Industrial Motor System Optimization Projects in the US: An Impact Study

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ABSTRACT

This study examines data from 41 industrial motor system optimization projects implemented between 1995 and 2001 that were developed into DOE case studies to determine the effect of the energy savings brought about by such projects. The study calculates aggregate energy savings, the net present value (NPV) of project savings, the internal rates of return of project cash flow (IRR) for each project as well as for all projects aggregated together and for projects having large capital expenditures versus those in which the systems were optimized primarily with engineering changes. Finally, the study makes some rough estimates of possible energy savings throughout US industry.

For this study, projects are considered financially worthwhile if the NPV of the project savings over a 10-year project life is greater than the project cost. Because the simple payback criterion is the norm in the DOE case studies, it is used as a complementary measure of success.

The initial results suggest that the NPV for most of the projects' savings in the sample are positive with 10 and 15-year project lives and that many are even positive with 5-year project lives. For projects involving large capital purchases a project life of 10 years is required for a positive NPV while for projects that primarily involve engineering changes a positive NPV was achieved with a 5-year project life. This suggests that motor system optimization projects do not necessarily require large capital expenditures to achieve substantial energy savings.

Introduction

Since the mid-1990s, manufacturing plants in the United States have undertaken measures to reduce energy consumption. One of the primary types of these measures has been to increase the efficiency of their motor systems. These efforts have been encouraged by the US Department of Energy's Office of Energy Efficiency and Renewable Energy (EERE) through its BestPractices program. The BestPractices program includes the publication of case studies and similar documents (approximately 150 since 1995) on industrial energy efficiency projects to raise awareness within industry of the benefits of such projects.

This study explores the effect of such projects by examining data from 41 separate projects that were developed into DOE case studies. Through this review, it is expected that a better understanding of the impact of industrial motor system improvement projects will be achieved.

This paper is organized in the following manner. The first part defines and discusses the methodology of the study. Next, the analytical tools employed are discussed, along with the data and the selection criteria. In the next section, the results are presented, discussed and interpreted. Finally, some concluding remarks are presented.

Methodology

The main objective of this study is to estimate the impact of motor system optimization on industrial competitiveness and to provide insights into the mechanisms by which such benefits are delivered to industry. Specifically, it is expected that the study will (1) provide planning-relevant information on the nature and magnitude of the financial impacts from industrial motor system optimization, (2) convey to the policy process the rates of return to US industry from expenditures on such efforts. The data from the 41 projects is aggregated to provide a collective estimate of their impact and extrapolated to estimate potential industry-wide energy savings, which will allow the results of this assessment to feed back into DOE's strategic planning process.

Empirical Measures

The primary quantitative measures employed in this study are net present value (NPV), internal rate or return (IRR), and simple payback. The NPV is used because it is an absolute measure of the value or expected value of an investment in constant dollar terms. It therefore portrays the annual energy savings from the projects as interest payments on a bond and can be used to compare the performance of expenditures on motor system improvement projects to the performance of other potential uses of financial capital. If the 10-year NPV of project savings exceeds the project cost, the project will be considered successful.

The IRR of project cash flow is the compound rate of return paid by an investment. In this study, the project cost is the investment and the IRR of project cash flow gives each project's total return on its project cost. By providing a rate of return measure, the IRR of project cash flow allows comparison with a designated opportunity cost of the funds being considered for the projects. For this study, an IRR of project cash flow that is greater than 50% will constitute a rate of return that makes a project successful. For the aggregate data, the IRR will be labeled the CRR of project cash flow (collective rate of return).

The simple payback is a complementary measure that serves as a modified benefit-cost ratio. According to the US Industrial Motor Systems Market Opportunities Assessment (MSMOA), many firms use only the simple payback as a decision tool[1] and DOE uses it in all of its case studies, making it relevant for this study. Although the MSMOA applies a 3-year simple payback to energy efficiency measures, some of the firms whose projects are used in the study report using a financial hurdle rate of 2 years or less on the simple payback to obtain project approval. Therefore, projects having a simple payback of 2 years or less will be considered successful in this study.

In addition to energy savings, many of the projects in the study have led to important non-energy benefits such as maintenance savings, increased or improved production, and lower emissions. These additional benefits are in effect positive externalities of motor system improvements. With these methods, this study provides both qualitative assessments and quantitative estimates of the net financial benefits resulting from industrial motor system optimization.

