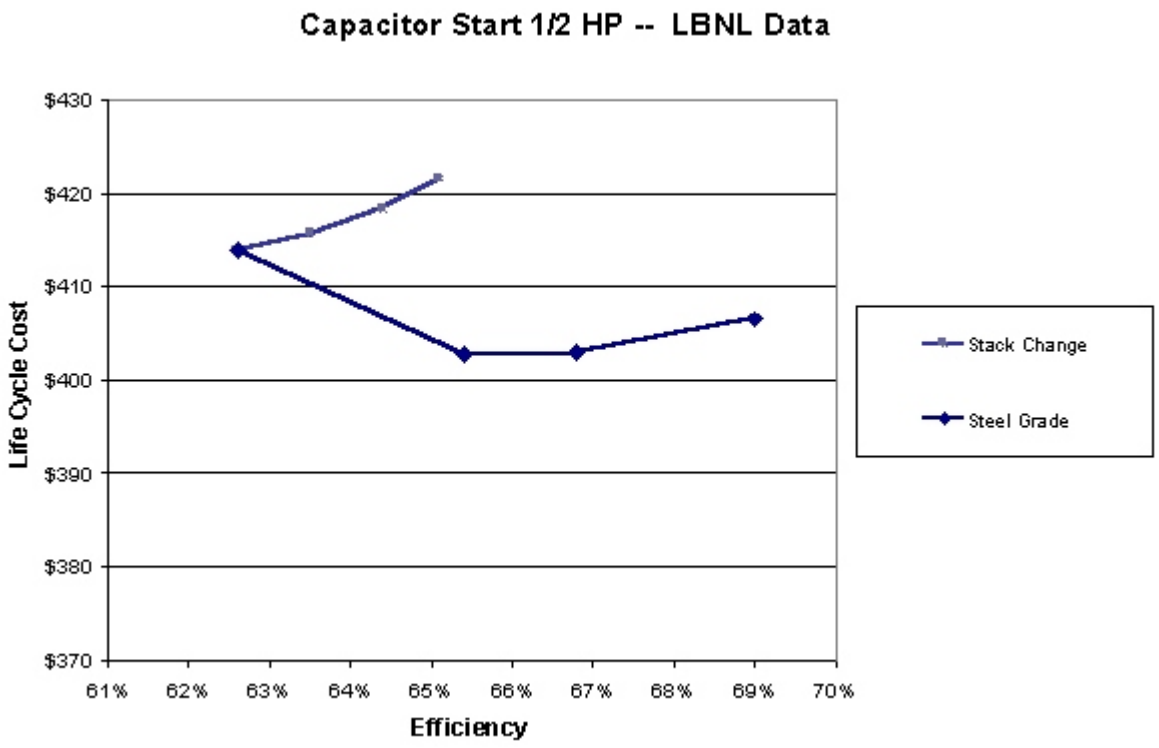
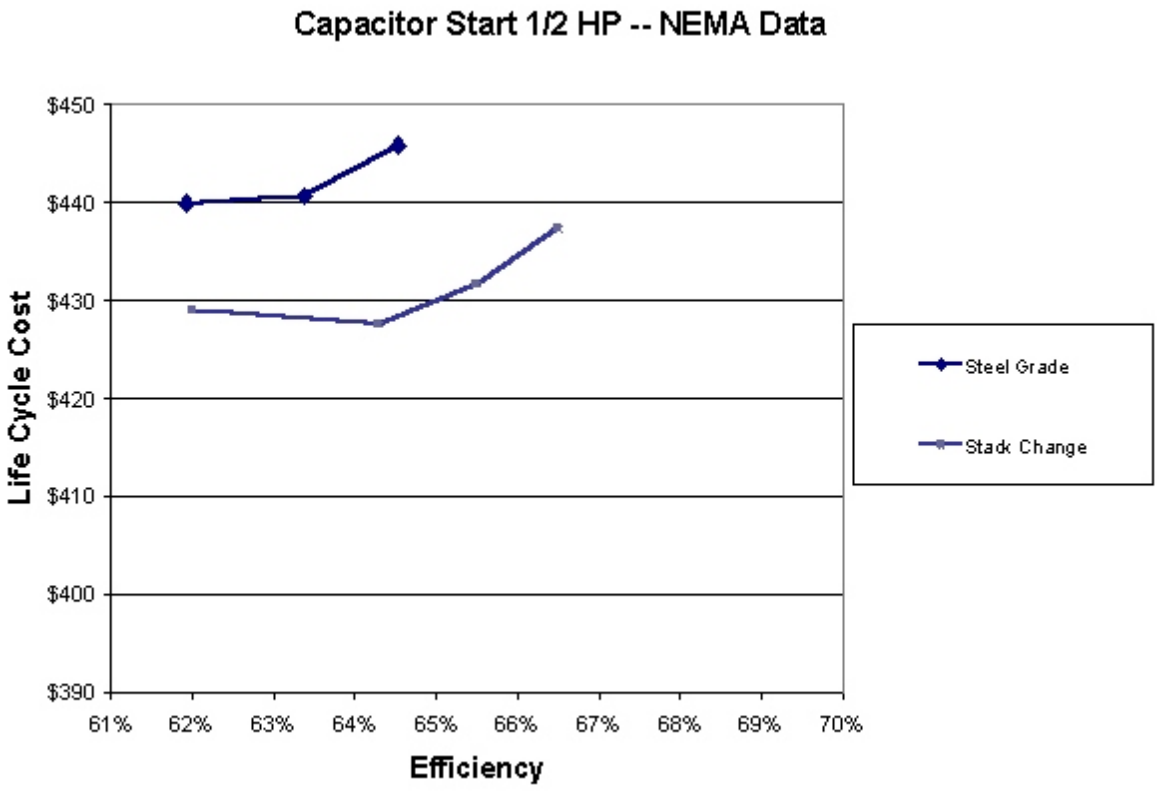


