Factors That Influence the Selection of Electric Motor Drives For Natural Gas Compressors

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EXECUTIVE SUMMARY

This report provides a summary and analysis of the strategic, engineering, and economic factors that currently influence the selection of electric motor drives (EMD) for natural gas compressors, and provides an industry-based consensus on the future use of EMD. The industry consensus was derived from a survey of INGAA Foundation members and other industry representatives who are recognized authorities on gas compression and drive systems.

The survey shows that while EMD have certain very desirable features (emission compliance, low capital and maintenance costs, controllability, etc.), the cost of electric power normally precludes their use in all but specific cases (e.g., when environmental issues are sufficiently critical to justify their added energy expense, or where electric power rates are unusually low). Industry respondents indicated that fuel/power costs often constitute a large percentage (over 50 percent) of the unit's life cycle costs, and that electric power rates on the order of 2 to 3.5 cents/kW hour would be required to make EMD cost competitive with present day gas turbine or engine drives.

Nevertheless, industry projections show that the use of EMD will maintain recent rates in the foreseeable future and will constitute some 17 to 25 percent of the six to seven million horsepower that must be added by the year 2010 to meet projected domestic gas demands. Gas turbine drives are projected to provide some 75 percent of this horsepower, with recip units playing a smaller role.

Virtually all of the negative evaluation factors for EMD were associated with "fuel" costs (i.e., the base cost of electric power, high demand charges, the cost of the transmission infrastructure required to get electric power to the compressor site, and the inability to negotiate effective long-term "customer-service" oriented power contracts). So long as natural gas is valued primarily as a fuel, it seems unlikely that electric rates can compete - even with deregulation of the electric power industry.

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INTRODUCTION

Objectives of Study

The objectives of this study are to define and quantify the factors that influence the selection of Electric Motor Drives (EMD) for compressors in the natural gas industry and to identify the advantageous characteristics of electric drives for various applications. This INGAA Foundation-supported investigation identifies relevant selection factors, collects data from the industry, and analyzes the decision process for selecting EMD over more traditional (I/C) engine or gas turbine units. Both qualitative and quantitative selection factors are presented, together with a projection of future EMD installations as the industry grows during the next 5 to 10 years.

Approach

Most of the significant factors involved in selecting a compressor drive are identified in recent industry publications, symposia, and workshops conducted specifically for the exchange of information related to the choice and use of electric and other types of compressor drives. One of the active symposia in this area is an annual Gas/Electric Partnership event sponsored by EPRI and others. The major factors described in this report were derived from these sources, from discussions with industry representatives, and from an industry survey that asked respondents to confirm, expand, and comment on EMD selection criteria. The salient factors are discussed later in this report.

An important part of the study was an industry survey designed to collect and compare quantitative and opinion data from industry personnel who have been, are, or will be involved in the selection of natural gas compressor drive systems. The survey was sent to all INGAA member companies with the intent that companies involved in the selection of compressor drives would respond. In addition, the survey was sent to members of the Gas/Electric Partnership referred to above, and to members of the PRCI Compressor Research Supervisory Committee.

These groups include the majority of identifiable industry experts on the selection, application, and design of electrical drives and compressor systems.

A significant response representing the position of the natural gas industry is provided by the survey results. In addition, the survey explored the decision process used for selection of compressor drives. The prevailing decision processes are identified and explained in this report, and the major factors are used as a basis for analyzing and estimating future use of EMD systems.

Background

The projected growth in the demand for natural gas is expected to reach some 30 TCF by the year 2010 or shortly thereafter, and the supporting increase in gas supplies, dictate a substantial corresponding increase in natural gas compression in the next 5 to 10 years, involving most of the major operating companies. In addition, the deregulated business environment and customer demands will require that planning for this increase in capacity be innovative, flexible, environmentally sensitive, and economically justifiable. In view of this situation, the INGAA Foundation requested a study of the factors that influence the use of EMD. It is expected that the collection of information and perspective in this report will provide at least a checklist for industry's use in selecting equipment best suited for projected expansion needs.

Both DOE and GRI concur in the projected demand of 30 TCF by the year 2010 or a few years thereafter, and that the major increase in demand will occur in the Northeast and Midwestern United States. Increases in the supply of natural gas will come largely from Canada and the Gulf of Mexico, and substantial increased pipeline capacity will be required to get this gas to market. The customers who make up this growing demand are largely open market customers, such as electric power producers, niche market manufacturers, and local distribution companies (LDC's) who also experience competitive pressures and need flexible, responsive fuel supplies and suppliers. To meet these market demands in the current competitive business environment, gas companies will need not only increased compression capacity but additional pipeline flexibility, increased storage capacity, and spur pipelines that are responsive to rapid swings in demand. These requirements add up to an increase in compressor horsepower needed along the pipelines and at specific market locations.

Environmental concerns at compressor stations and gas storage facilities (including noise, appearance, and emission compliance) are major factors when installing a new compressor drive. For many compressor locations, both the environmental regulations and the neighborhood are changing, requiring more detailed control technology at new and existing pipeline facilities. In non-attainment areas where permits for new or additional emissions are difficult and time consuming to obtain, the use of EMD can substantially eliminate the concern for environmental emissions from the station. Usually, EMD also produce lower noise levels and have less adverse visual impact on a station's surroundings.

The decisions on what types of compressors and drivers to install, including the potential use of Electric Motor Drives (EMD), are controlled by economic, environmental, and operational requirements and take advantage of the latest technology changes. Operational requirements include load and type of duty, operating schedule, reliability, availability, staffing and control issues. EMD can, of course, be applied to gas transmission lines, gas storage facilities, or other gas delivery situations, and can be used for either new or replacement horsepower. The schedule on which a compressor installation must be completed is another major factor in the selection of compressor and drive units, together with capital, maintenance, operating, and fuel costs. These and other factors are described and discussed as a result of the survey.

In comparison to the traditional gas fired reciprocating engines and gas turbine drives, electric motors can have lower installation costs and certainly lower site-specific emissions. Operating range and flexibility can be addressed with electric motors using variable speed drive technology, which has improved significantly in the past ten years. The reliability and O&M costs for electric motors are favorable aspects. The availability and cost of electric power for large motors, however, are potential negative factors for the use of electric motors—at least at some sites.

A significant number of successful EMD installations for natural gas compression exist in the industry today. There are an estimated 130 EMD units currently in use. Many of these installations have been selected because of environmental restrictions or noise considerations at the station involved. At one compressor station, only electric drives were able to satisfy the concern of the neighbors relative to fugitive emissions, noise, and appearance. At another compressor station, an older unreliable unit was replaced with an EMD, with a resulting improvement in reliability and emissions. Some have been installed because of low capital cost, relative short lead times, or operational flexibility of the unit. At a gas storage facility that supplies a large power plant, the flexibility of series/parallel EMD compressors using off-peak electric power provides an economic means to ensure gas supply for the power station. There have also been a number of cases where cost factors and other factors (such as no available, nearby high voltage power lines, or the inability to obtain long term, reliable, low-cost power contracts) have prevented the use of EMD. This study is intended to evaluate the influence of each of the major factors and the effect on the future trends for selecting electric motor compressor drives.

Overview of Results

In summary, the major observations from the study are as follows:

- EMD are considered for most compressor drive applications, but normally they are installed only where environmental considerations are overriding, and in a few others cases where operational and cost factors are favorable.

- The capital and maintenance costs of EMD are lower than for conventional drives, but for most situations, the cost for electric power is significantly higher than that for fuel gas.

- EMD will generally not be used where:
  - electric power service is not readily available,
  - where demand charges are restrictive, or
  - where the electric power costs are relatively high.

- The primary use for EMD is presently in locations and situations where the environmental requirements are the dominant concern. In such cases, EMD are used even when the power cost factors are not favorable.

- Based on projections of the gas industry growth to the year 2010, electric motor drives will account for some 17 to 25 percent of approximately 6 million more horsepower to be installed.

- The cost of electrical power and high demand charges are the most significant obstacles for the use of EMD. A large number of the surveyed companies would use more EMD if electrical power costs were 3.0 cents/kW hour or less.

EMD SELECTION FACTORS

Major Factors

The factors that influence the selection of EMD are listed in Table 1, under four major headings: Operational, Reliability, Environmental, and Economical. While other names can be put on most of these factors, the list includes (by one name or another) essentially all of the factors identified in this study that were cited by industry as influencing the selection of compressor drive types for various transmission and storage applications. The importance of individual factors can change for different installations or configurations. However, from a broad point of view, the important factors remain fairly constant.

Table 1. The Factors that Influence the Use of Electric Motor Drive Compressors

Operational Factors
Required Flow Rate and Flow Rate Range
Total Required Horsepower
Type of Compressor
Control and Automation Requirements
Compatibility and Company Experience
Reliability Factors
Reliability of Drive
Power or Fuel Availability
Duty Cycle, Availability, and Operating Hours
Environmental Factors
Emissions Compliance
Noise and Neighborhood Impact
Economic Factors
Fuel/Power Costs
Efficiency
Maintenance Costs
Capital Costs (including installation and instrumentation)
Operational Costs (other than fuel and maintenance)
Delivery/Construction/Startup Time

Operational Factors

The operational factors are often related to compressor types and design or engineering issues. At pipeline compressor installations, system demands such as maximum flow rate, flow rate range, suction and discharge pressures (compression ratio) have a major influence on the type of compressor selected. In turn, the type of compressor (reciprocating, centrifugal, or rotary) has a large impact on the drive unit selected. Reciprocating compressors are normally selected for high-pressure ratio service, although new-technology multi-stage centrifugal compressors can achieve the large-pressure ratios that older centrifugal compressors could not accommodate with reasonable efficiency. Centrifugal compressors have been selected more frequently in the past 10 or more years because of the large capacity that can be achieved with a single unit, and because of the substantial improvement in efficiency that is achieved in modern designs. Centrifugal compressors usually have a more limited flow rate range than variable speed reciprocating compressors, but modern centrifugals are nearly as efficient over a selected operating range as reciprocating compressors. Rotary compressors are very rarely used except for low-pressure delivery and occasional suction pressure boost applications.

Reciprocating compressors are generally older main line units or storage facility units, and were selected because of relatively high efficiency over the desired operating range, with the ability to handle large pressure ratios. Large numbers of comparatively small reciprocating units represent the traditional compressor station which derives flexibility from the number of units, their speed range, and their ability to accommodate a large range of pressure ratios. Reciprocating compressors provide relatively high efficiency over a wide operating range, but have a higher capital cost than centrifugal compressors. The drive units for most reciprocating compressors are usually natural gas fired I/C engines that match the speed and power requirement of the reciprocating compressors. Gas turbine drives are not generally selected to drive reciprocating compressors, because the speed ranges do not match, a speed reducing gear would be required, and flexibility would be limited. Variable speed EMD, however, are suitable for reciprocating compressors without use of a gear box to reduce speed.

Centrifugal compressors are usually selected when a large capacity and low (fairly stable) pressure ratio is required. Under such conditions, centrifugal compressors usually represent a lower installed cost than reciprocating compressors for the same conditions. These types of low head, high flow conditions usually occur at main line stations operating with fairly stabilized conditions. The operating range of a centrifugal compressor is limited by aerodynamic design factors, operating speed limits, and surge. Surge is a flow instability that limits the turndown or minimum flow of a unit to 25 or 30 percent below the design flow rate. One means of overcoming surge is to recycle flow from the discharge back to the suction to maintain a minimum flow through the machine; however, this is very costly in terms of wasted horsepower. Gas turbine engines are usually used to drive centrifugal compressors because of the continuous high-speed operation. EMD are suitable for centrifugal compressor drives, but may need a gear type speed increaser for higher speed compressors.