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[1] MSMOA, P. 54

Data

The data used in the study come from 41 separate motor system optimization projects that were implemented in manufacturing plants in the US between 1995 and 2001 and cover seven different motor systems across 17 industries. The 41 projects were selected because they all provided the following data: energy savings in US dollars, energy savings and consumption in kilowatt-hours (kWh), project cost, and power cost ($/kWh). These projects are neither a random sample nor do they present the largest or smallest energy savings among motor system projects. However, in many cases their manner of implementation is consistent with best industry practices for motor system optimization.

Along with the above-mentioned attributes, additional assumptions in the study include a discount rate of 5%, and a project life of 10 years. The 5% discount rate is used because that rate approximates the average yield on the 10-year US Treasury bond between 1995 and 2001. The 10-year project life is the typical life span reported by various consultants, manufacturers and personnel involved in many of the study's projects. Because a 10-year project life may not be universal, results for 5 and 15-year project lives are also presented to see how the results differ with time periods that are 50% shorter and 50% longer than the selected baseline.

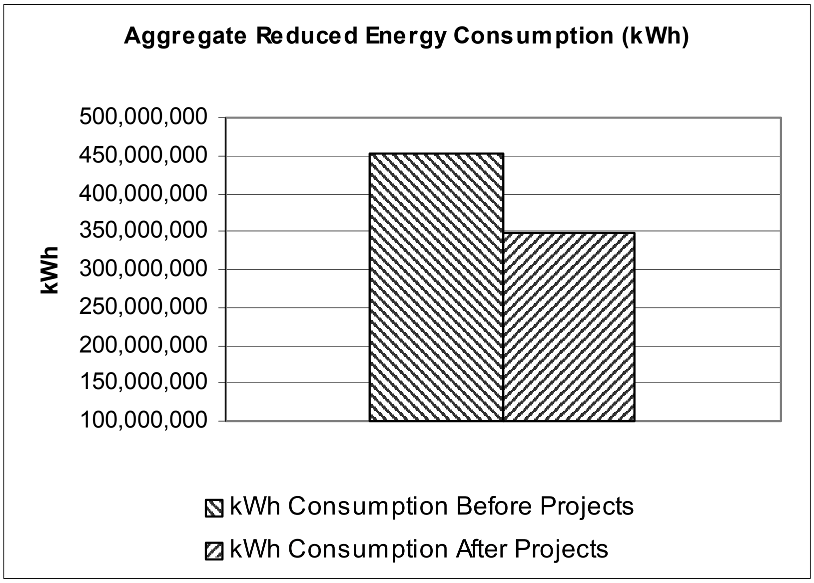
Results

The aggregate results show positive values for each of the measurement tools applied to the data. The aggregate project costs for all 41 projects total $16.8 million and the aggregate savings sum to $7.4 million and 106 million kWh. Using these figures, the NPV of project savings for the baseline analysis is $39,572,000, which exceeds the aggregate project cost. The CRR of project cash flow in this analysis is positive at 41% and the simple payback is 2.27 years. These results are summarized in Table 1 and Figure 1 shows the energy consumption before and after the projects. The initial aggregate results are skewed by two projects that were implemented with the intent of improving process reliability rather than saving energy. For these two projects, the costs vastly exceed the energy savings and they are viewed as outlyers. When these two projects are taken out of the sample, the NPV of project savings becomes $40,526,000, the CRR of project cash flow is 46% and the simple payback is 2.07 years. Because of the outlyers, median rather than average values of project costs and savings are provided in Table 1. Using the aggregate data, the NPV and CRR are also calculated for five and 15-year project lives. For the 5-year project life, the NPV figure is positive but smaller than the total project cost. The CRR figure reduces to 32% and the simple payback stays the same. In the 15-year project life, the NPV greatly exceeds total project cost and the CRR of project cash flow is 43%.

Table 1. Aggregate Data

Aggregate Data	N = 41	Without Outlyers (N = 39)
Total costs	$16,772,740	$15,072,740
Total savings	$7,401,700	$7,303,700
Median Cost	$240,000	$188,000
Median Saving	$115,000	$108,000
kWh	106,483,517	104,544,517
Simple Payback	2.27	2.06
CRR	41%	46%
PV	$56,344,762	$55,598,746
NPV 5-year	$13,913,292	$15,207,003
NPV 10-year	$39,572,022	$40,526,006
NPV 15-year	$61,975,378	$58,200,783

Figure 1. Aggregate Energy Consumption Before and After Projects



Once the initial aggregate results were calculated, the data was divided according to two main sets of features. The two main sets of features were plants belonging to the Industries of the Future (IOF) or non-IOF companies, and projects involving much capital spending vs. others that depended primarily on re-engineering.