**Table 5-2 Impacts of Efficiency Improvement on Typical End User, Capacitor-Start, 1/2 horsepower, NEMA Data**

| | 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 costs and performance of a typical motor
*** Estimated by LBNL based on Grainger catalog prices



## 5.3 Results for Polyphase Motor Options

Key results of the financial analysis for the most typical motors are presented in the tables below. The Department only presents 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 horsepower, 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 | |

*Data refer to a specific typical motor
**Based on actual motor price in Grainger catalog.

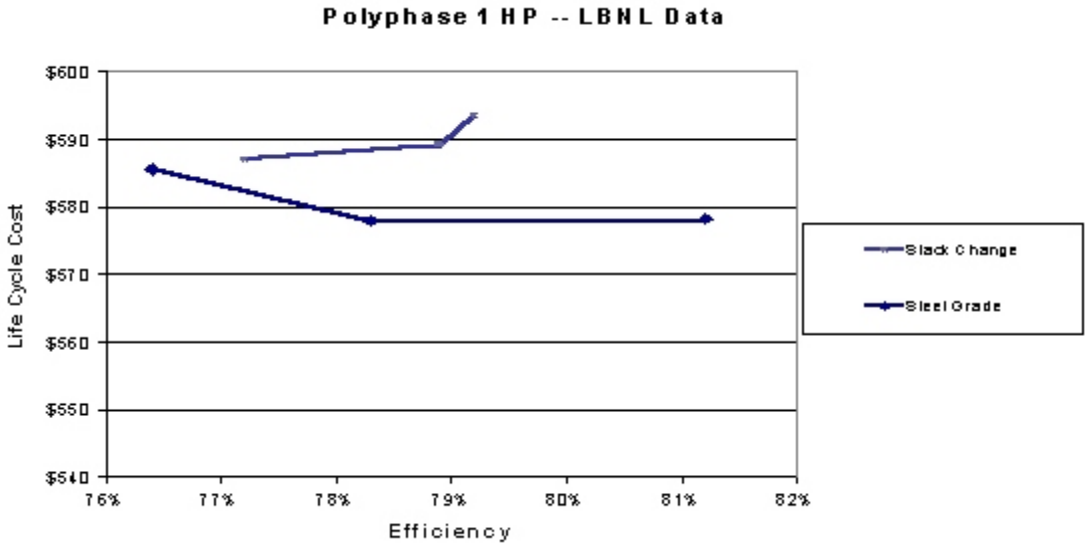
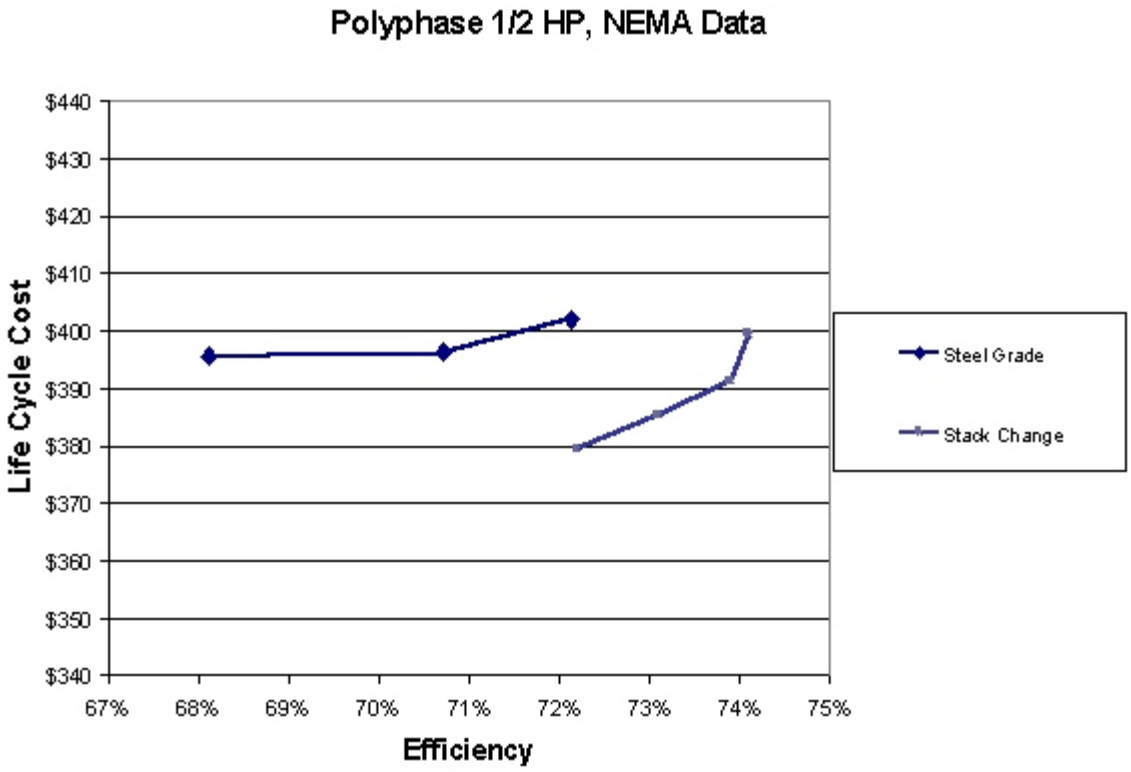


**Table 5-4 Impacts of Efficiency Improvement on Typical End User, Polyphase 1/2 horsepower, NEMA Data**

| | 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 costs and performance of a typical motor
*** Estimated by LBNL based on Grainger catalog prices



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

## 6.1 Method

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

| | |
|---|---|
| Capacitor-start motors | 1/2 horsepower |
| Polyphase motors | 1 horsepower |

The Department used the results of the LBNL and manufacturers' engineering analyses (Chapter 4) as the basis for national energy savings estimates. For polyphase motors, however, the Department only used the LBNL results, as the manufacturers' analysis was based on a 1/2 horsepower 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.

The Department believes that the motors analyzed (open drip-proof, four-pole) serve as reasonable proxies for enclosed motors and two- and six-pole motors. The Department 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 horsepower 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.

The Department assumes standards take effect in 2010 and calculates 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.

The Department 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. The Department extrapolated the 2010-2020 trend for the 2021-2040 period.

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

The Department discounted future costs and benefits using a rate of seven percent, 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 interpolating the data, the average annual growth rate is 1.5 percent. Although the motors being analyzed make up only around 20 percent of the motors covered by these data, industry experts suggest that growth in sales of the considered motors is likely similar to that of all fractional motors because the demand for both considered and non-considered fractional motors is closely tied to the general U.S. economy.

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, the Department estimated impacts for two scenarios of average annual growth in shipments in the 2010-2030 period: one with one percent and the other with 1.5 percent.

***Base Case Efficiencies***

Apart from the problem of estimating future market behavior, the Department has only limited knowledge regarding the past trend in efficiency because of insufficient data that are available. The perspective of the NEMA/SMMA working group and other motor industry experts the Department consulted is that the past 20-30 years have seen "very little to moderate" improvement in efficiency. Some gains occurred in the 1970's 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.

