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Implementing Advanced Control and Power Technologies to Improve Energy Efficiency and Reduce Operating Costs for U.S. Petroleum Refining and Petrochemical Manufacturing

PIER TECHNICAL REPORT

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Implementing Advanced Control and Power Technologies to Improve Energy Efficiency and Reduce Operating Costs for U.S. Petroleum Refining and Petrochemical Manufacturing

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PRODUCT DESCRIPTION

Assessing the effectiveness of advanced control and power technologies currently being used in U.S refineries and petrochemical plants was a task dependent upon cooperation from a variety of disciplines within the refining industry, particularly from electrical and process engineers. It was not a straightforward task of collecting data on which to base calculations. Responses to the concept of the introduction of advanced control and power technologies to refineries were varied and depended upon an individual's knowledge of those technologies and his experiences of them, either personal or vicarious. Reactions varied widely from a certain and definite resistance to change to a readiness to accept advanced control and power. The variety of these human responses paralleled the variety of the technical applications already in use. This investigation revealed dedicated and hard working people with little time and energy to spare. They were focused on efficient and uninterrupted production within the limits of business, environmental and regulatory constraints. The process-engineering group seemed to have the ultimate authority and although they expressed a desire to become more familiar with these technologies, that interest was tempered by the practical constraints of having to get the job done. There was concern about sharing proprietary information and self-exposure.

Results & Findings

The variety of control and power technologies that has penetrated refineries and petrochemical plants in the U.S. is wide ranging. Its success and acceptance was dependent upon the knowledge, experience, and technical expertise of the installers and the operators. Motor list data, cogeneration ratings and electricity usage data was available from electrical engineering. However, there was no readily available data for heat exchangers, furnaces or boilers from process engineering.

The judicial implementation of advanced control and power technologies could achieve energy savings, increased productivity, and increased reliability in U.S. refineries and petrochemical plants. The present situation is such that there is ample opportunity to make measurable and significant improvements based on the implementation of advanced control and power technologies from modest and limited installations to site-wide control optimization schemes. The achievable benefits include reduction of costs, less maintenance, freeing up of manpower, reduced environmental impact, additional headroom to develop sites, and a potential to export power on a net metering basis.

Based on the findings in this Report, U.S. refineries and petrochemical plants could save $10.4 Billion per year from the implementation of advanced control and power technologies. For an estimated investment cost of $18.5 Billion, savings of $10.4 Billion /year would yield a simple payback of 1.8 years ($18.5 Billion/ $10.4 Billion /year). These savings are summarized in the following Table.

Potential Annual Savings from Implementing Advanced Control and Power Technologies in U.S. Refineries and Petrochemical Plants, Assuming 100% Penetration

Opportunity	Annual Savings (Millions of Dollars)
Waste due to utility power related causes would be reduced	$725
Operations and maintenance costs would be reduced	$4,255
There would a reduced environmental impact cost	$1280
There would be increased electricity cost of	($150)
Total fuel related cost savings	$ 4,284
Total potential annual savings	$10,394

Challenges & Objectives

Successful implementation of these technologies is dependent upon understanding its principles, knowledgeable and detailed specification of equipment, expert installation, and a willingness to educate for change.

Applications, Values & Use

The work described in this Phase 1 Report determined the effectiveness of control and power technologies currently being used in U.S. refineries and petrochemical plants and identified opportunities for energy savings, increased productivity, and increased reliability that could be achieved based on alternative control and power technologies. A previous Phase 1 study determined the effectiveness of control and power technologies currently being used in California refineries and identified opportunities for energy savings, increased productivity, and increased reliability that could be achieved based on alternative control and power technologies [13]. The results from these two Phase 1 studies will provide the basis for proceeding with Phase 2 of this project.

In Phase 2 (potential future project), suitable demonstration sites will be selected for the implementation of advanced control and power technologies to improve reliability and energy efficiency in petroleum refining and petrochemical manufacturing.

In Phase 3 (potential future project), advanced control and power technologies will be implemented at Selected Sites.

EPRI/Global Energy Partners Perspective

End user feedback suggests that there are serious concerns that are preventing the application of advanced control and power technologies in petroleum refining and petrochemical manufacturing facilities. These concerns are so serious that older process control techniques and maintenance prone, hydraulic couplings and steam turbines are still being used to maintain control over the process, rather than expert systems and advanced power conversion techniques. Additional maintenance costs and energy inefficiencies associated with mechanical variable speed devices are accepted as a trade off against the risk of unknown performance by advanced power electronic alternatives. Speed devices are accepted as a trade off against the risk of unknown performance by advanced power electronic alternatives.

Thus, current older process control techniques result in energy losses in existing applications and prevent advanced power electronic controllers from being implemented in areas of the refineries and petrochemical plants where considerable savings from increased energy efficiency and productivity could be achieved. These older process control techniques also reduce the overall reliability of refineries and petrochemical plants and do not provide a method to achieve energy optimization over the entire site.

Full implementation of advanced control and power technologies could save U.S. refineries and petrochemical plants an estimated $10.4 Billion/year. This report identifies these savings opportunities for U.S. refineries and petrochemical plants.