Projects at IOF vs. non-IOF Industrial Facilities

Of the 41 projects in the study, 21 occurred in plants of companies that fall under DOE's Industries of the Future[2] designation, while 20 were implemented in facilities of non-IOF firms. IOF companies are considered to have the most energy intensive industrial processes and it was expected that motor system optimization projects in such facilities would have the greatest energy savings and highest returns. The results for the projects at

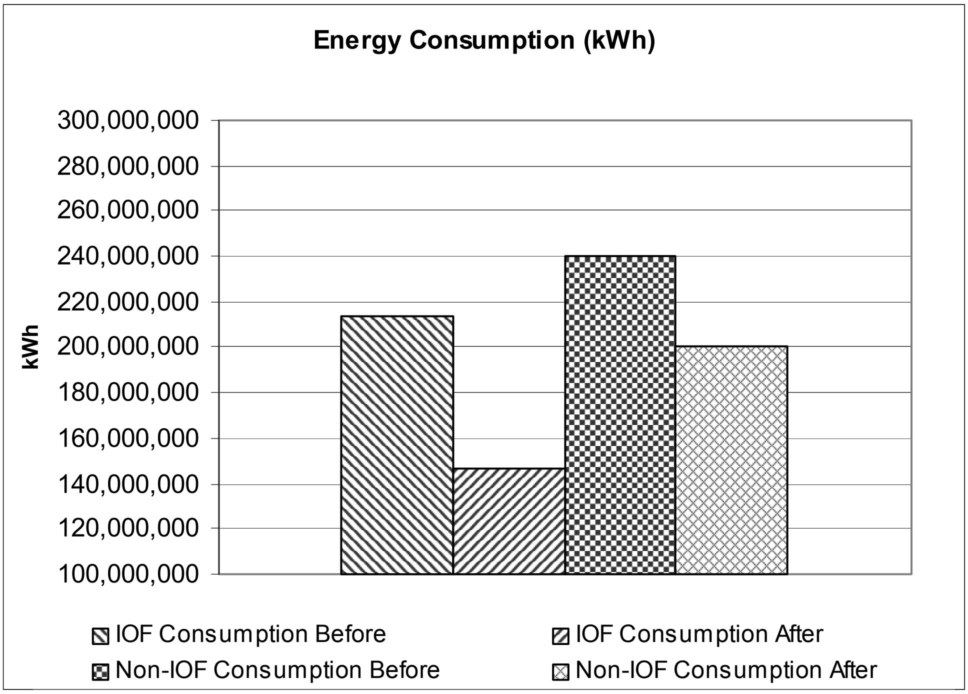
[2] Industries of the future are Mining, Forest/Paper Products, Steel, Glass, Metal Casting, Agriculture, Petroleum, Chemicals and Aluminum.

IOF companies bear this expectation out and are displayed in Table 2, which shows that the NPV of project savings and IRR of project cash flow for the IOF facilities' projects are greater than those of the non-IOF firms. The before and after energy consumption patterns are shown in figure 2.

Table 2. IOF vs. non-IOF Energy Consumption

	IOF Companies N = 21	Non-IOF Companies N = 20
Total Costs	$7,266,740	$9,506,000
Total Savings	$4,182,700	$3,219,000
Median Cost	$240,000	$219,000
Median Saving	$120,000	$99,000
kWh	66,993,517	39,490,000
Simple Payback	1.74	2.95
IRR	55%	31%
PV	$31,840,420	$24,504,342
NPV 5-year	$10,073,934	$3,839,358
NPV 10-year	$24,573,680	$14,998,342
NPV 15-year	$37,233,815	$24,741,564

Figure 2. Energy Consumption Before and After Projects for IOF & Non-IOF Companies



Because the NPV and IRR figures of IOF facilities' projects are greater than those of non-IOF facilities, this suggests that motor system improvement projects in such facilities are desirable. The non-IOF facilities' lower NPV, IRR and simple payback are partly because many of their projects incurred higher equipment costs than did the IOF facilities' projects. This higher cost is reflected by the fact that the weighted average of the non-IOF facilities' project costs is over 25% greater than that of the IOF facilities' projects.