The Department 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 percent compared to 62 percent). In the Moderate Efficiency Improvement base case, the average efficiency is one point better than the current base case motors.

## 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 one 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, the Department sees 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 horsepower motors would show lower savings than the above.

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

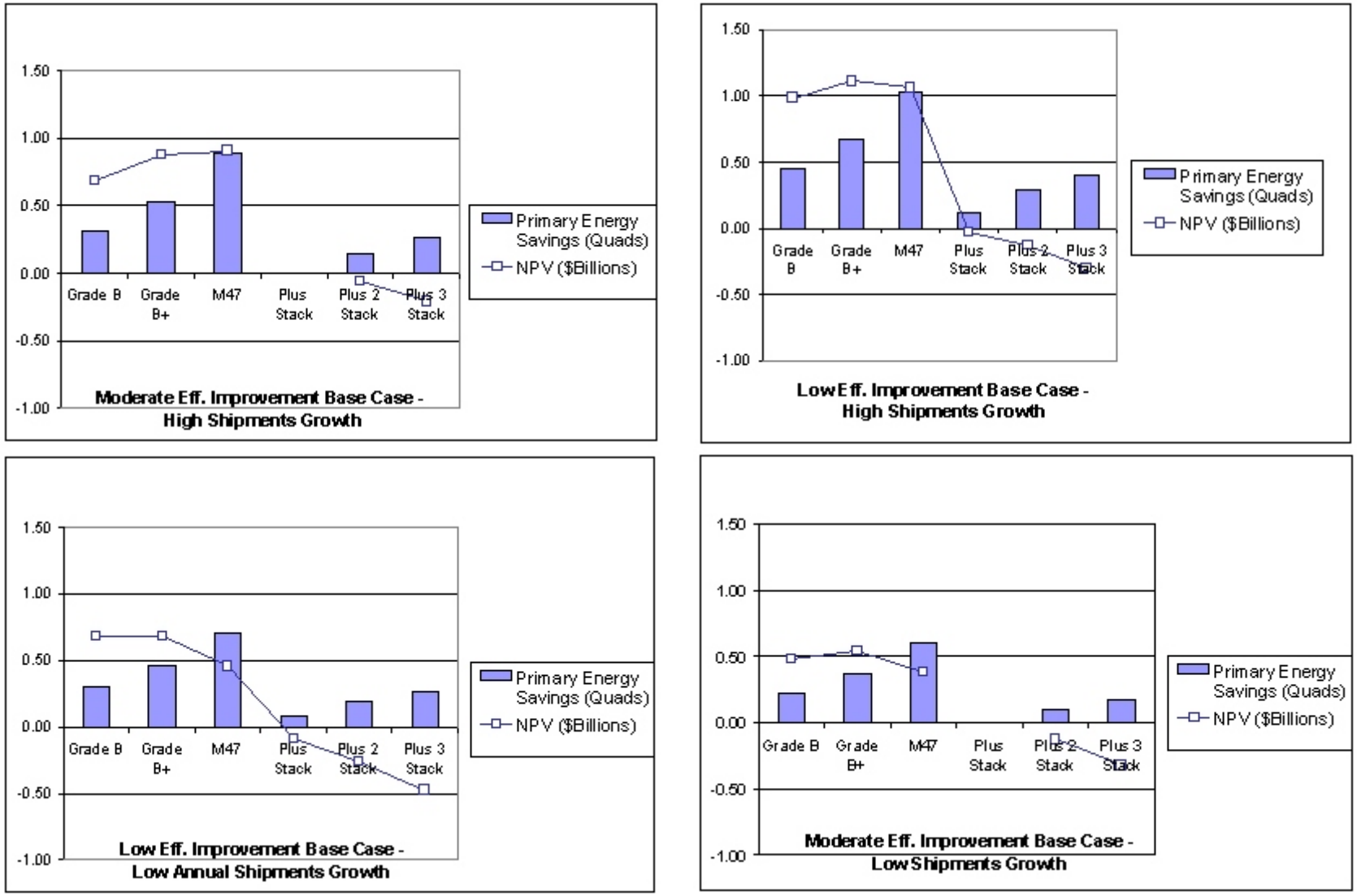