In some cases, the type of compressor selected is influenced by the total amount of horsepower per unit. Reciprocating units are generally in the 400 to 12,000 horsepower range. (Because operating speed is relatively low, their physical size becomes unmanageably large for higher horsepower levels.) Centrifugal compressors tend to come in larger sizes of 1,500 to 40,000 horsepower or more. There are exceptions to these general rules; however, one large centrifugal can usually provide the compression horsepower of several "large" recip compressors. Other operational factors that influence the details of compressor selection and installation are how they will be controlled, the degree of automation required, and the compatibility with other compression equipment and experience within the operating company.

Reliability Factors

Reliability of a compressor unit and its driver are major concerns to pipeline operating companies. The economic loss from compressor down time can be significant. Reliability of the fuel supply (whether it is natural gas or electrical power) can be a significant part of that overall compressor reliability. Both scheduled maintenance and unscheduled operational failures are important in this regard, but the adverse effect of scheduled maintenance can usually be minimized by proper scheduling. Operational reliability is therefore very important, and can be affected by start-stop operation, cool down sequences, and other operational and maintenance factors. If a machine runs for long continuous periods or for many short cycles, and whether these changes are regular or random, have a potentially large impact on the reliability of a drive unit. EMD can be technically advantageous when frequent start/stop operations are required, but electrical demand charges may become prohibitive under such conditions.

Environmental Factors

Environmental regulations (such as provisions of the Clean Air Act and other state and local regulations) can provide restrictions on the amounts of specific pollutants that are released at certain sites. Title IV of the Clear Air Act limits the amounts of nitrogen oxides (NO_x) and sulfur dioxide (SO_2) that can be released from selected sites. These are particularly important considerations in the Northeast and Midwest U.S., but can affect other areas as well. Under Title I, the ambient air quality including ozone, CO_2, and particulate matter are limited in such a way that certain geographical areas (non-attainment zones) have significant restrictions on new sources, while other areas are not noticeably affected. Federal regulations also require that each state develop and implement a program for issuing site permits for air emissions. Even where the permit process is not restrictive, it can be time consuming and costly. Each compressor drive project has its own magnitude of influences from environmental factors.

The neighbors that are near a potential compressor site can also have a significant influence on the requirements for a compressor drive. The urbanization of rural communities has substantially increased the emphasis on controlling emissions and noise and for assuming visual compatibility of compressor installation with the surrounding neighborhood. Air pollution, noise pollution, and general appearance have become more of a sensitive and restrictive factor. EMD can sometimes be used to successfully address these types of issues.

Economic Factors

Cost elements always have a major influence on any compressor and drive selection. In most cases, the total combined lifetime cost of each option is compared to determine which option is most economical. The factors considered in determining the life cycle cost of a compressor drive, as defined for this study, are capital (installed) costs, maintenance costs, operational costs (other than maintenance and fuel), and fuel or power (energy) costs. The efficiency of a unit in producing flow for the expenditure of fuel is considered in the fuel costs to meet the project requirements. Capital costs include the purchase cost of equipment, project installation cost, project engineering costs (in some cases), and other costs that will be financed over a period of time (e.g., electrical substations and transmission lines). The source, financing, and amortization of capital costs for a particular project can influence the significance of capital costs.

Maintenance costs for different types of compressor drives vary substantially and affect the relative life cycle cost of the drive. Reciprocating engines generally experience regular (annual) maintenance costs that adds up to a large cost over the life of the engine. Gas turbines experience once-per-overhaul costs (every few years) that are larger amounts than for other types of drives. EMD consistently have noticeably lower maintenance costs than other types of drives. In several recent studies by operating companies, the cost of large electric motors with their electrical switch gear and high voltage transmission equipment was higher than equivalent gas turbines until the maintenance costs were included. The significant maintenance costs can cause a gas turbine unit to be more costly in the long term.

Operational costs (other than maintenance and fuel) include staffing costs and perhaps specialized personnel that must be on station or available. Reciprocating engines generally require a higher level of routine manning than other drivers, and gas turbines can require skilled staff - particularly if frequent start and stop operations are involved. Electric motors can be operated with very low staffing requirements; however, many of the skills required are not generally available to traditional natural gas companies. Additional economic elements result from time restraints on project delivery, construction, and start-up schedules. All of these cost elements must be evaluated and compared for each individual compressor drive selection project.

Fuel cost is usually the deciding influence on the cost comparisons for compressor drive projects. Fuel cost differences accumulated over tens of thousands of operating hours in a compressor's life is usually the dominant cost element in a project. A small difference in the expected or assumed cost of fuel or power has a large effect on the analyzed cost of a project. Most published comparisons of fuel and power costs obtained during this study agree that where natural gas fuel costs are just over $2 per decathern ($2.35 DT), the equivalent cost of electrical power is approximately 3 to 3.5 cents/kW hour. To be equal, these costs need to include any demand charges or similar service fees. This survey of the industry and recent contacts with industry representatives indicate that for most compressor drive selections at this time, electrical power is at a cost disadvantage compared to natural gas, and costs approximately 4 to 5 cents/kW hour. This situation may change in the future if electrical power costs decrease as a result of deregulation.

SURVEY RESULTS

A strong response was received from INGAA Foundation members, including 13 companies or roughly 72 percent of the INGAA pipeline operating members. In addition, 9 responses were received from technical committee members with a few from the same companies, and most from additional operating companies. The surveys to INGAA Foundation company representative were sent by the INGAA office. Other survey forms were mailed to Gas/Electric Partnership members and PRCI Compressor Research Supervisory Committee representatives. A total of 22 survey responses were received and evaluated, which represents a significant share of the total natural gas pipeline operating companies in the U.S. The total pipeline mileage represented by the respondents includes 82 percent of the gas transmission piping in the U.S. A copy of the survey form is included in Appendix A.

Question 1

Survey responses for the first question indicate that Electric Motor Drives (EMD) are considered as potentially viable options for compressor drives by 92 percent of the INGAA member companies who responded, and by over 90 percent of all respondents. Variable speed electric drives receive more consideration than fixed speed drives according to the survey. Of the 22 responses, 18 consider variable speed drives for projects, and 11 consider fixed speed drives. In other words, variable speed drives are considered for approximately 80 percent of the projects, while the less expensive but less flexible fixed speed electric drives are considered by only 50 percent of the respondents. The selection/evaluation process generally requires about 3 to 4 months, although some companies indicated less than 3 months and a few more than 4 months. Details from the survey show that 3.9 months is the average for INGAA members and 3.3 months for the other responses. One important indication from the survey comments is that although 90 percent of companies are, or have evaluated, EMD for natural gas compressors, 6 of the 22 respondents indicated they will not be considering EM in the near future. Detailed reasons for not considering EMD in the future were not given; however, this response tends to indicate that EMD are economically unjustifiable in their current circumstances. Figure 1 shows the percent of INGAA representatives, other representatives, and total respondents who consider EMD for compressor service. It can be concluded from this data that electric motors are receiving consideration as compressor drives.

Question 2

In the second question, first part, the survey respondents were asked to indicate the probability of selecting EMD in the four different applications: gas transmission, spur lines or interconnects, storage/withdrawal, and gathering/distribution. For each company, this should indicate the type of application for which EMD are most compatible. The responses are shown in Table 2 and Figure 2. Gas transmission applications received the highest probability rating[1] by both INGAA members and other respondents. The overall probability for transmission service is 56 percent or realistically a medium probability. Gas storage/withdrawal applications received the second highest overall probability at 38 percent as an average from all of the responses.

Table 2. Probability of Selecting EMD by Application

Application Probability from	INGAA	Other	Total
Gas Pipeline Transmission	51%	63%	56%
Spur line or Interconnects	26%	48%	35%
Storage / Withdrawal	26%	56%	38%
Gathering / Distribution	8%	30%	17%

However, the INGAA members indicated a probability of 26 percent, while the other responses indicated a 56 percent probability of using EMD in storage/withdrawal applications. The non-

1 The manner in which probability is determined is to add 3 points for a high probability vote, 2 points for a medium probability vote, 1 point for a low probability vote, and 0 for not applicable or not likely. The total number is divided by the total possible points, such that all high probability votes would result in 100 percent. All medium probability votes would equal 67 percent, all low probability votes would equal a 33 percent, and not applicable votes would result in 0 percent.