Capital Spending versus Re-engineering

The other salient feature about many of the projects in the study was the degree to which equipment replacement and spending on capital equipment was significant in many projects. Spending on capital equipment was equal to or greater than 70% of the total project cost in 31 of the study's 41 projects. Furthermore, the main features in 35 projects included the replacement or addition of OEM (Original Equipment Manufacturer) devices such as pumps, fans, compressors, VSDs (Variable Speed Drives), and control systems.

The projects were divided into the following two categories: Capital Spending and Re-engineering. Projects that fell into the Capital Spending category were those for which most of the project cost was on new equipment or that were characterized by equipment replacement. The Re-engineering category included projects in which capital equipment purchases were small relative to the projects' costs or in which new equipment did not significantly contribute to the projects' results. Of the 41 projects in the study, 35 were classified as Capital Spending and six as Re-engineering.

The analysis for the two categories of projects produced vastly different results, which are shown in Table 3. Figure 3 shows both groups' energy consumption before and after the projects. While the NPV of Capital Spending projects' savings makes them successful according to the study's criteria, their IRR of project cash flow and simple payback are below the study's criteria for success. This category contains the two outlyer projects and when they are abstracted, the IRR of project cash flow and simple payback for the category remain below those criteria at 43% and 2.18 years. By contrast, the projects in the Re-engineering category are successful according to all three metrics. Also, the NPV of project savings for the Re-engineering projects is greater than the total project costs under the 5-year scenario.

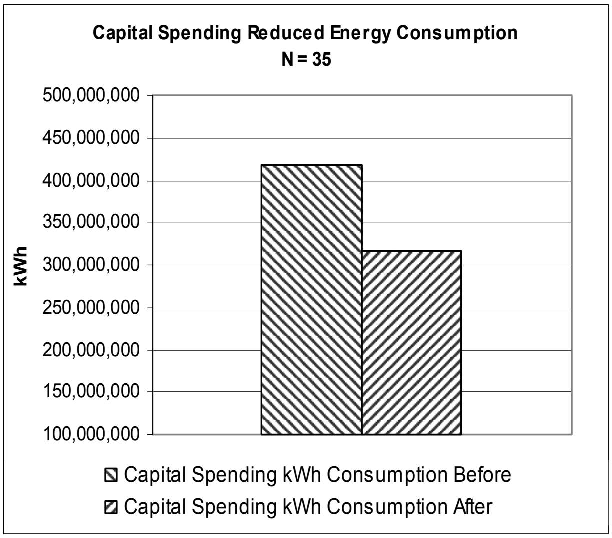
Table 3. Capital Spending vs. Re-engineering

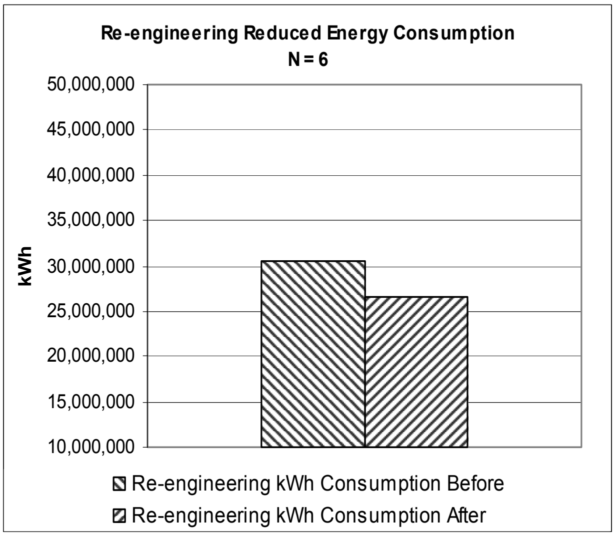
	Capital Spending N = 35	Re-engineering N = 6
Total Costs	$16,533,740	$239,000
Total Savings	$6,999,700	$402,000
Median Cost	$264,000	$35,000
Median Saving	$115,000	$44,500
kWh	102,523,517	3,960,000
Simple Payback	2.4	0.6
IRR	40%	164%
PV	$53,284,574	$3,060,188
NPV 5-year	$12,485,677	$1,427,615
NPV 10-year	$36,750,834	$2,821,188
NPV 15-year	$57,937,423	$4,037,956

While the data from the Re-engineering projects in this study show that higher rates of return were obtained through reconfiguration of or adjustments to existing motor systems, this does not indicate that equipment replacement is not justified. In many of the Capital Spending projects, the new OEM equipment was smaller than the devices it replaced. Also, the new equipment was more technologically advanced or contributed to more efficient operation of the motor systems involved, which obviated the need for previously anticipated equipment purchases. However, the Re-engineering projects' results do suggest that large capital equipment expenditures are not a necessary condition for energy efficiency.