**Figure 6-2 Capacitor-Start Motors, National Energy and Consumer Impacts, NEMA Data**

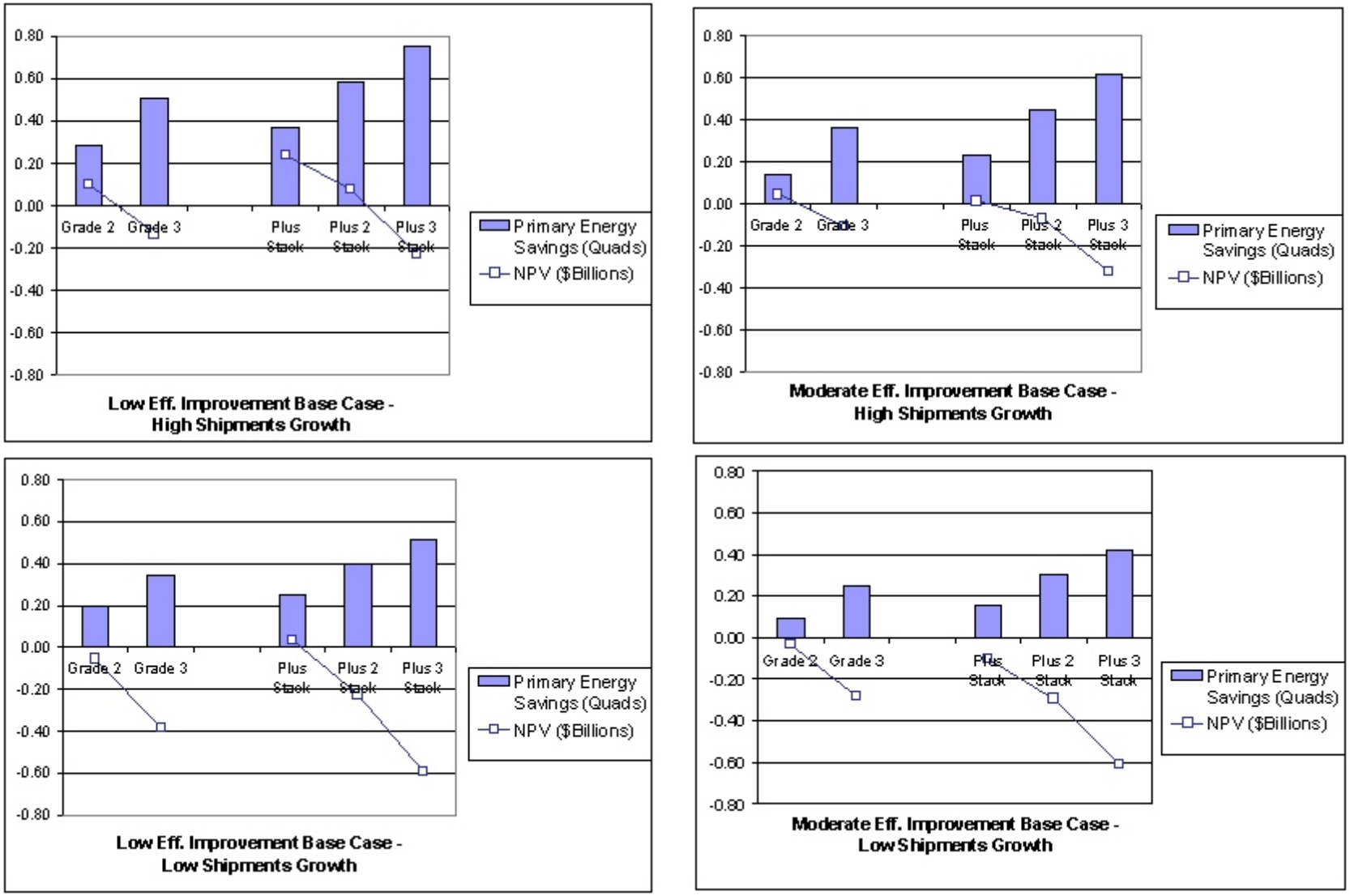
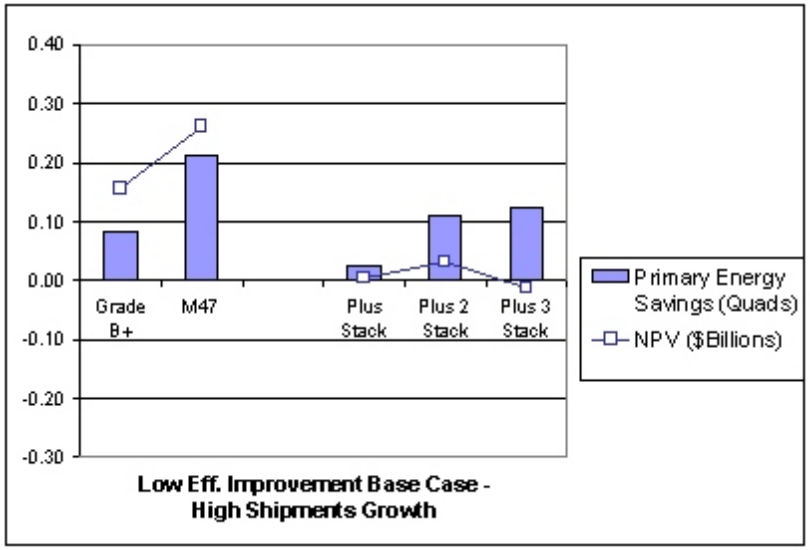
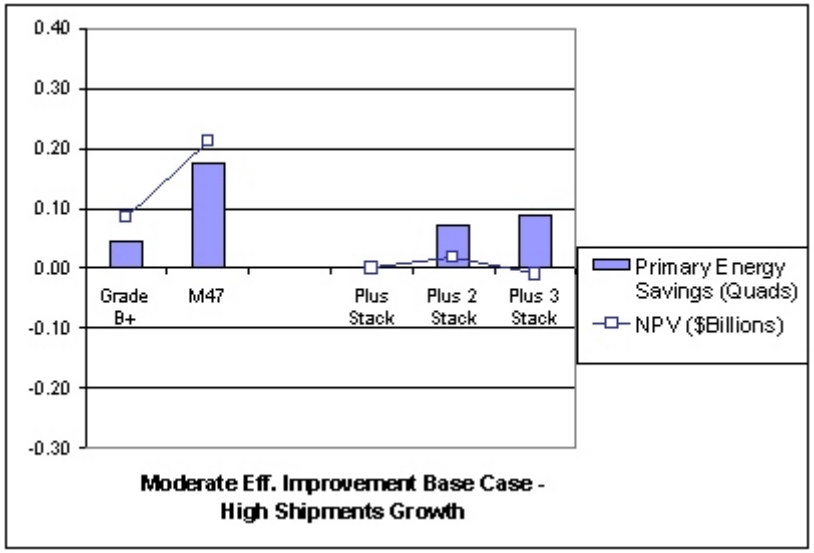
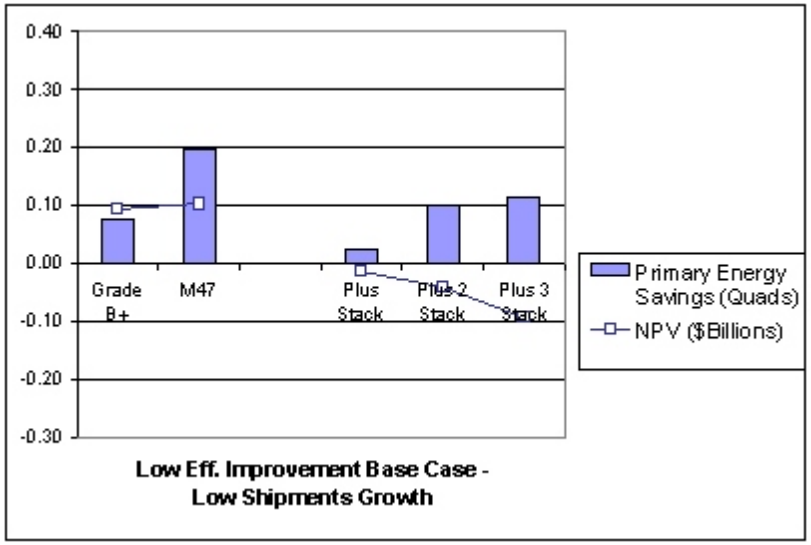
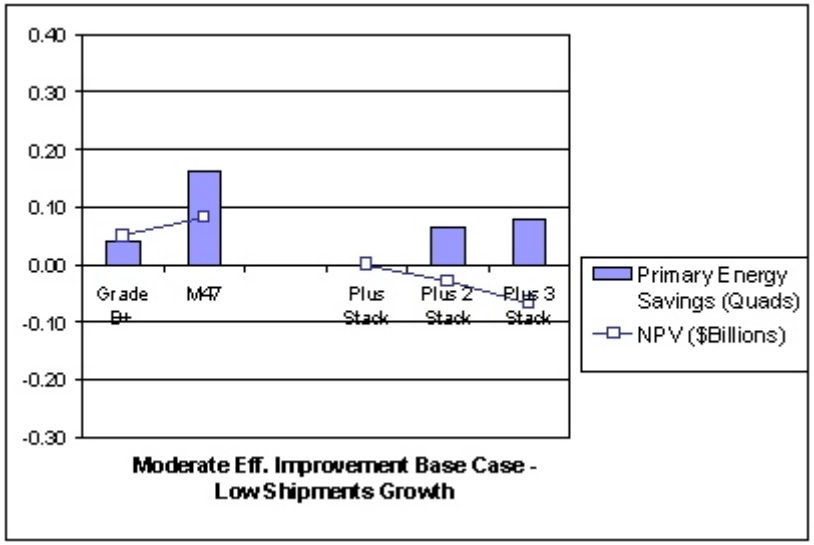