Approach

The California Energy Commission (CEC) and the U. S. Department of Energy (DOE) contracted with Global Energy Partners to assemble a collaborative of utilities, state/federal agencies, and refineries and petrochemical plants to document the reliability and energy efficiency benefits of advanced control and power technologies and transfer technology to refining and petrochemical industries. The project will be approached in three phases. The decision to fund each phase is independent and can be based on the relevance and applicability for the participant.

This Phase 1 Report addresses only the effectiveness of control and power technologies currently being used and opportunities for energy savings, increased productivity and increased reliability that could be achieved based on alternative control and power technologies in U. S refineries and petrochemical plants.

Keywords

Petroleum refining
Petrochemical manufacturing
Control technologies
Power technologies
Electric drives
Electric motors
Energy efficiency
Self-learning controls
Reliability

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1 INTRODUCTION

Background

A study, "Using Advanced Control and Power Technologies to Improve the Reliability and Energy Efficiency of Petroleum Refining and Petrochemical Manufacturing in California," was completed in March 2004. This study expands the scope of the study already completed for California to petroleum refineries and petrochemical manufacturers across the United States. Energy savings, increased productivity, and increased reliability can be achieved by the use of advanced control and power technologies in refineries and petrochemical companies throughout the United States. In order to assess the effectiveness of advanced control and power technologies currently being used, approaches were made to a representative number of U.S. refineries and petrochemical companies. Personnel at various levels of seniority were contacted within both large and small companies.

The investigation considered the present state of use of both control and power technologies and the expectations for these technologies for the future. Technical, environmental and regulatory challenges were examined along with business challenges. Technical data was gathered and analyzed when it was made available. Credence was given to observations, experiences, and opinions that were expressed. Electrical data was readily made available. Data associated with the process was more difficult to obtain.

Methodology

The methodology used during this investigation evolved substantially as a practical and necessary response to obstacles that became apparent as the study got underway. The initial survey was composed to gather data relating to all hydraulic energy used in refineries and petrochemical companies. The electrical engineers had data. It was possible to get motor lists. However, the process engineers did not have data available in a single source. In addition they were unable to cite the performance of the heat exchangers. This was unexpected but understandable because the complexity of refineries and petrochemical companies is extremely high and the individual components are not instrumented for economic reasons. A willingness to contribute was often tempered by lack of readily available data and no time to devote to collecting it from scratch, or by corporate, industrial, regulatory and government constraints. Important contributions were gathered from one-on-one conversations and not limited only to research fact sheets gathered from the respondents.

A second survey was developed that addressed the effectiveness of control and power technologies in refineries and petrochemical companies. A quantitative calculation of specific energy savings was not possible because of a lack of quantitative data. However, a qualitative assessment of areas where substantial energy could be saved was feasible.

Contact was made with a total of twenty refineries and seven petrochemical plants across the U.S., including California. An information package and a confidentiality agreement for contributors were developed, together with a letter of invitation that was revised in conjunction with respondents. A letter of support from the DOE was solicited that was used to encourage and foster participation.

An Information Summary (Appendix A) was composed that was further developed to form the Refinery and Petrochemical Survey (Appendix B). The survey was sent to willing respondents. Telephone interviews were conducted. A total of six site visits was completed that covered four major refinery sites and one petrochemical site: ChevronTexaco Richmond Refinery, California, Chevron Texaco Pascagoula Refinery, Mississippi, Shell Wilmington Refinery, California, Valero Benicia Refinery, California and Equistar Chemicals, Houston, Texas. Documented replies were reviewed for completeness. An MS Excel spread sheet (Appendix C) was used to enter information for early respondents and included in the package for subsequent respondents. The scope of the survey was amended and reduced in order to retain contributors and a new survey was developed for phone interviews (Appendix D). Results were analyzed and information from research, telephone conversations, site visits, and data provided by respondents was summarized.

Contributors to this report include ChevronTexaco, Pascagoula, Mississippi, Chevron Texaco, Barber's Point, Hawaii, Chevron Texaco Richmond Refinery, California, Chevron Texaco, El Segundo, California, Shell, Norco, Louisiana, Shell, Wilmington, California, Shell, Bakersfield, California, Shell, Martinez, California, Valero, Benicia, California, ExxonMobil, Joliet, Illinois, Exxon Mobil, Torrance, California, ConocoPhillips, Sweeny, Texas, ConocoPhillips, Ponca City, Oklahoma, ConocoPhillips, Wood River, Illinois, ConocoPhillips, Rodeo, California. ConocoPhillips, Wilmington, California, BP, Carson, California, BP, Cherry Point, Washington, BP Chemicals, Lima, Ohio, Tesoro, Martinez, California, Apex, Long Beach, California, Kern, Bakersfield, California, DOW Chemicals, Freeport, Texas, Equistar Chemicals, Houston, Texas, BASF, Houston, Texas, Solutia, Greenwood, South Carolina, Dupont, Old Hickory, Kentucky.

There was universal support for the project. However, for many companies the levels of contribution were limited or curtailed owing to corporate pressures, staff reductions, plant closures, time constraints, and the number of personnel available either to answer questions or to complete the survey provided.