The results in Table 3 display the NPV of project savings for 5 and 15-year project lives to show how the rates of return differ with time periods that are 50% shorter and 50% longer than the 10-year baseline project life. However, these time frames may not be appropriate. The 5-year scenario is very short for the Capital Spending projects and the 15-year project life is may be unrealistic for the projects that fall under the Re-engineering category because it is unlikely that the results will persist for that length of time. Therefore, the more appropriate timeframes to view the NPV of project savings for the Capital Spending projects are the 10 and 15-year ones while for the Re-engineering projects, the 5 and 10-year NPVs would be more realistic and reflective of the findings obtained in the study.

Figures 3A & 3B. Energy Consumption Before and After Projects: Capital Spending & Re-engineering





Individual Project Results

All 41 projects were individually analyzed under 5, 10 and 15-year project lives. Table 4 shows the results along with the percentages that those results represent.

Table 4. Individual Project Results of 41 Total Projects

	5 Year Project Life		10 Year Project Life		15 Year Project Life	
All Projects	Number of Projects	Percentage of Projects	Number of Projects	Percentage of Projects	Number of Projects	Percentage of Projects
NPV > Project Cost	27	66%	34	83%	39	95%
IRR > 50%	22	54%	24	59%	26	63%
Simple Payback > 2 Years	27	66%	27	66%	27	66%
Capital Spending						
NPV > Project Cost	21	58%	28	78%	33	92%
IRR > 50%	18	50%	19	53%	20	56%
Simple Payback > 2 Years	21	58%	21	58%	21	58%
Re-engineering						
NPV > Project Cost	6	100%	6	100%	6	100%
IRR > 50%	5	83%	5	83%	6	100%
Simple Payback > 2 Years	6	100%	6	100%	6	100%

As Table 4 shows, the NPV of project savings exceeds the project costs in a majority of the 41 and the IRR of project cash flow is greater than 50% in each project life scenario. This is also true for the projects that fell under the Capital Spending label and particularly so for the re-engineering projects.

Indirect Impacts

While the vast majority of the projects provided measurable energy savings, some yielded unanticipated benefits that can be seen as positive externalities. Typically, many additional improvements or savings were generated in one or more of the following areas: productivity (production and/or product quality), maintenance, emissions, ancillary products, plant safety and avoided equipment purchases. In addition, some firms received rebates or incentive payments for implementing their projects. Because not every project in the study resulted in all of the above-mentioned benefits, they are considered more ad hoc and should not be expected each time that a motor system is optimized.

Of the 41 projects, 22 resulted in reduced maintenance requirements on the motor systems involved. Twelve of these 22 plants were able to quantify their maintenance savings, which together total $900,000. Improvements in productivity in the form of production increases or better product quality was reported in 14 projects, three of which were able to quantify annual revenue increases that total $568,000. Others reported percentage increases in production or decreases in product reject rates. Lower emissions or purchases of ancillary products such as treatment chemicals were reported in eight projects and two projects resulted in improved plant safety. Also, six projects forestalled equipment purchases and one project averted an expensive asbestos abatement campaign. Together, these seven projects' avoided costs total $770,000. Finally, 10 projects resulted in incentive payments to the firms that performed them that total $1.2 million. When the incentive payments were factored out of the results, the average simple payback for these 10 projects increased by 28% to 6.5 and the IRR of project cash flow decreased by an average of 33% to 46%. When added to the total energy savings achieved, the indirect benefits from motor system optimization projects present a compelling case for their implementation.