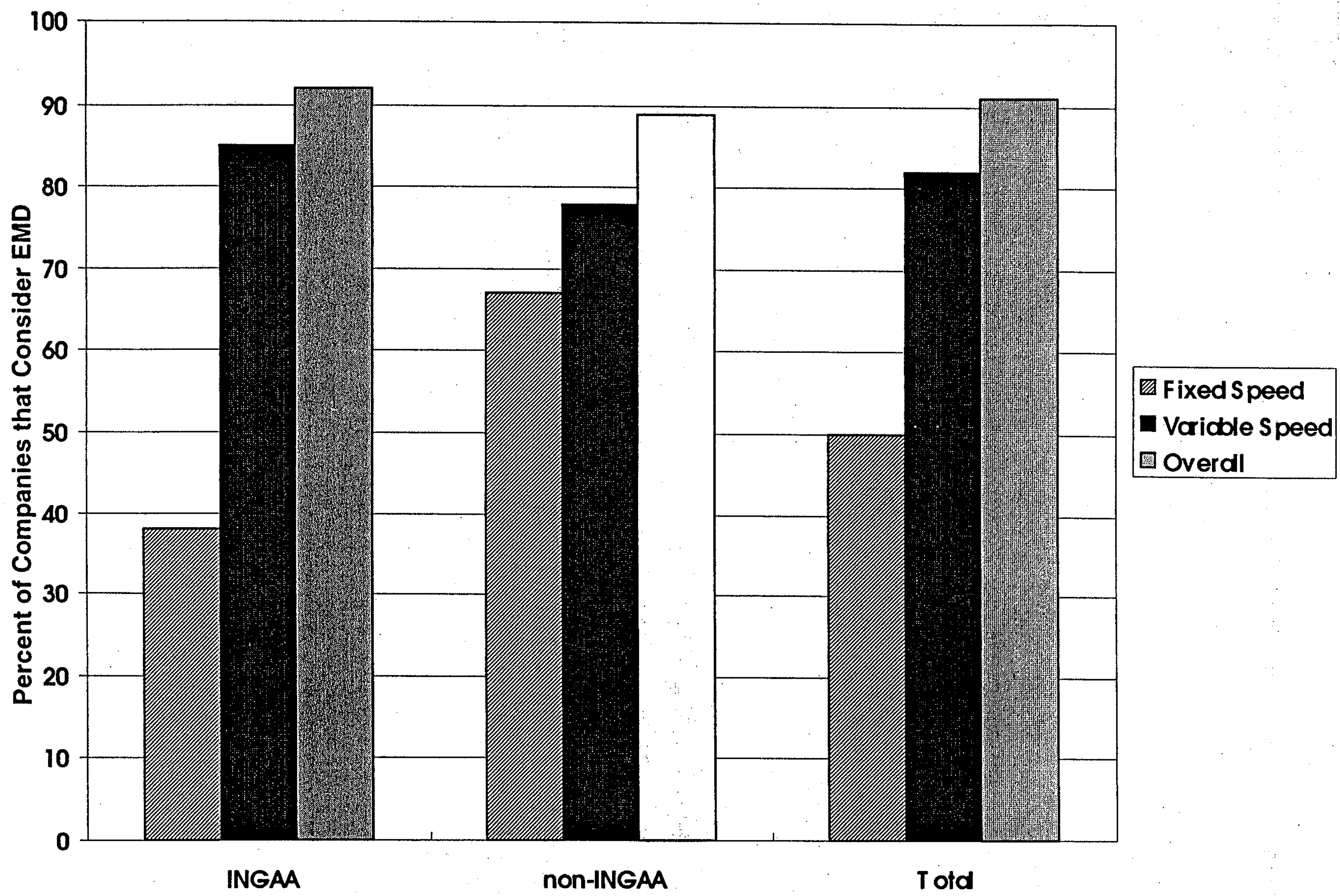

Figure 1. Percent of Companies that Consider EMD for Compressor Service

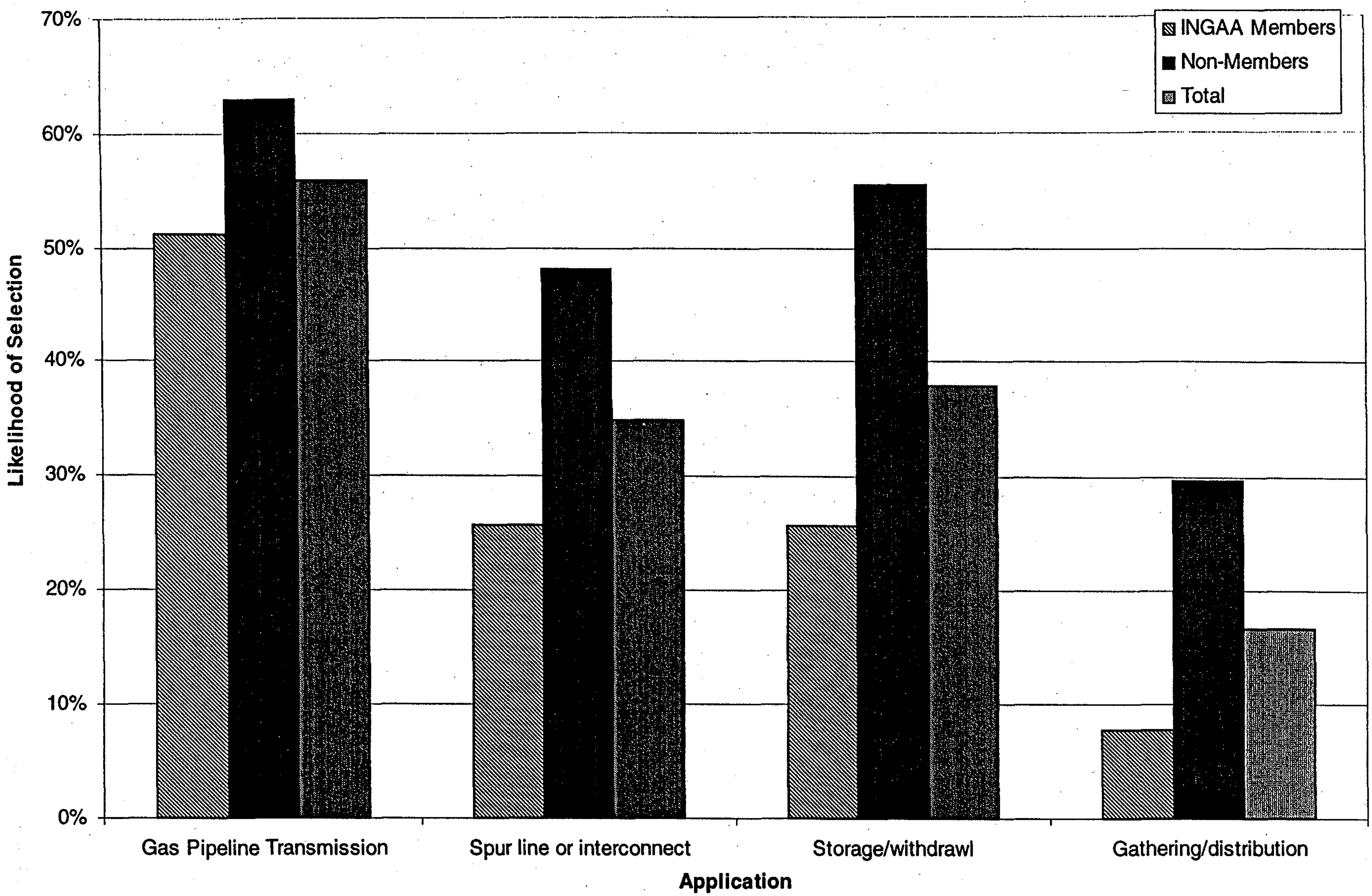

Figure 2. Probability for Selecting EMD for a Particular Application

INGAA respondents may represent senior engineering personnel with particular technology knowledge or may reflect companies with more storage applications than the INGAA Foundation members who responded. For whatever reasons, there is a significant difference in the indicated probability of use for storage/withdrawal application between low for INGAA respondents and medium for other respondents. The spur line or interconnect application received an overall probability of 35 percent, a low probability, with a similar but not as wide a diversity of option between INGAA and non-INGAA responses. Table 2 and Figure 2 indicate that there is a medium probability that EMD will be used in gas pipeline transmission applications and that the other applications have, on average, a low probability.

Some of the comments that accompanied these responses were informative. Six of the respondent's comments pointed out the necessity for near-by-electrical power to make EMD feasible. Four comments indicated that EMD would only be used where the economic cost of power was favorable. Four comments indicated that EMD would be used where environmental restrictions justified the cost and application. Two of the comments indicated EMD are most suitable for base or constant flow loads. In contrast, two responses indicated that EMD are most applicable for peak or variable load service. Experience has shown that EMD can be used for either steady or variable load service, if other factors are favorable.

In the second part of question 2, the survey respondents were asked to indicate the probability of selecting EMD for certain compressor installations, or for projects where major factors were identified. Respondents were asked to indicate the probability of selecting EMD for:

- Environmentally sensitive areas,
- Centrifugal compressors,
- Low HP reciprocating compressors,
- High HP reciprocating compressors,
- Peak load services,
- Continuous operations,
- Fixed speed units,

- Variable speed units, and
- High reliability (no curtailment) situations.

The results are shown in Table 3 and Figure 3. The situation which received the highest probability was the environmentally sensitive area, where the average probability was 83 percent and the INGAA members indicated 92 percent. Accurately, 83 percent is mid way between all high probability and all medium probability but, in fact, it represents more than half of the respondents indicating a high probability for use of EMD in the situation where the installation is an environmentally sensitive area. All other situations received probability ratings between medium and low. These are (in approximate order) for continuous operations at 58 percent, for centrifugal compressors and high reliability situations both at 57 percent, for high horsepower reciprocating compressors at 54 percent, for fixed speed and variable speed units both at 51 percent, and for peak load service and low horsepower reciprocating compressors both at 48 percent. A close examination of Table 3 or Figure 3 will show that in these medium to low probability cases, the INGAA and non-INGAA respondents did not always agree on the order (most probable to least probable) but generally did agree on the magnitude of the likelihood of using EMD for a given situation. The use of EMD is considered only moderately likely for most situations with the typical types of compressors, services, reliability requirements, and speed variations. The most significant result from the second part of question 2 is that the industry considers EMD as a highly probable compressor drive for installations in environmentally sensitive areas.

Table 3. Probability of Selecting EMD by Situations

Situation	INGAA	Non-INGAA	Total
Environmental Sensitive	92%	70%	83%
Centrifugal Compressor	61%	52%	57%
Low HP Reciprocating	39%	59%	48%
High HP Reciprocating	47%	63%	54%
Peak Load Service	47%	48%	48%
Continuous Service	56%	63%	59%
Fixed Speed Unit	50%	52%	51%
Variable Speed Unit	56%	44%	51%
High Reliability Required	58%	56%	57%

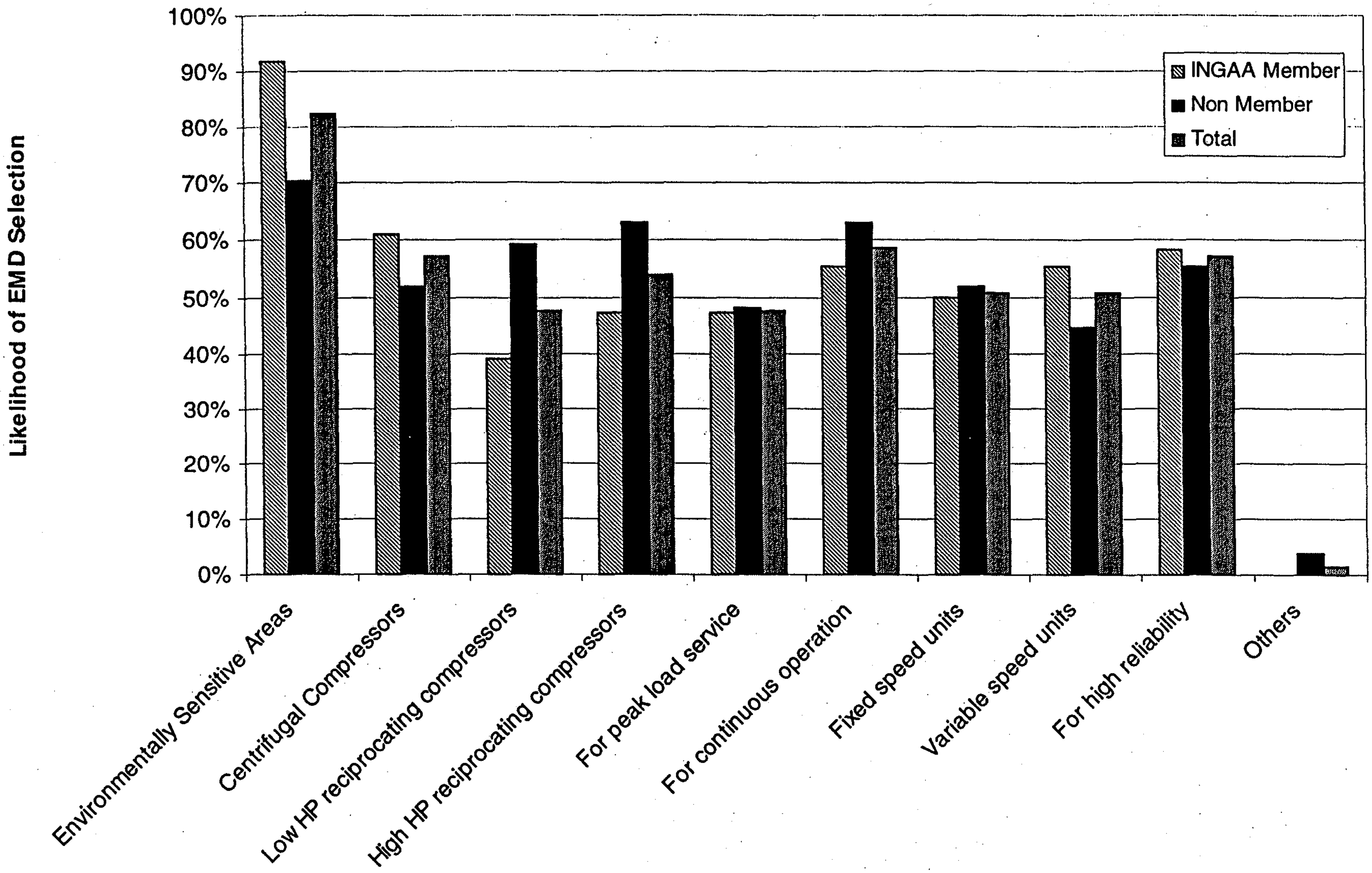

Figure 3. Probability of Selecting EMD for Various Compressor Station Scenarios

Question 3

Question 3 deals with the total horsepower that companies have installed recently or plan to install in the near future. The period of time for which information is requested is the past five years (1992-1996), the current 3 years (1997-1999), and the next four years (2000-2003). The yearly average horsepower (installed or planned) for the past, current, and future periods are shown in Table 4. The total horsepower installed by the surveyed portion of the industry is 583 thousand HP/year for the past 5 years, 613 thousand HP/year for the current 3 years, and a predicted 154.5 thousand HP/year for the next four years. The lower estimated horsepower to be installed in coming years undoubtedly reflects the uncertainty in long term planning and the uncertainty of the business environment. As discussed later, the amount of horsepower to be installed in the future is most likely at least twice what is shown in Table 4, and may be similar to the past and current years. In any case, a substantial amount of new horsepower will be installed by the natural gas industry in the next 4 to 12 years.