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PRESENT USE OF CONTROL AND POWER TECHNOLOGIES

Present Use of Control Technologies

Control Technology is an enabling technology. It facilitates the translation of physical requirements into an automated process. To what extent and to what effect it is used depends upon the acceptance of current electronic advances. Table 2-1 and Table 2-2 show the current use of control and power technologies in U.S. refineries and petrochemical plants. In general, control technology has penetrated more uniformly into petrochemical companies. This is understandable as many petrochemical plants were constructed at a time when these technologies were becoming available, whereas the majority of refineries were already established.

Contributors of information for this report described a very wide range of control techniques currently in use in refineries. They ranged from 50's style pneumatic control, through single loop analog control, distributed control systems (DCS) and multi variable control, to the most advanced neural net sub systems. A brief definition of these terms is described in Appendix E. The speed of penetration of more advanced control did not seem to be directly attributable solely to a company but rather more influenced by the drive and persistence of an individual involved in any particular site. One company, for example, used a majority of pneumatic control at one plant and yet had considerable neural net application in another. The success of any move to advanced control is very much dependent on the refinery engineer taking ownership once the subcontractor's work is complete.

Refinery research indicated that specific improvements had been recorded as a result of changes made. A move from pneumatic control to DCS control provided savings of 10% to 25% in total energy with possibly another 5% to 10% that could still be obtained. Survey responses indicated that operators of manual control systems use safety margins that result in wasted energy. Such conservative operation ensures process stability, although this does not foster peak economic efficiency. Steam heater efficiency, in particular, can be considerably enhanced by the use of automatic multivariable control. In a case where a move to DCS did not produce a noticeable reduction in energy usage, the process efficiency was improved in that there were fewer upsets and problems. The result was more continuous production time and therefore more opportunity to take advantage of any changes in the marketplace. Basic DCS is not an advanced control technology. This term is used fairly loosely and may include some elements of predictive control, and even multi variable control. Very specific savings of 30% to 40% have been recorded as savings in certain distillation columns. However, in the same plant, savings of only 2% to 3% have also been recorded under similar circumstances, indicating that results may vary

Table 2-1
Use of Control and Power Technologies in U.S. Refineries

Refinery*	Control**	MV Penetration	Considering Advanced Control	Electric Penetration	ASD Penetration	Considering Advanced Power	Operating Margin	Cogen	Remarks
1	All MV units	100%	No	95%	5%	Yes	Tight	Yes	Information via corporate
2									Not contacted
3	DCS and MV	80%	Yes	85%	1%	No	Tight	NA	Information via corporate
4	DCS few on MV	30%	Yes	85%	1%	No	Tight	Yes	Process engineer
5									Closing, not able to contribute
6	Single loop electric	0%	No	95%	0%	No	Tight	Yes	Process engineer
7	Fully DCS some MV	20%	Yes	85%	1%	Yes	Tight	Yes	Process engineer
8	All MV units	100%	No	95%	5%	Yes	Very tight	Yes	Information via corporate
9								Yes	Energy engineer study not completed
10	Single loop electric	0%	Yes	85%	1%	No	Tight	Yes	Information via corporate
11	DCS some MV	20%	Yes	85%	1%	Yes		Yes	Process engineer
12	DCS	0	Yes	95%	1%	No		Yes	Process engineer
13								Yes	Declined to contribute
14	DCS	0	Yes		1%	No	Tight	Yes	Electrical engineer
15	MV	95	Yes	90%	4%	Yes	Tight	Future	Maintenance engineer and via corporate

Table 2-1
Use of Control and Power Technologies in U.S. Refineries, Continued

Refinery*	Control**	MV Penetration	Considering Advanced Control	Electric Penetration	ASD Penetration	Considering Advanced Power	Operating Margin	Cogen	Remarks
16	MV	80%	Yes	80%	1%	Yes	Tight	Yes	Information via corporate
17									Unable to contribute
18	MV	90%	Yes	85%	2%	Yes	Tight	Yes	Process engineer
19	MV	90%	Yes	85%	1%	Yes	Tight	Yes	Information via corporate
20	DCS	90%	Yes	90%	1%	Yes	Tight	Yes	Information via corporate
21	MV	100%	Yes	95%	5%	No	Tight	No	Information via corporate

* Refinery random reference
** MV = Multivariable Control, DCS = Distributed Control System

Table 2-2
Use of Control and Power Technologies in U.S. Petrochemical Plants

Petrochemical Company*	Control**	MV Penetration	Considering Advanced Control	Electric Penetration	ASD Penetration	Considering Advanced Power	Operating Margin	Cogen	Remarks
1	MV	95%	Yes	80%	6%	Yes	Improving	Yes	Energy engineer
2	DCS	5%	No	100%	96%	No	Chapter 11	No	Maintenance engineer
3	MV	90%	Yes	80%	4%	Yes	Improving	NA	Process engineer
4	MV	90%	Yes	80%	3%	No	Very tight	Yes	Electrical engineer
5	DCS	10%	No	96%	90%	No	Closing	Yes	Utility engineer
6	MV	90%	Yes	80%	3%	Yes	Tight	Yes	Electrical engineer and Process engineer
7	MV	90%	Yes	80%	5%	No	Very tight	Yes	Electrical engineer

* Petrochemical random reference
** MV = Multivariable Control, DCS = Distributed Control System

widely. The overall average energy savings was 25% for this refinery under multivariable control.