**Figure 6-3 Polyphase Motors, National Energy and Consumer Impacts, LBNL Analysis**



## 7. SUMMARY OF RESULTS

The most attractive design options for improving the energy efficiency of the considered small motors involve changes in steel grade and stack length. The relative merits of one versus the other vary among motor manufacturers.

The design options considered in this study have the energy savings potential shown below. Differences in estimates of the efficiency and cost increase associated with the options and uncertainty about future shipments and efficiency trends produce a range of estimates for economic impacts.

Capacitor-start, induction-run motors. The analysis of design options conducted by LBNL shows cumulative energy savings from steel grade changes, the more favorable design option in this analysis, ranging from 0.6 to one quad (Table 7-1). The corresponding cumulative NPV range is $0.4 billion to just over $1 billion.

Analysis based on average data provided by the NEMA/SMMA working group indicates lower potential energy savings and economic benefits. The highest savings scenario, which in this case refers to the stack change design option, shows energy savings of 0.6 quads with an NPV of 0.1 billion. In the scenario with least savings, the options all have negative NPV.

**Table 7-1 Cumulative Energy and Consumer Impacts of Energy Efficiency Improvement for Capacitor-Start, Induction-Run Motors Projected to be Sold in the 2010-2030 Period***

| Future | Energy Savings (Quads) | | NPV (Year 2000 dollars in billions, discounted at 7 percent ) | |
|---|---|---|---|---|
| Scenario | LBNL | NEMA/SMMA | LBNL | NEMA/SMMA |
| Low efficiency gain base case, high shipments growth | 0.85 | 0.6 | 0.9 | 0.1 |
| Moderate efficiency gain base case, high shipments growth | 1.0 | 0.2 | 1.05 | 0.05 |
| Low efficiency gain base case, low shipments growth | 0.7 | 0.25 | 0.65 | 0.05 |
| Moderate efficiency gain base case, low shipments growth | 0.6 | 0.1 | 0.4 | -0.05 |

* The values given for each scenario correspond to the design option with the combination of highest energy savings and most favorable consumer NPV.

The LBNL and NEMA/SMMA data are in reasonably close agreement with respect to the stack change design option. For steel grade changes, however, the data are not in agreement. The reasons for the differences between the LBNL and NEMA/SMMA data are somewhat uncertain, as the NEMA/SMMA working group did not wish to share details of the calculations from the four companies that submitted data.

Better resolution of the uncertainty would require both more information from the NEMA/SMMA group and 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.

Polyphase motors. The LBNL analysis shows cumulative energy savings from steel grade changes ranging from a low of 0.15 quad to a high of 0.21 quad (Table 7-2). The corresponding cumulative NPV range is from $0.09 billion to $0.27 billion. The stack change options do not show positive NPV in most cases.

For polyphase motors, the Department did not make estimates of national impacts using the NEMA/SMMA data, as the manufacturers' analysis was based on a 1/2 horsepower motor instead of the more typical one horsepower size. Furthermore, the manufacturers' analysis shows some efficiency gains, but with an increase in life-cycle cost, which would lead to a negative NPV.