Table 4. Average Annual Horsepower Installation by Category

Category	Past HP	Past %	Current HP	Current %	Future HP	Future %
Total	582800		612800		154500	
Reciprocating	66475	11.4	47975	7.8	17050	11.0 *
Centrifugal	516150	88.6	563000	91.9	119975	77.6 *
Rotary	200	0.03	400	0.07	0	
Undefined	30900	5.3	28575	4.7	70750	45.8 *
Recip Engine	40150	6.9	14150	2.3	5175	3.3
Gas Turbine	465725	79.9	457750	74.7	71050	46.0
Electric						
Fixed Speed	12250	2.1	27300	4.4	3500	2.3
Variable Speed	33800	5.8	85000	13.9	4050	2.6
* Reflects uncertain future plans.						

The percent of total annual horsepower represented by each type of compressor and by each type of drive is also shown in Table 4. The survey data indicates that centrifugal compressors will represent some 75 to 90 percent of the new horsepower sold, that reciprocating compressors will constitute 11 percent (with an uncertainty of around 3 to 4 percent), and that other compressors including rotary compressor will account for less than 1 percent of the total horsepower installed. This trend can be expected to continue in the next 5 or more years.

The percent of horsepower for each type of driver is also identified in Table 4. In the recent, past, and current years, gas turbines have represented 75 to 80 percent of compressor drivers. Gas engines (I/C) averaged approximately 7 percent of drivers in past years but only accounted for 2.3 percent between 1997 and 1999. This may reflect the environmental, maintenance, controllability, and overall cost concerns related to internal combustion engines, or just a general change in technology. The projected use of gas fired reciprocating engines is estimated to be about 3 percent (with an uncertainty of 2 to 3 percent), which is consistent with current installation trends. Electric motors accounted for approximately 8 percent of the installed horsepower in the past years, over 18 percent in the current years, and somewhere between 5 percent, and 28 percent in the future. The industry estimate for the next four years shows 46 percent of the horsepower to be gas turbine drivers, approximately 5 percent EMD and 46 percent undefined. This *undefined* result indicates that driver type is yet to be determined for at least 46 percent of the horsepower to be installed in the next four years. Neglecting the small (3 percent) effect of internal combustion engines, if 75 percent of the undefined horsepower is selected as gas turbine drives, then 80 percent of the future horsepower would be gas turbines, and approximately 17 percent would be EMD. If only half of the undefined horsepower becomes gas turbines, then EMD could be as much as 28 percent of the future installed horsepower. This part of the survey indicated that it is likely that 17 to 25 percent of future horsepower (over the next 4 to 12 years) will be in the form of EMD.

Table B-1 in Appendix B gives more detailed information on horsepower totals for past, current, and future time periods, as seen by INGAA members and other survey respondents. The per company (or per respondent) averages and the standard deviation from the results are also shown in Table B-1. Although the per company averages seem fairly consistent with the totals and the annual averages in Table 4, it is noted that the standard deviation is fairly high, and corresponds to a one company level in many cases. The results shown should be considered with an uncertainty of approximately 10 percent. Despite this uncertainty, responses provided by the industry show that EMD would have a significant but not dominate use in natural gas compressor drive systems.

Figure 4 shows the company average horsepower for each type of compressor, for INGAA respondents, non-INGAA respondents and the total for the past, current, and future time periods. Again, the total horsepower per respondent for the future years may be underestimated because of the uncertainty related to future projects. The results in Figure 4 show that approximately 75 to 80 percent of horsepower is and will be from gas turbine engines, and that the horsepower for EMD has grown from 8 to 18 percent and may continue to be some 17 to 28 percent in the next ten years. The future percentage is obtained by allocating 75 to 80 percent of the undefined future horsepower to gas turbines and the remainder to EMD. This method neglects the small effect of internal combustion engines, but clearly indicates that EMD units will have a place in future compressor drive applications.

Question 4

Question 4 asked survey respondents to numerically rate various factors as favoring gas fired or electric drives. The scale for answers shows "0 to 5" on the electric side and "0 to 5" on the gas side, with 5 indicating a very strong favorable effect for that factor on the selected side, and 0 representing a neutral influence for that particular factor. The factors in the list for question 4 are those listed in Table 1 in the discussion of factors. The results are determined as the numerical average from all respondents with the electric side as negative numbers and the gas side as positive numbers. Obviously, the sign of the number only distinguishes which type of driver that answer favors, and allows results from one respondent on the gas side to be balanced by other results on the electric side. The numerical averages for INGAA members, non-INGAA surveys, and all of the responses are shown as bars on the chart in Figure 5. Since 1 is only slightly

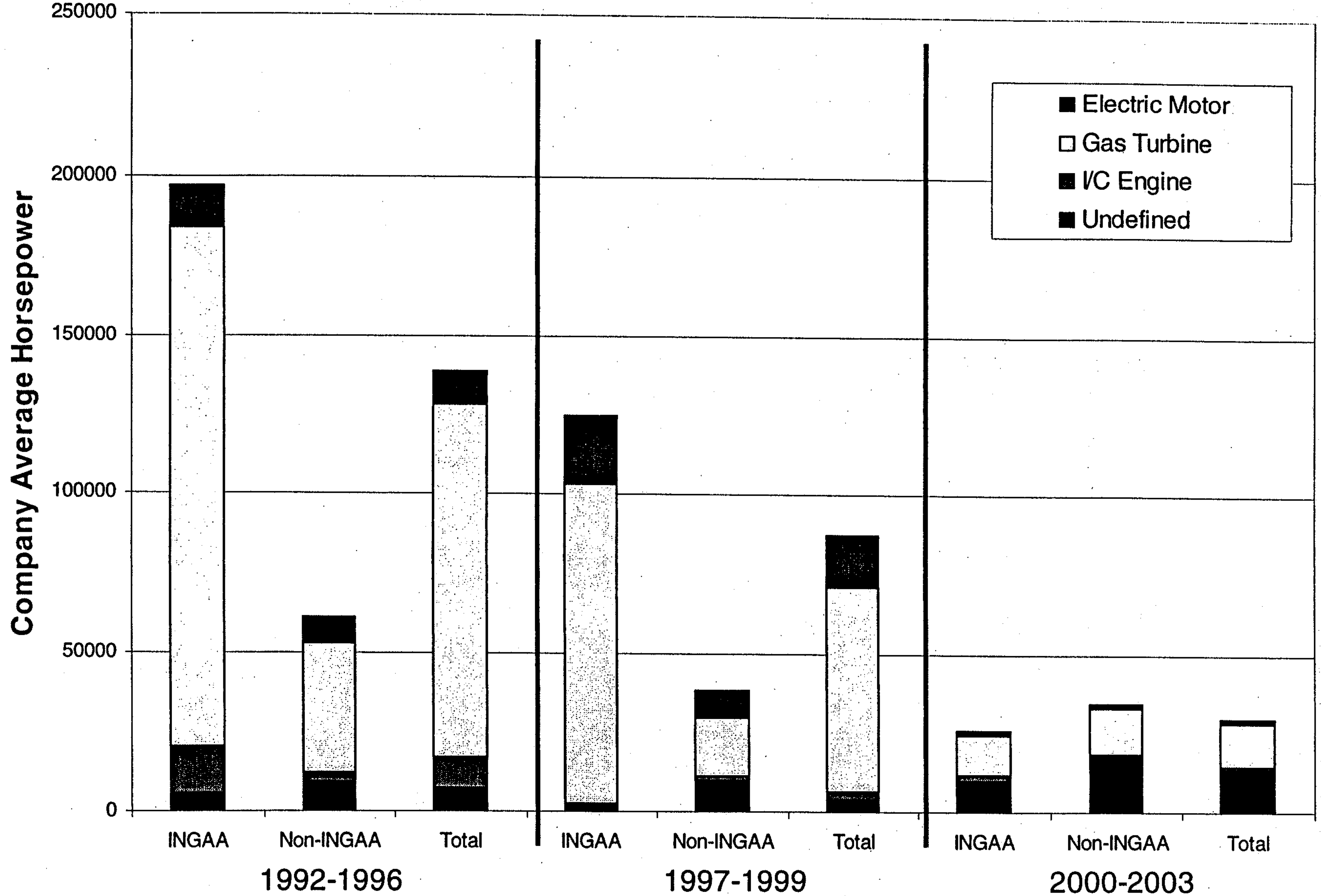

Figure 4. Company Added Horsepower by Drive Type for Past, Current, and Future Years