The most difficult challenge in the refining process is the control of the rate of output, in particular, control of the CAT Cracker. A number of CAT Crackers operate under the control of a multivariable system. There are cases where capital equipment is obsolete and funds are neither available nor justifiable for investment in the most up to date units. Even pumps having adjustable speed control are considered too expensive. The most important consideration is keeping a refinery running. Reducing production rates in order to maintain equipment needs careful management. Any process disruption may result in delays and a reluctance to revert to multivariable control after a manual start up.

The petrochemical industry differs from the refining industry in that it produces a wide range of products for the marketplace and its position in the delivery chain is complex. The refinery process is more easily defined compared with the petrochemical process. The petrochemical industry is ahead of the refining industry in process control, having pioneered the DCS system, and it is now widely utilizing multivariable predictive control. Respondents had great difficulty in tying economic payback to the level of control because there was no information available on which to base these calculations. However, they were very aware of the positive impact of control on the process and are now considering what the next step should be in the evolution of control schemes. Presently, the problems associated with existing control applications that need improvement are robustness, control uptime and, for some applications, the range of control. Range of control is particularly important as applied to catalysts. To date, multivariable controllers have been applied to sections of plants, although not to complexes as a whole. The goal of petrochemical plants is to achieve quality and consistency from their plants. They audit the process for suitability of optimum performance quite separately from energy auditing. Pinch technology was reported as being utilized to good effect by one respondent. It should be noted that respondents that produced final product, such as extruded manmade fiber, saw no need for more sophisticated control at this time. Based on industrial trends for improved quality and output and energy intensity it seems evident that this attitude will change. Further advanced control will afford improvements for the petrochemical industry.

Control using throttling valves presents special performance issues for both refineries and petrochemical plants because there are stringent monitoring and correction requirements for throttling valves in place. In the past only California had to face such issues. Now these regulatory constraints are penetrating other states. Problems for refineries are further increased by regional requirements for “boutique” gasoline tailored to meet regional requirements. Control valve stems are a major source of fugitive gasses. To minimize this problem the valve stem packing is tightened down. The control schemes associated with this require 0.25% to 0.5% accuracy. Sticking valve stems prevent this. Advanced power control could alleviate the problem. Both the EPA and the Texas Commission on Environmental Quality have recently lowered thresholds on reportable release to one pound.

There is an understanding that real energy benefits can be achieved by using advanced control and there is a perception that the challenge to be faced is not technology itself but rather operator confidence in technology. In terms of energy efficiency, the focus is to decrease energy intensity or to reduce energy usage per unit of output.

Present Use of Power Technologies

Power Technology, like Control Technology, is enabling. It facilitates the translation of energy from one form to another. A key example of this transference is the introduction of hydraulic power to the process under control. This technology covers both the introduction of energy and the extraction of energy. Both mechanical and electrical techniques are represented. Hydraulic power is associated with changes as related to fluid and gases. It covers heating, cooling, pumping, compressing, converting, condensing, and the extraction of kinetic energy.

To understand the full impact of electrical power technologies as applied to refineries and petrochemical plants in U.S. it is essential to understand the current methods of energy transfer from utility source to process material. Energy is applied to basic raw material in the form of heat. This heat is predominantly produced from the combustion of natural gas and by-products of the process, namely fuel gas. The heat from the combustion is converted into steam that is used in four ways: generation of electricity, heating process material, direct injection into the process material, and powering of steam turbines. Owing to the exothermic nature of sections of the process, certain stages of the gas flow require that energy be removed from the hydraulic system. This energy may be wasted or converted into steam or into electrical energy. Historically, this element of the energy has not been optimally controlled.

Research has shown that in a number of refineries nationwide there is little enthusiasm for the introduction of variable speed control as a method of optimizing energy delivered to the hydraulic system. There is a reluctance to move from pressure control to speed control. There have been a number of poor experiences associated with adjustable speed drives, in particular large units, where expectations have not been met and this overshadows the possibility of installing new large drive systems. Feedback indicates that, in the case of a particular large drive application, reliability was poor and it was felt that the complexity of the equipment installed necessitated specific expertise in dealing with it for success. Availability of relevant education and training was a factor and it was felt also that the number of people who understood it and could work on it limited the drive's performance. Economic justification was difficult to endorse in such a situation. However, where there has been successful implementation of variable speed control in refineries, for example on smaller unit installations on fans, it has been met with enthusiasm and proved to be an asset. Reliability is not an issue in such applications largely because there are multiple smaller units and no single unit would significantly impair the throughput of the refinery. Contrast this with a single 4000hp drive application for variable control on a hydrocracker compressor that is singly critical to plant refinery output. One petrochemical respondent reported the successful use of two modern concept permanent magnet couplings. These devices provided the full speed control necessary for the pump whilst avoiding the size and environmental constraints of adjustable frequency drives. This method of controlling pump output eliminated throttling losses. Successful application of variable speed control can only be accomplished through careful specification of equipment and diligent follow up. Successful installations of large drives for variable speed control are best achieved by a total systems approach to engineering; equipment installations need to work together as a whole. In the refinery industry no new refineries are being built and retrofits are not being done and therefore the penetration for larger electrical drives for variable speed control is very small.