**Table 7-2 Cumulative Energy and Consumer Impacts of Energy Efficiency Improvement for Polyphase Motors Projected to be Sold in the 2010-2030 Period***

| Future Scenario | Energy Savings (Quads) | | NPV (Year 2000 dollars in billions, discounted at 7 percent ) | |
|---|---|---|---|---|
| | LBNL | NEMA/SMMA | LBNL | NEMA/SMMA |
| Low efficiency gain base case, high shipments growth | 0.21 | Not Available | 0.27 | Not Available |
| Moderate efficiency gain base case, high shipments growth | 0.18 | Not Available | 0.21 | Not Available |
| Low efficiency gain base case, low shipments growth | 0.2 | Not Available | 0.1 | Not Available |
| Moderate efficiency gain base case, low shipments growth | 0.17 | Not Available | 0.09 | Not Available |

* The values given for each scenario correspond to the design option with the combination of

highest energy savings and most favorable consumer NPV.

## APPENDIX A. INFORMATION COLLECTION PROCESS ON USE OF SMALL MOTORS

Small motors are used in a variety of equipment. Easton Consultants identified 14 industrial categories and North American Industry Classification System (NAICS) categories 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, and
- 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; and
- Other selection related information.

Type 3 – Quantitative (shipments) information

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

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

- **Step 1 –In-house expertise.** The Department started with our expertise on each of the categories from past projects. The Department assembled this information as the starting point.
- **Step 2 --Industry associations**. The Department 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.** The Department 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**. The Department 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**. The Department worked with a former director of market research of a motor manufacturer who has extensive industry background to extend our expertise.
- **Step 6 --Direct motor-using company informal discussion**. After the above sources had been fully utilized, the Department conducted a series of informal phone interviews with equipment designers and engineers in each of the sectors. These were designed to collect the specific information needed, and varied for each category depending on the specifics of what was needed for that category. In these interviews the Department 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, and
  - 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 the Department 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, the Department has 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.

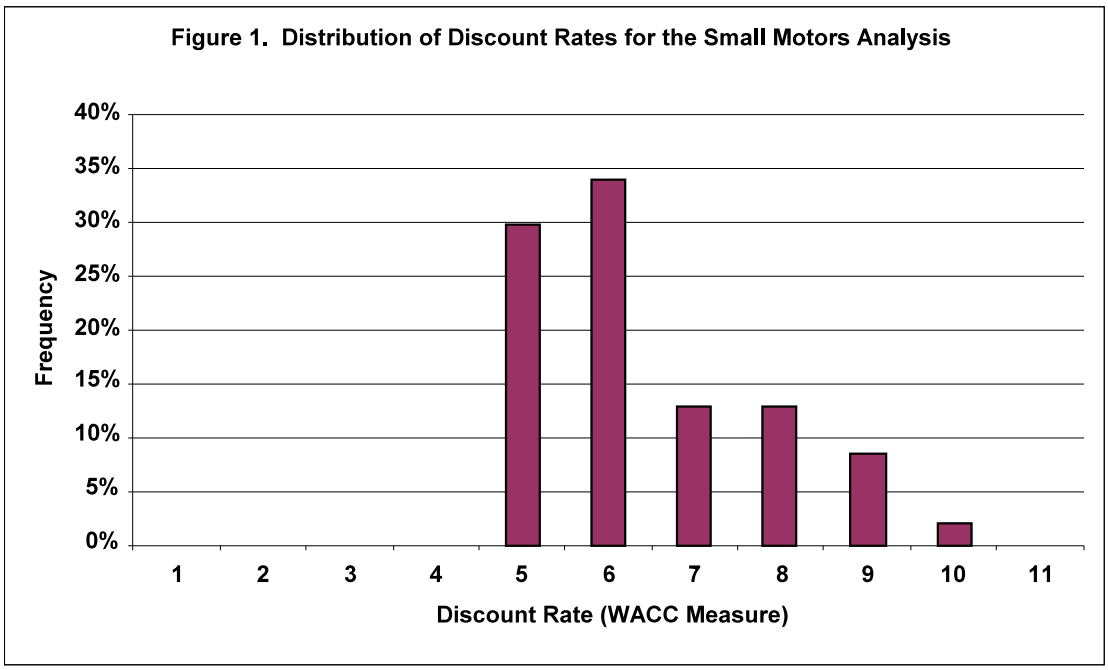
In the following chart the Department has defined the role of each source of information in making the estimates.

| 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 percent to 11 percent (Figure 1). The average cost of capital, after deducting for expected inflation, is 6.0 percent. The standard deviation of the cost of capital is 1.4 percent.




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

[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% |
| Intlawest 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 Pply 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 Pply 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 L | 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%.