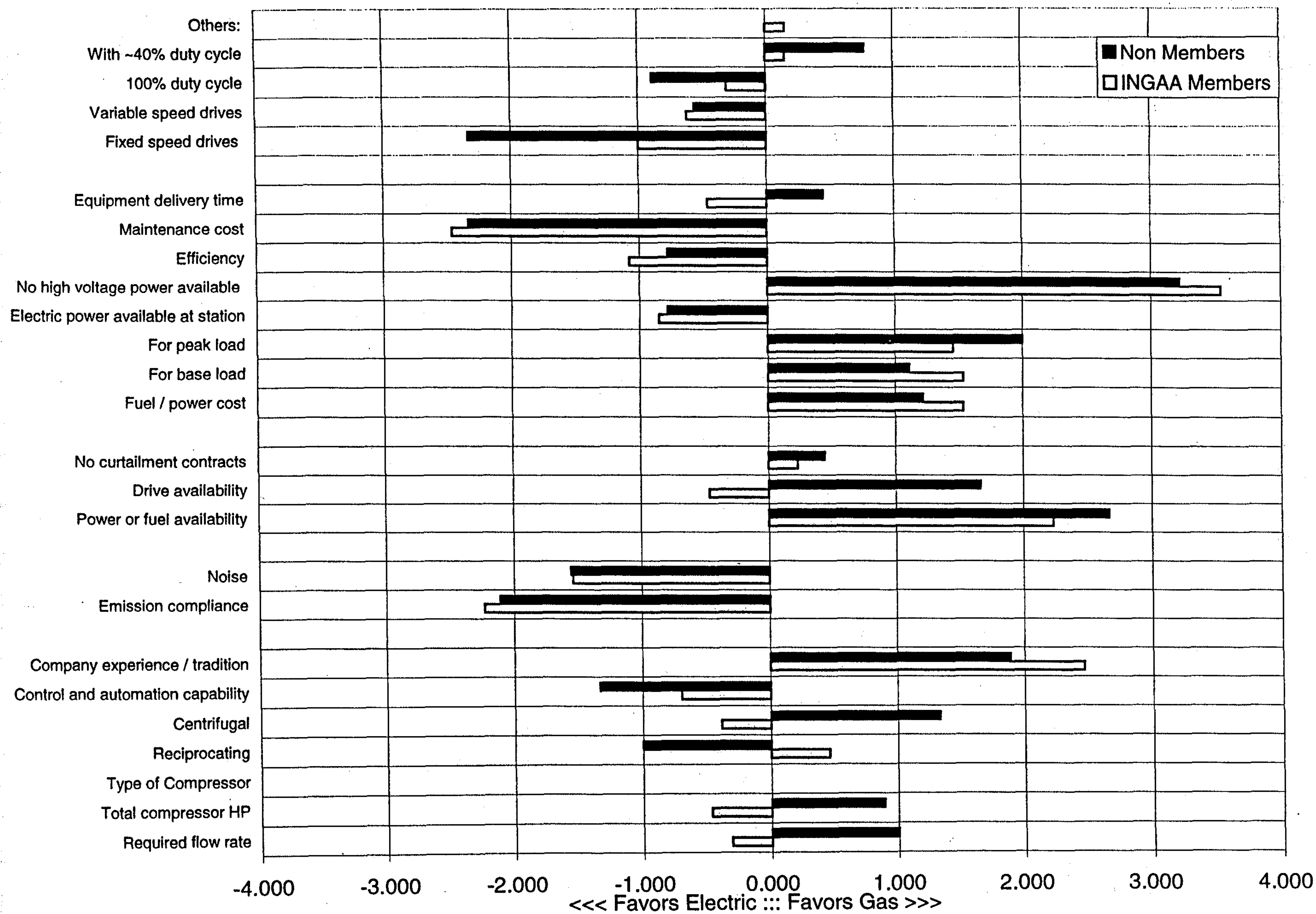

Figure 5. Strength of Factors in Favoring Gas or Electric Compressor Drives

favorable and zero is completely neutral, any average results between -1.0 and + 1.0 is considered to be insignificant (not favoring either type of drive).

Values between 1 and 2 are moderately favorable and the distribution of data indicates that average results above 2, on either side, are significant factors favoring one type of drive over the other. The most favorable factors for gas fired engines are no high voltage power near the compressor station with a rating of 3.4, reliability of fuel availability at 2.4, and company experience at 2.23. The most favorable factors for EMD are maintenance costs at -2.41 and emission compliance at -2.18. Thus if no high voltage power is available near a station, an electric drive is highly unlikely. If emission compliance is essential, EMD will probably be used. If fuel reliability is a critical requirement, gas fire drivers are likely to be used. If maintenance costs are a swing economic factor EMD will be selected. If a company values compatibility with their traditional equipment and the experience of their staff, they will select gas-fired engines. In any given decision these factors must be summed on a job-by-job basis, and the results will depend on the overall situation and the issues that are critical for a given selection.

Figure 5 shows the INGAA respondent and the other respondent average favoring score for the 24 factors that the survey identified. The factors that favor the use of gas engines are: 1) no high voltage power near the station, 2) fuel reliability, 3) company experience, 4) peak load service, 5) fuel/power cost, and 6) base load use. The factors that significantly favor EMD are: 1) maintenance costs, 2) emission compliance, 3) noise reduction, and 4) fixed speed compressors. Two other factors that are nearly at the significant level that favor EMD are efficiency and control and automation capability. The other half of the 24 factors do not have a significant effect either way on the selection of gas or electric drives.

Question 5

In question 5, the survey participants are asked if deregulation of the electric utility industry has significantly enhanced the comparative position of EMD. The majority, 11 out of 19 responses, indicated that it has not. Only 8 of the responses indicated that electric power deregulation would have a significant effect on reduced power rates and thereby enhance the competitive position of EMD. The INGAA representatives are evenly divided at 5 responses, indicating a positive effect of electric utility deregulation, and 5 to the contrary. A little over half of the comments provided by the industry members (8 of 14) indicate that it is too early to tell, or that they are hopeful that electrical power rates will be reduced in the future.

Question 6

Question 6 deals with specific regulations or regional policies that provide impediments or incentives for installing EMD. For the most part, respondents identified few if any specific regulations or local policies that would significantly impede or provide incentives for the selection and use of EMD. A total of 5 regulations are cited: 3 OTAG, 1 regional haze, and 1 MACT standard in the responses, which provided the opportunity for over 120 regulations to be cited. A few local regulations and non-attainment zones, such as in California, are referenced by respondents. Noise is cited as a local incentive issue is some cases. The difficulty of obtaining permits for fired sources in areas is a potential incentive for EMD use, but most of the other regulations appear to have very limited effects. Although survey respondents did not site specific environmental regulations, most companies are strongly aware that for some locations, the requirements for permits and emission limitation affect the choice of compressor drive units.

Question 7

In question 7, the survey requested information about various factors as overriding issues that influence for or against the selection of EMD. Each respondent marked each factor as for/against/or not important in determining the use of EMD. The results are tabulated as the number **for**, minus the number **against**, divided by the number of **responses**, and multiplied by 100 to obtain a percentage. A summary of results is shown in Table 5 and Figure 6. A significant positive percentage indicates that the factor in question strongly encourages the use of EMD, while a negative percentage indicates the use of gas fired drivers would be preferred. The factors that may provide an overriding influence for EMD are: <u>maintenance costs</u>, <u>electrical</u>

power availability, emission compliance, fixed speed units, noise reduction, and controllability. The factors that may provide an overriding influence against EMD are: no high voltage power available near the station, the cost of electric power versus gas, the availability (reliability and non-curtailment) of electric power, and the spare parts and familiarity of company personnel issues. All of the results are shown in Figure 6, where it can be seen that the other factors have overriding influence magnitudes of 25 percent or less, and are not overriding factors in most decisions.

Table 5. The Overriding Influence Rating of Factors for or Against EMD; Positive for EMD, Negative for Gas

Factors	INGAA	Non-INGAA	Total
Emission Compliance	42%	50%	45%
Noise	33%	44%	38%
Community Relations	25%	22%	24%
Fuel/Power Availability	-25%	-56%	-38%
Customer Requirements	10%	14%	12%
No Curtailment Penalty	0%	13%	5%
Cost of Power versus Gas	-67%	-78%	-71%
Maintenance Cost	75%	78%	76%
Fixed Speed Drive	22%	67%	44%
Variable Speed Drive	18%	11%	15%
Power Available	58%	56%	57%
Power Not Available	-83%	-75%	-80%
Controllability	18%	56%	35%
Compressor Ratio	0%	11%	5%
Spare Parts/Familiarity	-27%	0%	-15%
Delivery Schedule	20%	-22%	0%
Efficiency	30%	0%	16%

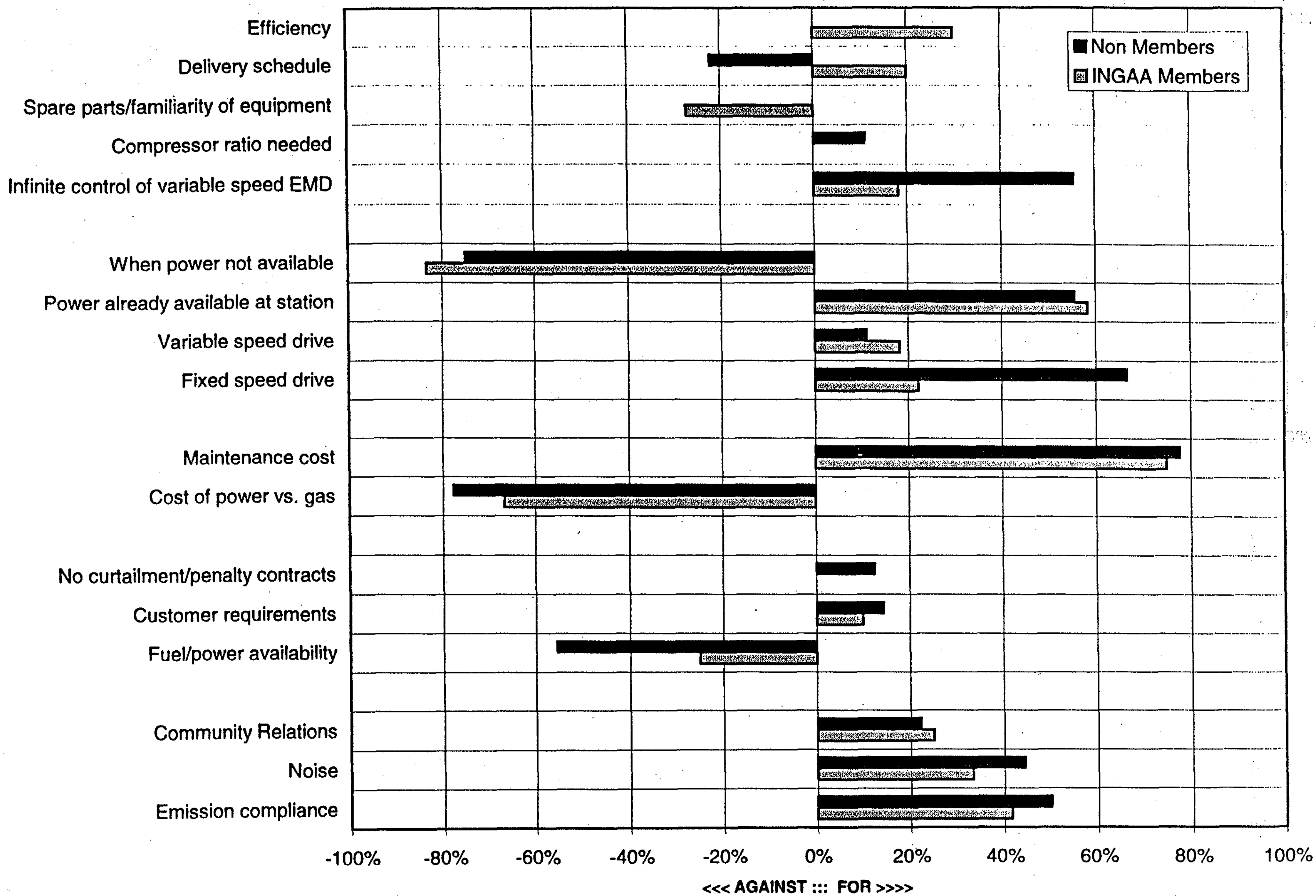

Figure 6. The Overriding Strength of Factors for or Against the Selection of EMD

From the results of question 7, it appears that if high voltage power is not available within a reasonable distance, or if the cost of electric power is high, or if there are power reliability or curtailment issues, or if the operating company cannot overcome the unfamiliarity with electric equipment, then electric motor drives will most likely not be used. On the other hand, if maintenance costs are a significant concern, high voltage power is available, emission compliance is a requirement, the unit is fixed speed, noise reduction is required, or controllability is an issue, then electric motor drives become a more viable option, and may be required in some cases. One of the largest differences between responses of the INGAA representatives and the other industry representatives is in the area of fixed speed drives. INGAA representatives see that the ability to use a fixed speed unit does not significantly enhance the EMD option (a 22 percent ranking), while the other representatives see fixed speed operation substantially improves EMD potential (67 percent rating). The advantage of fixed speed operation is, of course, that no variable speed power supply is needed, and the overall driver cost is substantially reduced. Similar differences between the INGAA member responses and the other company representative responses occur in the areas of fuel availability (reliability or non-curtailment), controllability, spare parts and familiarity, delivery schedules, and efficiency.