There are two entirely different characteristics of petrochemical plants. There are those that are almost indistinguishable from refineries in that they are physically close to a refinery, probably right next door, and they use similar equipment. They may use the product from that refinery. There is a symbiotic relationship. These petrochemical plants tend to manufacture chemicals, often unrecognizable to the layperson, that in turn are used by other remote petrochemical plants. These other remote petrochemical plants are geographically separate from refineries and they manufacture end products that are more recognizable to the layperson as, for example, pesticides or nylon. These two groups of companies use technology in different ways. Petrochemical plants geographically close to a refinery use similarly styled processes to those in refineries. For example, a petrochemical facility and a refinery could both have alkylation processes and catalytic reforming. Remote petrochemical plants, however, tend to be product specific and need dedicated specialized process equipment. Within the petrochemical industry there are different rates of acceptance and penetration of power technology.

Petrochemical plants closely associated with refineries have accepted small adjustable speed drives and found them to be successful in the following applications: cooling towers, product blending, extruding, dosing, cooling fans, and fin fans. Steam turbines are widely used where speed variation is required for fan, pump and compressor applications and they have been found to be robust and reliable.

Petrochemical plants remote from refineries reported extensive use of electrical variable speed control on process equipment. This use of speed control has been successfully applied to pumps, fans, and air washers and has been driven by improved energy conservation. Productivity itself hasn’t improved but energy has been conserved by the elimination of throttle valves.

Advanced power control techniques are more readily accepted as smaller applications in both petrochemical plants and refineries. They have been explored more widely in petrochemical applications. Where larger applications have been implemented they are more likely to be used in the petrochemical industry at this point, and as such they may also be part of petrochemical production within a refinery.

3
OPPORTUNITIES FOR CONTROL AND POWER TECHNOLOGIES

Process Conditions that Currently Allow Energy to Be Wasted

Conditions in the process that currently allow energy to be wasted need to be addressed by applying the Laws of Thermodynamics to best advantage. Respondents explained that between 30% and 40% of all energy used in the refining process goes into the distillation of crude oil. Most of this energy escapes as low-grade heat. Refinery efficiency and air quality would be improved if this was avoided and the heat was reused. For the safety of equipment and workers in refineries and associated petrochemical plants, safety margins are always necessarily in place. Excessive safety margins employed for increased process stability leads to wasted energy. A clogged heat exchanger uses excessive energy, as do throttling valves, tight control valves, and using two pumps instead of one. Ambient temperature changes cause energy to be wasted. Fixed speed pumps and fin fans cannot adequately compensate for variable ambient conditions. Exothermic energy, when it is changed into steam instead of being converted directly to electricity, absorbs energy that could be used elsewhere in the process. Steam loops typically waste 66% of energy. Using steam where an electrical drive could be used is wasteful also and scant knowledge of the capabilities of process components leads to over consumption of energy. Respondents believed that tighter control of process variables would result in better product and energy savings.

Energy Savings Opportunities in Existing Applications

Energy savings could be made in existing applications by implementing an improved level of control which, when combined with advanced power technologies, will reduce wastage associated with valves, pumps, furnaces, reactors, and heat exchangers. It can also reduce wastage from excessive safety margins while maintaining security. For the refining and petrochemical industries implementing plant wide control optimization will facilitate substantial energy savings. When variable speed control is implemented, along with an appropriate range of advanced technology, to a variety of applications, the outcome will be decreased energy intensity. Changing from steam turbines to electric motors wherever possible will also provide favorable energy savings.

Fixed Speed Equipment Applications that Could Benefit from Alternate Technologies

Fixed speed equipment applications that could benefit from alternate technologies are compressors; furnace ID fans, fin fans, blowers, and pumps with existing throttle control. There are additional applications that are two-speed controlled that could benefit from comprehensive variable control. In situations where one pump supplies many throttle valves, alternate technologies could provide significant improved control and energy benefits.

Opportunities for Advanced Control Technologies

The potential for advanced control technology in U.S. refineries and petrochemical companies is significant. Table 3-1 shows the present state of adoption of control technologies in U.S. refineries. Table 3-2 shows the present state of adoption of control technologies in U.S. petrochemical companies. Completion of the evolution towards distributed control systems (DCS) and multivariable control needs to be encouraged because it offers a potentially large benefit to the U.S. This initial evolutionary stage must be succeeded by the use of the next generation of self-learning tools that have the capability to optimize control of a complete facility. This progression will require investment, but it is a vital and necessary step in order to take full advantage of every aspect of advanced control algorithms. [5,6,7,8,9] Future control [tables 3-1 and 3-2] refers to the most advanced features of control … that which can be achieved using a combination of available advanced technology. This chapter deals with opportunities. 0% indicates that the refineries have not implemented these aspects of advanced control owing to a variety of constraints described in this report. Refineries are conservative. Refineries and petrochemical plants operate as sub-sections that each complete identifiable products and together comprise a total plant. Thus it is possible for a subsection (an entity in itself) to be 60% multivariable while the refinery as a whole has made no moves at all toward integrating the sub sections into a control system that would optimize the operations of the whole refinery. Tables 3-1 and 3-2 summarize the extent that control technology has been utilized in refineries and petrochemical plants, and illustrates the potential for future improved control.