Drivers of Motor System Projects

Although each of the projects in the study yielded energy savings, not all of them were implemented with such savings as their primary objective. A review of the reasoning behind each project's implementation revealed a range of drivers for the projects. These motives can be divided into five separate categories: Production Issues, Energy Savings, Motor System Effectiveness, Plant Expansion, and Process Reliability. The Production Issues category refers to projects that were implemented because a motor system was unable to support production processes effectively and the plant was experiencing severe production stoppages and/or high product reject rates. The Energy Savings group represents plants in which there was recognition that a particular motor system was wasting energy and that optimizing it to capture energy savings was a worthwhile pursuit. The Motor System Effectiveness label describes motor systems that were able to support production equipment but that operated erratically or unsatisfactorily. The Plant Expansion category includes plants that underwent an expansion of production equipment and optimized a motor system to support the expansion. Finally, two projects in the study were undertaken with the primary aim of ensuring process reliability. The five categories and the numbers of projects performed according to each are shown in Table 5.

Table 5. Drivers of Motor System Projects

Category	Number of Projects	Percent of Total
Production Issues	8	20%
Energy Savings	14	34%
Motor System Effectiveness	15	37%
Plant Expansion	2	5%
Process Reliability	2	5%

Potential Industry-Wide Energy Savings

To provide planning-relevant information useful for strategic planning, the study extrapolates energy savings for US industry based on estimates of annual energy consumption by industrial motor systems. Ballpark estimates of potential industry-wide energy savings were calculated using data from two separate sources: the United States Industrial Motor-Driven Systems Market Assessment written by the US DOE's EERE and the EIA's Manufacturing Energy Consumption Survey (MECS) from 1998.

According to EERE's assessment, U.S. industry consumed 691 billion kWh in process motor-driven systems in 1994. The MECS industrial end-use consumption figures reveal that direct industrial uses and processes in US manufacturing plants consumed over 711 billion kWh in 1998. The aggregate pre-project power consumption by the motor systems in the study's 41 plants is 453 million kWh. The energy savings by the plants in the study (106 million kWh) represent a 23% reduction in their aggregate energy consumption. Whether all industrial facilities in the US would achieve similar energy savings rates from implementing projects aimed at improving motor system efficiency is not evident. However, because many of the projects in the study employed best practices in industry for motor system optimization, it is not too far-fetched either. Therefore, a range is presented in Table 6 that indicates how much energy and money could be saved under various implementation rates based on the 23% energy savings rate achieved in this study.

Table 6. Total US Energy Savings from Potential Motor System Optimization Projects (figures are in millions of kWh and U.S. Dollars)

	EERE Assessment		
Implementation Rates	10%	25%	50%
kWh	16,228	40,570	81,139
Dollars	779	1,947	3,895
	MECS Data		
Implementation Rates	10%	25%	50%
kWh	16,698	41,744	83,488
Dollars	801	2,004	4,007

As shown in Table 6, manufacturing plants in the US could potentially save as much as 83 billion kWh and 4 billion dollars if manufacturing plants that account for 50% of industrial energy consumption would implement projects of similar quality as those in this study. While these sets of figures are tentative, they provide a rough estimate of the range of industry-wide energy savings that industrial motor system optimization projects might achieve in the US. Additional savings can also be obtained by improving other industrial systems such as steam and direct-fired process heating systems.

Conclusion

This study's intent has been to estimate the impact on industrial competitiveness resulting from motor system optimization projects. The impact of 41 motor system optimization projects was evaluated individually and collectively using three metrics: NPV, IRR and simple payback. The main findings are that:

- A majority of the 41 projects was successful according to the study's criteria.
- Projects that were implemented in energy intensive manufacturing plants obtained a greater rate of success and a higher rate of return.
- Projects involving large expenditures on capital achieved lower rates of success and return than projects characterized primarily by engineering or process changes.
- Many projects resulted in positive externalities such as maintenance savings, better productivity, lower emission levels, reduced purchases of ancillary products, improved plant safety and avoided purchases of plant capital or other costs.

The important finding, is that motor system optimization is an underrated source of productivity. Many of the 41 projects were performed in response to production problems. Once the projects were complete, the production problems went away and the plants began to notice the energy savings. Improvements in production occurred in 34% of the plants in this study and while many of them could not quantify the production impact of their project, they recognized that production increased or that production equipment operated more effectively after the project completion. Instead of re-allocating resources, motor system improvements cause the specific systems to use fewer resources (namely, energy) while allowing for a desired production level or standard of quality. Because of this, such projects increase industrial competitiveness and productivity. To view some of the case studies whose data was used in this report, please visit: http://www.oit.doe.gov/bestpractices/case_studies.shtml.

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