Question 8

Question 8 of the survey requested information about the decision process used by the companies to select drive units. The responding companies overwhelmingly agree that the selection process can be characterized as considering a few overriding issues, followed by a detailed cost analysis of particular issues to compare the drives. Responses showed that two strongly agree, eighteen agree, one is neutral, and only one disagreed. The comments received included indications that cost is usually the major factor, that life cycle cost is what is considered, and fuel cost is often 80 percent of the total life cycle cost. The comments also indicated that location of the compressor installation is an important consideration in terms of availability of power and emission requirements, and that unless location issues such as emission, noise, or power availability are significant, cost is the deciding factor. Some of the other factors that are mentioned as part of the decision process are risk/benefit analysis, and reduced space requirements for EMD over gas fired drivers.

Question 9

Information about cost differences for fuel/power, operation and maintenance, and installation for EMD versus gas fired units was requested in question 9. Only about half of the respondents were able to provide data of this type; however, information from 11 companies about the relative costs provides a reasonable estimate of the magnitude of cost factors. The information was requested as a positive percent difference if the EMD unit is less costly, and a negative percent difference if a gas unit is less expensive. A summary of the total cost differences, as positive and negative percentages, is shown in Table 6. Figure 7 shows the percent relative cost for each cost category. A more detailed analysis of the cost by each INGAA respondent and non-INGAA respondent, including the number of responses in each category and the standard deviation of the results, is shown in Table B-2 in Appendix B. The uncertainty in cost estimates is large and generally of the order of the cost percentage; however, the trends shown by the mean values are considered representative of industry-wide cost factors. Data indicates that EMD are less costly to install by approximately 8 to 25 percent, and are less costly to operate and maintain by 12 to 63 percent. However, electrical power is more costly than fuel gas by approximately 22 to 36 percent. Given that power costs are between 50 and 80 percent of typical life cycle costs (according to several of the large operating companies), the total cost of EMD over the life of the unit, as estimated by the survey respondents, is roughly 17 percent higher than for gas fired units.

Question 10

The survey asked for a rating of the major obstacles for the selection of EMD. Table 7 and Figure 8 show the results rated on a scale of 0 to 10, with 0 as no obstacle, and 10 a complete obstacle. The potential obstacles for which ratings are requested are high demand charges, duration of demand charges, cost of supplying electrical infrastructure, cost of power versus gas, and others. The industry did fill in two other obstacles of reliability of electrical power and availability of long term power contracts. Table 7 shows the numerical values and Figure 8 provides a bar chart display of the important obstacles in the selection of EMD. The reliability of electrical power is considered as a significant obstacle, 5.8 out of 10 by INGAA members but not (1 out of 10) by other respondents. The most significant obstacles in the use of EMD (in order) are the cost of electric power versus gas, high demand charges, duration of demand charges, and the cost of electrical infrastructure.

Table 6. Cost Factor Differences from Survey Results (Negative Differences Favor Gas Drives)

Cost Factor	No. of Responses	Average Difference
Operating Cost (fuel/power only)		
EMD vs. Engine	9	-36.6%
EMD vs. Turbine	10	-21.8%
Operation and Maintenance		
EMD vs. Engine	9	62.8%
EMD vs. Turbine	10	12.0%
Installation Costs		
Fixed Speed EMD vs. Engine	11	25.0%
Fixed Speed EMD vs. Turbine	11	13.6%
Variable Speed EMD vs. Engine	9	12.2%
Variable Speed EMD vs. Turbine	12	8.3%

In the comments associated with this question, industry representatives provided electrical power costs data from their own studies and analysis. The range of electrical power cost required for a neutral cost influence is between 2.0 to 3.5 cents/kW hour. The responses show that at least 10 of the 22 surveyed companies would use more EMD if the cost of electrical power was 3 cent/kW hour or less.

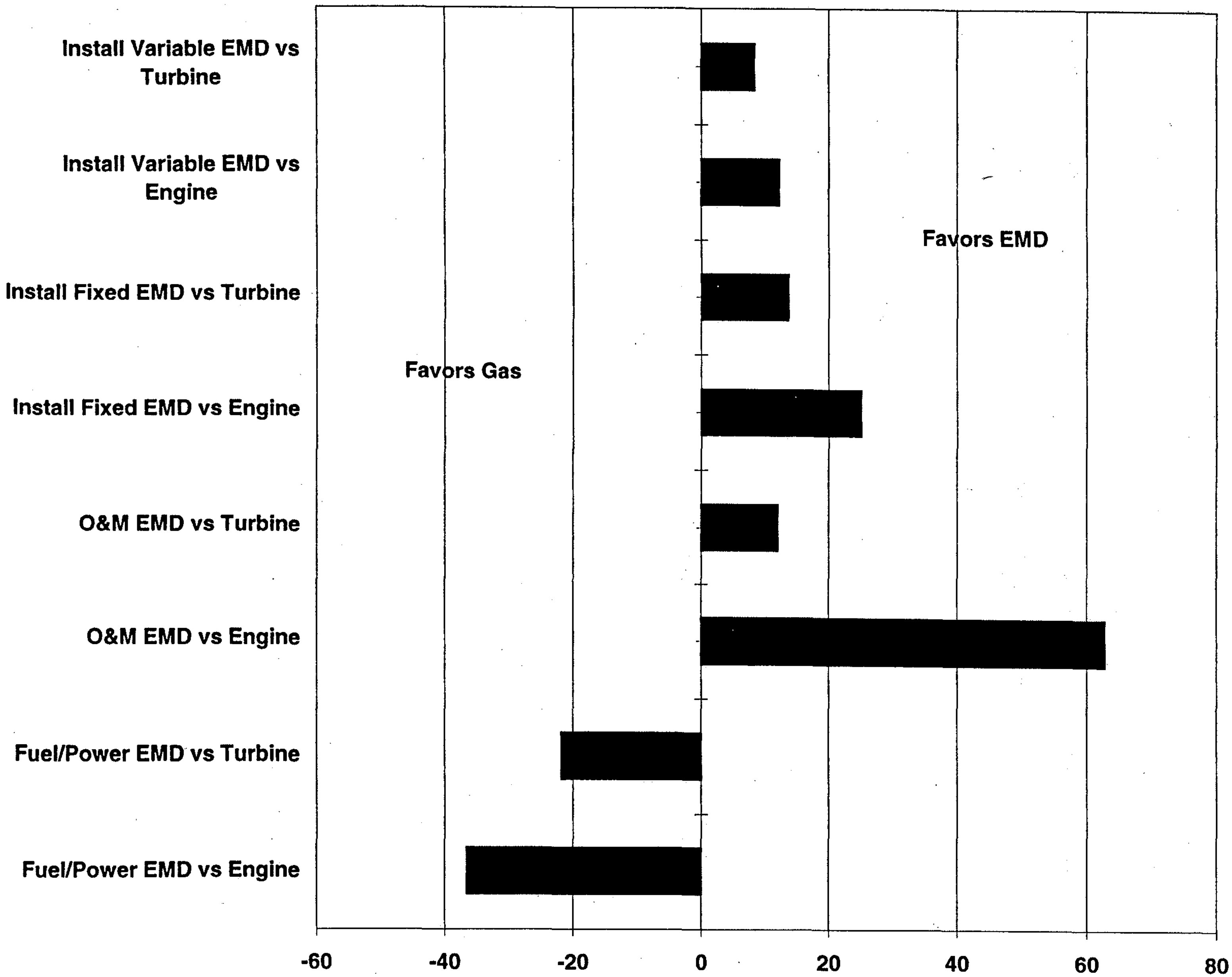

Figure 7. Relative Cost Difference for Fuel and Power, Operation and Maintenance, and Installation Costs Between EMD as Positive and Gas as Negative for Lower Cost

Table 7. Rating of Obstacles to the Use of EMD

Obstacle	INGAA	Non-INGAA	Total
High Demand Charges	7.77	7.00	7.45
Duration of Demand Charges	7.92	5.88	7.14
Electrical Infrastructure Cost	7.31	5.67	6.64
Cost of Power versus Fuel	8.54	8.00	8.33
Reliability of Electric Power	5.78	1.00	4.58
Long Term Contract Available	5.78	4.33	5.42
Numbers are obstacles rating from 0 to 10; 0 – no obstacle; 10 – maximum obstacle.			

Question 11

The survey respondents were asked to identify any additional factors or situations that would lead to the advantageous use of EMD, and several comments are summarized here:

1. The overall efficiency of electric motor drive systems is good, and they should be considered for that reason.

2. Advantageous situations include when the electric power company is willing to enter into a flexible customer service arrangement, where there is a local power generation facility, and when the compressor unit must come on-line quickly.

3. Installation at noise sensitive locations or with total automation requirements are candidates for which EMD have advantages. If space requirements are significant or frequent unit starts and stops are required, EMD should be considered.

Questions 12 and 13

The final questions in the survey requested information about knowledgeable people in the industry, reference reports or publications, and the company's experience with the use of EMD