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Table 3-1
Present State of Adoption of Control Technology in U.S. Refineries

Present Control Technology	Sub Section of the Refinery	Whole Refinery
Move to DCS	98%	98%
Move to Multivariable	60%	0%
Move to Neural Net	5%	0%
Future Control	0%	0%

Table 3-2
Present State of Adoption of Control Technology in U.S. Petrochemical Plants

Present Control Technology	Sub Section of the Petrochemical Company	Whole Petrochemical Company
Move to DCS	100%	100%
Move to Multivariable	80%	0%
Move to Neural Net	10%	0%
Future Control	0%	0%

Opportunities for Advanced Power Technologies

The implementation of advanced power technology in U.S. refineries and petrochemical companies offers much potential. Table 3-3 shows the present state of power technology adoption in U.S. Refineries. Table 3-4 shows the present state of power technology adoption in U.S. Petrochemical Companies. Adopting advanced power technology will afford refineries and petrochemical plants more time between outages, immunity from power transients, reduced heat load, reduced wear on pipes and flanges, reduced bearing failure rates, reduced steam load, and reduced electrical load. More energy will be able to be extracted from the fluid. There will be potential for increased accuracy in flow control, potential for exporting electrical power, and a more effectively integrated total system. Tables 3-3 and 3-4 illustrate that subsections within refineries and petrochemical plants have made similar moves towards power technologies, as have the plants as a whole. Tables 3-3, and 3-4 show that the move to fixed speed electric drives is advanced whilst the implementation of speed control has barely started. Tables 3-3 and 3-4 illustrate the potential for future improved power control.

It is worth noting the comparison between tables 3-1 and 3-2 that deals with control technology, and tables 3-3 and 3-4 that deal with power technology. Both the sub sections of plants and plants have adopted power technology equally as a whole whereas control technology has penetrated subsections of plants to some degree but not whole plants. This illustrates the potential penetration of control and power technologies for the future.

Table 3-3
Present State of Adoption of Power Technology in U.S. Refineries

Electric Drives	Sub Part of Refinery	Whole Refinery
Move to fixed speed electric motor	90%	90%
Move to variable speed electric motor	2%	2%
Move to advanced power control	< 1%	< 1%
Fully optimized control	0 %	0 %

Table 3-4
Present State of Adoption of Power Technology in U.S. Petrochemical Plants

Electric Drives	Sub Part of Petrochemical Company	Whole Petrochemical Company
Move to fixed speed electric motor	60%	60%
Move to variable speed electric motor	3%	3%
Move to advanced power control	< 1%	< 1%
Fully optimized control	0 %	0 %

4

ANALYSIS OF SAVINGS FOR A TYPICAL U.S. REFINERY AND A TYPICAL U.S. PETROCHEMICAL PLANT

In order to extrapolate from refinery data collected during the study, two reference documents were used: a recent energy balance for petroleum refineries [2] and information published in the Oil and Gas Journal [1].

From reference [1] it is possible to calculate the average power consumed by an average sized petroleum refinery in the United States:

There are a total of 133 refineries in the U.S.

Total supply for heat and power for all 133 refineries for one year = 3,478 Trillion Btu [2]

For one average sized U.S. refinery

The supply of heat and power = 3,478 Trillion Btu/ 133 Refineries

= 26.1503 Trillion Btu per year

Converting to MW = 26.1503Trillion Btu per year / 8,760 Hours per year

= 2.985 x 10^9 Btu per hr
= (2.985 x 10^9) Btu per hr x (2.928 x 10^{-7}) MW hr/Btu
= 874 MW

In the U.S., 133 refineries use 16,623,301 Bpd of crude oil [1]

The average sized refinery in the U.S. = 124,987 Bpd

The efficient refinery can be recognized by the presence of the following features: vacuum distillation, coking, alkylation, catalytic cracking, catalytic reforming, catalytic hydrocracking, and catalytic hydrotreating. The more of these features there are, the more committed the refinery is to technologies that enable the extraction of more gasoline from crude oil.

Savings for a Typical U.S. Refinery

The information collected from one refinery was scaled to represent an average U.S. refinery. The average sized refinery in the U.S. utilizes 124,987 Bpd. A refinery of this size, from the study data, requires 140 MW of electric power. Most commonly an average 29% of electrical power is produced by cogeneration [2]. This arrangement not only provides flexibility, but an economic advantage to the refinery. Both the cost and the reliability of such an electrical supply are important.

All motors that together have nameplate ratings of 162,225 kW were included in the power distribution shown in Table 4-1. Output throttles controlled 75% of these motors. It was not possible to complete a control audit at the site due to a turnaround condition.

Table 4-1
Typical Electric Motor Use from Study Respondent Scaled to Match the Average U.S. Refinery

	Proportion	kW	Quantity
Low voltage motors (based on 50 hp)	38%	61,190	1224
Medium voltage motors 100 to 1000 hp	26%	42,567	152
Medium voltage motors 1000 to 15,000 hp	36%	58,468	28

The following analysis considers a typical U.S. refinery [1, 10]

From survey information received from one respondent refinery that used vacuum distillation, coking, alkylation, catalytic cracking, catalytic reforming, catalytic hydrocracking, and catalytic hydrotreating and was scaled to match the U.S. average of 124,987 Bpd, the electric power consumed in the refinery = 140 MW. (Note: the refinery selected also provided a complete and accurate motor list)

Loss in the electric motor driven systems:

Motor loss (6%) = 8,400 kW (6% of 140MW)

Pump loss, from PSAT [16] is in the range 25%-40%

Pump loss (Assume 25%) = 0.25 (25%) x (140,000 kW – 8,400 kW)

= 32,900 kW

Throttle loss, from EPRI research is in the range 20%-50%,

Throttle loss (Assume 20%) = 0.20 (20%) of (140,000 kW – 8,400 kW – 32,900 kW)

= 19,740 kW

Calculating the potential for energy savings that could be made from eliminating throttle loss with the implementation of advanced power control:

From the study refinery, 75 % of the electric motors were throttled.