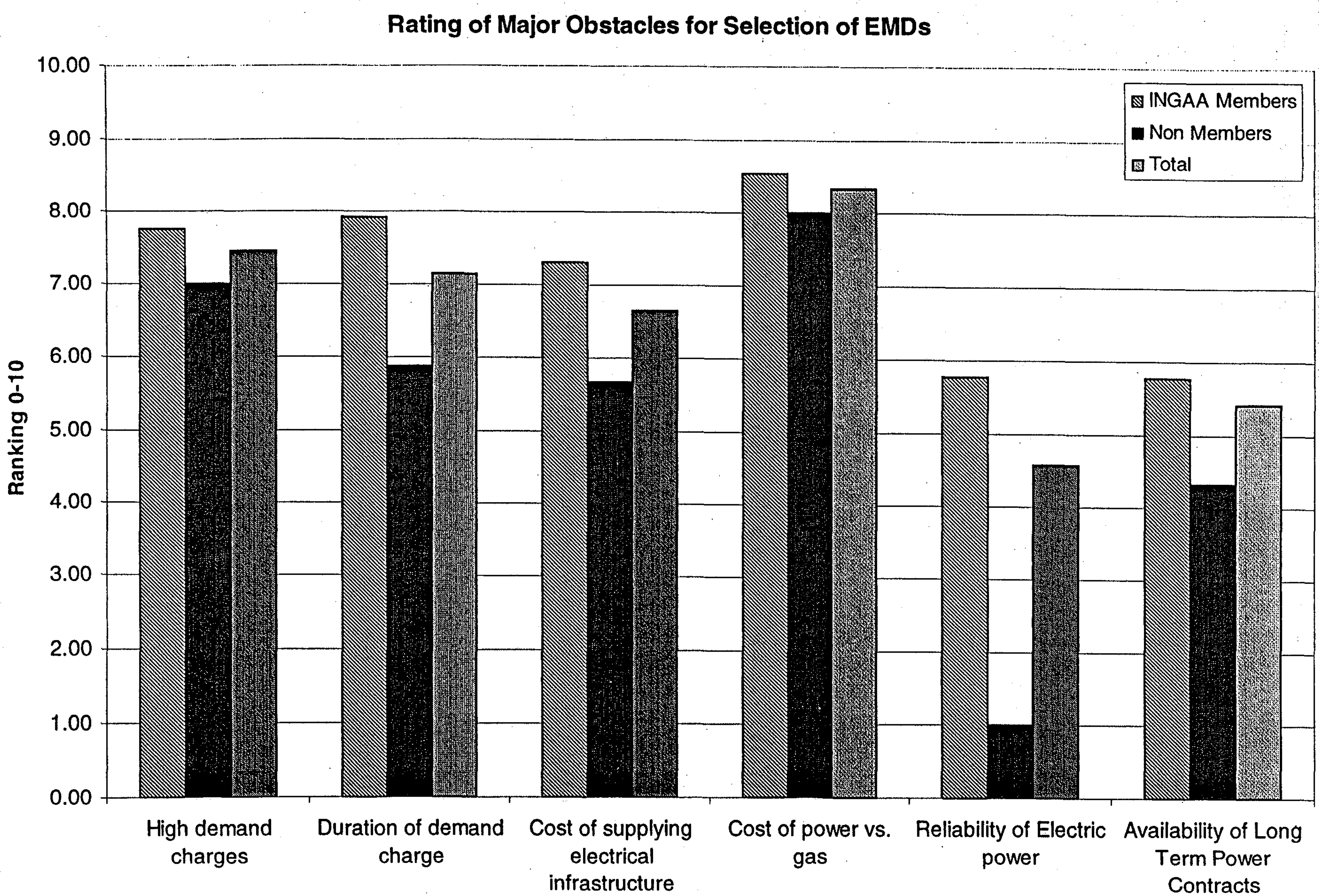

Figure 8. Ranking of Obstacles to the Use of EMD for Gas Industry Compressor Drives

units. A number of industry people with expertise and experience were identified, together with a number of reports and papers presented through EPRI and the Gas/Electric Partnership. No paper or reports where identified from gas industry conferences such as the A.G.A. Operating Section Conference. Some of the surveyed companies have fairly extensive experience with EMD, including dozens of units, while other companies have no actual operational experience.

ANALYSIS OF RESULTS

Decision for Driver Type

When operating companies determine that new, additional, or replacement compression capacity is required to meet forecast needs in specific services or locations, an engineering team is assigned the duty of selecting and presenting the best options for that requirement. The major system decisions prior to a cost comparison are:

1. What types of compressors are best for the service requirement, and what are the strengths and weaknesses of each option?

2. What are the options to meet the environmental requirements and satisfy the neighbors?

3. What types of compressor drives can be used, and what are the advantages and disadvantages of each?

Other factors such as project schedule, reliability, flexibility, maintenance, and operations must be considered, but these are usually outcomes of the major decisions rather than separately selected features. The compressor type and specifications must be specifically selected, and the environmental concerns and permitting must be specifically addressed. The compressor driver that accommodates the first two major decisions must also be specified. Design details, auxiliary equipment, and drawings are developed and specifics of schedules, flexibility, maintenance, and operational requirements are addressed once the major options are identified. If specific concerns or requirements for schedule, reliability, and operating restrictions are identified as a result of the options, then these may favor or eliminate one or more of the options. The final major decision for most companies is the economically best option from the remaining choices. The life cycle cost elements of each of the selected options are considered and summarized, and the most economical option that satisfies the preceding major decisions are generally selected as best for the project in question.

The overriding issues or factors that most strongly influences a selection one way or another seem to be (from the survey results) power availability, environmental restrictions, concerns of the neighbors, reliability of power, and cost considerations. The dominant cost consideration is cost of power compared to fuel gas, with maintenance and installation costs as lesser additional elements.

As an example of a selection situation, assume that a reciprocating compressor with a wide power range is needed for application in an area that is (or may become) environmentally sensitive. In such a case, the only practical choice for a drive unit to accommodate a wide range of power variation for a low speed compressor might well be an electric motor. There are several documented cases for which EMD were the only potential drive selection due to a zero or negligible environmental emissions allowance. In other cases where EMD were a potentially beneficial option, the nearest high voltage transmission line was a large distance away (tens to hundreds of miles) from the compressor site and, therefore, not available at a reasonable cost.

Effects of Industry Growth

It has been predicted that the natural gas industry in the U.S. will grow to a capacity of 30 trillion cubic feet of gas per year (TCF) by approximately 2010. The current U.S. gas delivery is nearly 22 TCF, and the projected growth is, therefore, around 40 percent in the next 10 to 12 years. The natural gas industry currently has a total compression capacity of around 17.5 million horsepower according to A.G.A. A 40 percent increase in this horsepower to accommodate the 40 percent increase in capacity would be a total increase of 7 million horsepower by the year 2010 or shortly thereafter. The average growth rate of compressor horsepower during the past 8 years has been over 550 thousand horsepower per year (see Table 4) which would equal at least 6 million added horsepower by the year 2010. Even if the industry is able to achieve a slight improvement in efficiency in terms of millions of cubic feet delivered per horsepower, it is reasonable to assume that at least 5 million new horsepower, plus some replacement horsepower, will be installed in the next 10 to 12 years. A nominal growth of 6 million added horsepower can be used with reasonable confidence.

The effect of the growth of the gas industry on the requirement for compressor drives is, therefore, significant. If the growth projections from question 4 are correct, then 75 to 80 percent of this new horsepower (or approximately 4.5 million horsepower), will be gas turbine units. Most of the remainder, 17 to 25 percent (± 3 percent), or up to 1.5 million horsepower, will be in the form of Electric Motor Drives (EMD).

CONCLUSIONS

Major conclusions from the study are summarized as follows:

1. Industry projections indicate that EMD will account for some 17 to 25 percent of the six million compression horsepower that will be required to meet expanding domestic gas demands by the year 2010.

2. Gas turbines are expected to provide some 75 to 80 percent of this added horsepower, with recip drivers playing a much smaller role.

3. Major factors favoring the use of EMD are:

   - Reduced site-specific emission levels and noise;
   - Low O&M costs; and
   - Low capital costs.

4. Major factors against EMD are:

   - Cost of electric power versus natural gas;
   - High demand charges;
   - Cost of the electric infrastructure to support EMD;
   - Availability of long-term customer-service oriented electric power contracts; and
   - Reliability of electric power versus gas supply.

5. The feasibility of EMD is substantially increased when electric power is available at the site and when fixed speed operation is adequate. In the final analysis, however, electric power rates of 2 to 3.5 cents/kW hour will be required to make EMD economically competitive.

6. By far the overriding factor favoring EMD is in environmental compliance. Although capital and maintenance costs are favorable, the total life cycle costs for EMD (adding

power to the capital and O&M costs, averaged of the life expectancy of the unit) are substantially higher than those for gas turbine drives in most cases. Energy costs often constitute a large percentage (over 50 percent) of the life cycle costs for EMD. Therefore, EMD are normally justifiable only for those instances where environmental concerns are sufficient to warrant the higher energy costs.

7. Deregulation of the electric power industry is not expected to significantly enhance the competitive position of EMD by reduced electric rates. The effect of gas/electric mergers is unknown, but EMD would seem to add some flexibility in scheduling and peak shaving, particularly if gas storage is available.

Appendix A

Survey Questionnaire

Survey of Factors that Affect Decisions to Use Electric Motor Drive Compressors

The Interstate National Gas Association of America (INGAA) is sponsoring a study at SwRI to identify and quantify the factors that affect the selection of electric motor drives (EMD) for gas compression. The objectives of this survey are to define and to compare the factors that influence decisions to install EMD compressors compared to other drivers. Due to your knowledge and experience, we solicit your help to answer the following questions and to provide any additional information that you feel is relevant. Your time and ideas will be greatly appreciated.

1. a) Has your company recently assessed the use of electric motor drives?

	YES	NO
Fixed Speed	❑	❑
Variable Speed	❑	❑

b) Do you have plans to do so in the near future? YES ❑ NO ❑

Comments:______________________________________

____

c) How many months does/will the selection process take? ______

2. a) What do you consider the probability for selecting electric motor drives in your system in the following applications:

	High	Medium	Low	N/A
Gas pipeline transmission	❑	❑	❑	❑
Spur line or interconnect	❑	❑	❑	❑
Storage / withdrawal	❑	❑	❑	❑
Gathering / distribution	❑	❑	❑	❑

Comments: (When does one type of service favor EM drives over another?)

____

____

b) For the following compressor installation considerations, rate the probability or desirability of selecting an electric motor drive:

	High	Medium	Low	N/A
Environmentally sensitive areas	❑	❑	❑	❑
Centrifugal compressors	❑	❑	❑	❑
Low HP reciprocating compressors	❑	❑	❑	❑
High HP reciprocating compressors	❑	❑	❑	❑
For peak load service	❑	❑	❑	❑
For continuous operation	❑	❑	❑	❑
Fixed speed units	❑	❑	❑	❑
Variable speed units	❑	❑	❑	❑
For high reliability (i.e., no curtailment)	❑	❑	❑	❑

Others: (describe)

____

____

3) Please estimate the amount and type of compressor horsepower your company has added/replaced (or plans to add/replace) in the following periods:

	1992 - 1997	1997 - 1999	2000 - 2003
a) How much HP:	_____	_____	_____
b) Of this:			
Reciprocating HP	_____	_____	_____
Centrifugal HP	_____	_____	_____
Rotary HP	_____	_____	_____
Other HP (please specify)			
____________________	_____	_____	_____
c) Probable driver type:			
Undefined	_____	_____	_____
Integral reciprocating	_____	_____	_____
Separable reciprocating	_____	_____	_____
Gas turbine	_____	_____	_____
Electric Motor			
Fixed speed	_____	_____	_____
Variable speed	_____	_____	_____
Undefined	_____	_____	_____
HP per unit	_____	_____	_____
Number of units	_____	_____	_____

4. How would you rate the influence of various strategic and operational issues on the selection of compressor drivers. (Rate the influence, from 1 to 5, as favoring either electric or gas drivers or 0 for no influence. A '5' rating is a very strong incentive, and tends to exclude the other type of drive. A '0' rating is neutral, favoring neither drive type.)

	Influence Rating		
Issue	**Electric**		**Gas**
Operations:			
Required flow rate	5 4 3 2 1	0	1 2 3 4 5
Total compressor HP	5 4 3 2 1	0	1 2 3 4 5
Type of Compressor			
Reciprocating	5 4 3 2 1	0	1 2 3 4 5
Centrifugal	5 4 3 2 1	0	1 2 3 4 5
Control and automation capability	5 4 3 2 1	0	1 2 3 4 5
Company experience / tradition	5 4 3 2 1	0	1 2 3 4 5
Legal / Community Issues:			
Emission compliance	5 4 3 2 1	0	1 2 3 4 5
Noise	5 4 3 2 1	0	1 2 3 4 5
Reliability:			
Power or fuel availability	5 4 3 2 1	0	1 2 3 4 5
Drive availability	5 4 3 2 1	0	1 2 3 4 5
No curtailment contracts	5 4 3 2 1	0	1 2 3 4 5
Economic:			
Fuel / power cost	5 4 3 2 1	0	1 2 3 4 5
For base load	5 4 3 2 1	0	1 2 3 4 5
For peak load	5 4 3 2 1	0	1 2 3 4 5
Electric power available at station	5 4 3 2 1	0	1 2 3 4 5
No high voltage power available	5 4 3 2 1	0	1 2 3 4 5
Efficiency	5 4 3 2 1	0	1 2 3 4 5
Maintenance cost	5 4 3 2 1	0	1 2 3 4 5
Equipment delivery time	5 4 3 2 1	0	1 2 3 4 5

Issue (cont.)	Influence Rating Electric		Gas
Capital Cost:			
Fixed speed drives	5 4 3 2 1	0	1 2 3 4 5
Variable speed drives	5 4 3 2 1	0	1 2 3 4 5
100% duty cycle	5 4 3 2 1	0	1 2 3 4 5
With ~40% duty cycle	5 4 3 2 1	0	1 2 3 4 5
Others:			
______________	5 4 3 2 1	0	1 2 3 4 5
______________	5 4 3 2 1	0	1 2 3 4 5
______________	5 4 3 2 1	0	1 2 3 4 5

5. Does deregulation of the Electric Utility industry significantly enhance the comparative positions of EM drive systems in your case? ❑ YES ❑ NO

   How: ______________________________

   ____

6. a) Concerning emissions compliance issues, can you cite current or anticipated regulations or local policies (name the state) that provide significant impediments or incentives for installing EMD?

   ____

   - ❑ OTC
   - ❑ OTAG
   - ❑ Global Climate
   - ❑ Regional Haze
   - ❑ PM 2.5
   - ❑ MACT Standards

   b) Excluding emissions compliance issues, can you cite current or anticipated regulations or local policies (name the state) that provide significant impediments or incentives for installing EMD?

   ____

7. In your system, do any the following issues provide an overriding influence (i.e., mandate) for or against compressor EMD?

Issue	For / Against/ Not Important	% of Cases
Legal / Community Issues:		
Emission compliance	F A N	___ %
Noise	F A N	___ %
Community Relations	F A N	___ %
Other: (specify)		
______________	F A N	___ %
______________	F A N	___ %
Reliability:	F A N	___ %
Fuel / power availability	F A N	___ %
Customer requirement	F A N	___ %
Provide an example: ______________		
No curtailment / penalty contracts	F A N	___ %
Other: (specify)		
______________	F A N	___ %
______________	F A N	___ %

Issue (cont.)	For/Against/Not Important	% of Cases
Economic:		
Cost of power vs. gas	F A N	___ %
Maintenance cost	F A N	___ %
Capital cost:		
Fixed speed drive	F A N	___ %
Variable speed drive	F A N	___ %
Power already available at station (substation cost only)	F A N	___ %
When power is not available	F A N	___ %
Other Factors:		
Infinite control of variable speed EMD	F A N	___ %
Compression ratio needed	F A N	___ %
Spare parts / familiarity of equipment	F A N	___ %
Delivery schedule	F A N	___ %
Efficiency	F A N	___ %
________________	F A N	___ %
________________	F A N	___ %

8. a) Could your company's compressor driver selection process be characterized by consideration of a few overriding issues (such as in question 7 above), then followed by a detailed cost analysis of particular issues to compare drivers?

Strongly Agree   Agree   Neutral   Disagree   Strongly Disagree

Comments: ____

____

b) Have any significant factors been overlooked in items 4 or 7 above? (please describe)

____

____

____

____

9. Please estimate the percent cost differential of Electric Motor Drives for the following comparisons. (Express the percentage as favorable to EM drives [+] or unfavorable [-], i.e., gas is approximately 20 percent less than electric power, therefore –20% difference.)

Comparisons	% Difference
Operating Cost (fuel / power only):	
EMD vs. engine	___ %
EMD vs. turbine	___ %
Operation and Maintenance Combined:	
EMD vs. engine	___ %
EMD vs. turbine	___ %
EMD vs. engine	___ %
Installation Cost:	
Fixed speed EMD vs. engine	___ %
Fixed speed EMD vs. turbine	___ %
Variable speed EMD vs. engine	___ %
Variable speed EMD vs. turbine	___ %
Other Significant Costs:	
________________	___ %
________________	___ %

10. Please rate, on a scale of 0 to 10, which factors are major obstacles for selection of EMD.

Issue	Ranking
High demand charges	0 1 2 3 4 5 6 7 8 9 10
Duration of demand charge	0 1 2 3 4 5 6 7 8 9 10
Cost of supplying electrical infrastructure	0 1 2 3 4 5 6 7 8 9 10
Cost of power vs. gas	0 1 2 3 4 5 6 7 8 9 10
Other:	
________________	0 1 2 3 4 5 6 7 8 9 10
________________	0 1 2 3 4 5 6 7 8 9 10

Please identify any remedies or targets which could neutralize the disincentives (i.e., with power cost at ~0.04/kW-hr, there is no incentive for gas over electric.)

____

____

11. Please describe any additional factors or situations that might help identify when and why EM drivers are needed or advantageous:

____

____

____

12. Please recommend anyone else (in your company or elsewhere) who is particularly knowledgeable or has evaluation experience on the subject of EMD:

____

____

____

13. Do you have (or know of) any reports or papers on the subject? Please identify:

____

____

____

We will greatly appreciate your participation in this study. If you have comments you would like to share verbally, please feel free to call either Ray G. Durke at (210) 522-3001, e-mail: rdurke@swri.org or Robert J. McKee at (210) 522-3000, e-mail: rmckee@swri.org

Thank you.

____

Robert J. McKee, *Principal Engineer*

Appendix B

Compilation of Horsepower, Compressor Type and Driver Type— Past, Present, and Future

(Covering those 21 operating companies that responded to the survey.)

- **INGAA Foundation Members**
- **Non-Foundation Members**
- **Totals**

Table B-1. Total and Company Average HP Log Compressor Types and Drive Type; from INGAA and Non-INGAA Respondents for Past, Current, and Future Years

Question 3 Please estimate the amount and type of compressor horsepower your company has added/replaced in the following period:

	1992-1996		INGAA		1997-1999		INGAA		2000-2003		INGAA		1992-1996		NON INGAA	
	R	Sum	Avg	Std	R	Sum	Avg	Std	R	Sum	Avg	Std	R	Sum	Avg	Std
How much HP	12	2362863	196905	380855	12	1494478	124540	359187	12	308100	25675	27232	9	551240	61249	65605
Of This:																
Reciprocating HP	12	258930	21578	30566	12	39918	3326.5	5353.8	12	28200	2350	5318.6	9	73440	8160	7786.8
Centrifugal HP	12	2103933	175328	380283	12	1450260	120855	354862	12	209900	17492	27169	9	476800	52978	66106
Rotary HP	12	0	0	0	12	0	0	0	12	0	0	0	9	1000	111.11	314.27
Probable Driver Type:																
Undefined	12	71018	5918.2	12706	12	0	0	0	12	118000	9833.3	21483	9	83600	9288.9	15210
Integral reciprocating	12	76970	6414.2	20269	12	17968	1497.3	2846.1	12	0	0	0	9	6353	705.89	1240.3
Separable reciprocating	12	97200	8100	15993	12	11250	937.5	1487.4	12	20700	1725	5269.3	9	20168	2240.9	5284.4
Gas turbine	12	1959675	163306	364615	12	1205260	100438	298081	12	153150	12763	26986	9	368969	40997	59650
Electric Motor		158000	13167	26321		260000	21667	59143		16250	1354.2	4491.3		72150	8016.7	17710
Fixed Speed	12	46000	3833.3	8446.2	12	15000	1250	4145.8	12	0	0	0	9	15150	1683.3	2846.5
Variable Speed	12	112000	9333.3	17875	12	245000	20417	54997	12	16250	1354.2	4491.3	9	57000	6333.3	14863

	1997-1999		NON INGAA		2000-2003		NON INGAA		1992-1996		TOTAL		1997-1999		TOTAL		2000-2003		TOTAL	
	R	Sum	Avg	Std	R	Sum	Avg	Std	R	Sum	Avg	Std	R	Sum	Avg	Std	R	Sum	Avg	Std
How much HP	9	343930	38214	23115	9	310000	34444	28968	21	3E+06	138767	293652	21	2E+06	87543	269351	21	618100	29433	27371
Of This:																				
Reciprocating HP	9	104020	11558	17907	9	40000	4444.4	6358.6	21	332370	15827	24647	21	143938	6854.2	12822	21	68200	3247.6	5735.8
Centrifugal HP	9	238710	26523	24842	9	270000	30000	27951	21	3E+06	122892	293117	21	2E+06	80427	268830	21	479900	22852	27542
Rotary HP	9	1200	133.33	377.12	9	0	0	0	21	1000	47.619	212.96	21	1200	57.143	255.55	21	0	0	0
Probable Driver Type:																				
Undefined	9	85700	9522.2	18089	9	165000	18333	29756	21	154618	7362.8	13575	21	85700	4081	12900	21	283000	13476	25109
Integral reciprocating	9	8900	988.89	2797	9	0	0	0	21	83323	3967.8	15566	21	26868	1279.4	2767.6	21	0	0	0
Separable reciprocating	9	4390	487.78	1379.6	9	0	0	0	21	117368	5589	12788	21	15640	744.76	1431.6	21	20700	985.71	4074.5
Gas turbine	9	167990	18666	25116	9	131000	14556	25698	21	2E+06	110888	280986	21	1E+06	65393	226087	21	284150	13531	25808
Electric Motor		76950	8550	22602		14000	1555.6	3108.1		230150	10960	23118		336950	16045	55973		30250	1440.5	5676.7
Fixed Speed	9	66950	7438.9	19460	9	14000	1555.6	3108.1	21	61150	2911.9	6714.1	21	81950	3902.4	13240	21	14000	666.67	2216.1
Variable Speed	9	10000	1111.1	3142.7	9	0	0	0	21	169000	8047.6	16403	21	255000	12143	42733	21	16250	773.81	3460.6

Table B-2. Estimate Percent Cost Differences by INGAA and Non-INGAA Respondents for Operating Cost (Fuel/Power) Operations and Maintenance (Exclusive of Fuel) and Installation Costs

Question 9 Please estimate the percent cost differential...

Comparisons	INGAA Responses	Average	Standard Deviation	NON-INGAA Responses	Average	Standard Deviation	TOTAL Responses	Average	Standard Deviation
Operating Cost (fuel/power only):									
EMD vs. engine	4	-53.75	34.49	5	-22.80	26.25	9	-36.56	32.51
EMD vs. turbine	5	-27.50	50.93	5	-16.00	15.17	10	-21.75	35.94
Operation and Maintenance Combined:									
EMD vs. engine	4	33.75	19.74	5	90.00	118.95	9	65.00	90.00
EMD vs. turbine	5	13.00	10.95	5	15.00	11.18	10	14.00	10.49
Installation Cost:									
Fixed speed EMD vs. engine	5	40.00	20.31	6	32.50	15.41	11	35.91	17.29
Fixed speed EMD vs. turbine	5	21.00	10.84	6	15.83	12.81	11	18.18	11.68
Variable speed EMD vs. engine	3	35.00	13.23	6	15.83	17.44	9	22.22	18.05
Variable speed EMD vs. turbine	7	9.29	6.73	5	11.00	9.62	12	10.00	7.69