Assume that there is a 50 % penetration rate of drives displacing throttle losses.

Potential savings for one average refinery = (19.740 kW) x (0.5) (50% penetration) x (0.75) (75% motors throttled) kW

= 7403 kW = 7.403 MW

Thus, 133 U.S. refineries will save potentially: 133 (refineries) x 7.403 MW = **984 MW**

Additionally, consider the potential for energy savings by converting a steam turbine to an electric drive:

Reference [3] and [4] both indicate that a single turbine to electric drive conversion will save 0.5 MW in energy. Such a conversion will also conserve 600psig steam and coolant water. Extrapolating from these two case histories, it is possible to see that for the 16 such drives present in the typical refinery requiring 140 MW of electrical power described above would alone provide 1064 MW of energy savings. (16 drives x 0.5 MW/drive x 133 refineries = **1,064 MW = $280 M @ $0.03 per kWh**)

Calculating total energy converted by the average U.S. refinery:

Using the calorific value of 5.6M Btu per barrel, the rate of energy flowing through an average U.S. refinery = 124,987 (bpd) x 5.6 (MBtu per barrel) x .2928 (MW hr per MBtu) /24hrs

= **8,539 MW**

From respondent information for a group of major refineries, the internal loss in a typical refinery was estimated to be 5% of the calorific value of the crude oil input used i.e. 8,539 MW x 0.05 (5%) = 427 MW. This is a very conservative figure as the internal loss for a typical complex refinery is commonly stated as 10% [10].

Coordinated refinery control will conservatively be able to save a further 10% of the current loss or 0.5% of the average refinery throughput, i.e. 427 MW x 0.1 (10%) = 43 MW. For the 133 U.S. refineries, the savings from advanced control are predicted to be 43 MW x 133 (refineries) = **5,719 MW**.

The above calculations show the basic energy savings' numbers. Further real benefits for the U.S. will be derived from reduced waste heat and improved yields through sharper cuts, when advanced control is introduced. Implementation of advanced power technology will lessen environmental impacts. Problems associated with control valve stems will not be completely eliminated. However, movement and continued wear will be reduced to a negligible rate. The service and repair costs for the refinery will be reduced. Control of fluid flow will reduce pump impellor wear and tear and eliminate cavitation failures. The changes will permit more process improvement and avoid the need for unnecessary governmental intervention.

For 133 U.S. refineries, the savings from advanced control are predicted to be 5,719 MW. This is equivalent to an annual saving of 5719 MW x $0.03 per kWh = $1,503 Million. (Assuming power cost = 3 cents per kWh). A summary of this analysis, as applied to the 133 U.S. refineries, is provided below, assuming 100% control and 50% power penetration:

- Annual energy losses would be reduced by $1,503M
- Annual hydraulic power consumed would be reduced by 5% or 984 MW, which is equivalent to $259M, assuming a power cost of 3 cents per kWh.
- Annual fuel savings from converting steam turbines to electric drives =$280M
- The total fuel related cost savings = $2,042M

A summary of benefits, as applied to the 133 U.S. refineries, is provided below, assuming 100% control and 100% power penetration:

- Annual energy losses would be reduced by $1,503M
- Throttle conversion benefit = $518 M (2 x $259M)
- Steam turbine conversion to electric drives = $525 M (30/16 x $280M)
- The total fuel related cost savings = $2,546M

Total U.S. refinery costs and savings [Figure 4-1, Figure 4-2, and Figure 4-3] were developed using published statistics [1], [11], [15] in conjunction with the projected improved conversion efficiency expected from the implementation of advanced control and power technologies as calculated above.

Including energy related annual savings, it is estimated that the annual operational benefits shown in Table 4-2 would accrue. The savings shown in Table 4-2 were calculated by subtracting the "opportunity" items in Figure 4-3 from the corresponding values in Figure 4-2.

Table 4-2
Potential Annual Savings from Implementing Advanced Control and Power Technologies in U.S. Refineries, Assuming 100% Penetration

Opportunity	Annual Savings (Millions of Dollars)
Waste due to utility power related causes would be reduced	$430
Operations and maintenance costs would be reduced	$2,530
There would a reduced environmental impact cost	$760
There would be increased electricity cost of	($90)
Total fuel related cost savings	$ 2,546
Total potential annual savings	$6,176

This would provide a predicted total annual savings for U.S. refineries of $6.2 Billion. Based on an estimated investment cost of $11 Billion, savings of $6.2 Billion/year would yield a simple payback of 1.8 years ($11 Billion/$6.2 Billion/year). Note: Payback does not include financing cost.

It should be noted that the scope of this report does not address potential increases in refining capacity that could result from implementing advanced control and power technologies. It is recommended that this additional benefit be the subject of further investigation.

Savings for a Typical U.S. Petrochemical Plant

In order to extrapolate from petrochemical data collected during the study, two reference documents were used: a recent energy balance for chemical plants [11] and information published in the OIT/ Profiles and Partnerships [12]

From [11] it is possible to calculate the energy delivered as utility supplies to operate all of the chemical plants in the United States and convert this energy to equivalent power

Total energy used = 3,729 trillion Btu / year

= 3,729 trillion Btu / (365 days / year) / (24 hr / day) Btu/hour

= 0.4257 trillion Btu / hour

= 0.42 trillion Btu / hour x 0.2928 (W per Btu) trillion watts

= 122,967 MW

From [12] this energy is delivered by energy sources

Energy source = 122,967 MW equivalent

From [13]: Of this equivalent power used in the chemical industry, according to MECs, 60% is used in petrochemicals

Equivalent Power used in petrochemical plants = 122,967 MW x 0.60 (60%) = 73,780 MW

Assume the 5% of petrochemical plants (those remote from refineries and delivering final product) have fully implemented speed control

Then 95% of petrochemical plants are potential candidates for the implementation of advanced control and power technologies

Total equivalent power =73,780 MW x 0.95 (95%) = 70,091 MW

The respondent petrochemical plant (an acrylonitrile unit within a large petrochemical complex was selected because a detailed motor list was available) used as an example has been scaled to fit the typical plant size in the U.S.

Respondent plant energy input:

Natural gas volume = 850,000 scf per hour

Natural gas energy = 850,000 scf per hour / 1000 scf per MBtu

= 850 MBtu per hour

Natural gas equivalent power = 850 MBtu x 0.2928 (W per Btu) MW

= 249 MW

Off gas volume = 690,000 scf per hour

Off gas energy = 690,000 scf per hour / 1000 scf per MBtu

= 690 MBtu per hour

Off gas equivalent power = 690 Mbtu/hour x 0.2928 (MW hour per MBtu) MW

= 202 MW

Electricity = 135 MW

Total energy = 249 MW (natural gas equivalent) + 202 MW (off gas equivalent) + 135 MW (electricity)

= 586 MW

From above, the total power supplied to U.S. petrochemical plants = 70,091 MW

In order to extrapolate from energy savings calculated in the typical petrochemical plant to savings predicted for the whole U.S. petrochemical industry, the multiplier = 70,091 MW petrochemical industry total / 586 MW per petrochemical plant = 120

All motors that together have nameplate ratings of 195,060 kW were included in the power distribution shown in Table 4-3. Output throttles controlled 80% of these motors. It was not possible to complete a control audit at the site due to time pressure.

Table 4-3
Typical Electric Motor Use from a Study Respondent Petrochemical Plant Scaled to Match a Typical U.S. Petrochemical Plant

	Power range	Number of Motors
Low voltage motors	1-10 hp	1,587
Low voltage motors	10-100 hp	1,194
Low voltage motors	100-1,000 hp	429
Medium voltage motors	1,000-10,000 hp	117

From survey information received from one respondent and scaled to match a typical U.S. petrochemical plant, the electric power consumed in the plant = 135 MW.

Loss in the electric motor driven systems:

Motor loss (6%) = 8,100 kW (6% of 135 MW)

Pump loss, from PSAT [16] is in the range 25%-40%

Pump loss (Assume 25%) = 0.25 (25%) x (135,000 kW – 8,100 kW)

= 31,729 kW

Throttle loss, from EPRI research is in the range 20%-50%,

Throttle loss (Assume 20%) = 0.20 (20%) x (135,000 kW – 8,100 kW – 31,729kW)

= 19,034 kW

Calculating the potential for energy savings that could be made from eliminating throttle loss with the implementation of advanced power control:

From the study petrochemical complex, 80 % of the electric motors were throttled

Assume that there is a 50 % penetration rate of drives displacing throttle losses

Potential for savings for one typical petrochemical complex = (19,034 kW)(throttle loss) x (0.5)(penetration rate) x (0.8)(proportion of motors presently throttled) kW = 7,614 kW = 7.614 **MW**

Thus, using the multiplier 120 to scale from one plant to the whole US petrochemical industry, U.S. petrochemical plants will save potentially 120 (multiplier) x 7.614 MW (potential savings from throttle losses at each typical plant) = **914 MW** = $240 M @ $0. 03 per kWh

Assume that there is 100% penetration rate of drives replacing throttle losses

Potential for savings for U.S. petrochemical industry = $480M ($240M x 2) (increase from 50% to 100%)

Additionally, consider the potential for energy savings by converting a steam turbine to an electric drive:

Reference [3] indicates that a single turbine to electric drive conversion will save 0.5 MW in energy. Such a conversion will also conserve 600psig steam and coolant water. Extrapolating from this case history, 17% of steam turbine power can be conserved by converting to an electric drive. The typical petrochemical plant contains 162 MW of steam turbines.

Therefore the potential for energy savings for the typical plant containing an acrylonitrile unit referenced previously = 27.54 MW (162 MW x 0.17 (17%))

Hence, for the U.S. petrochemical industry as a whole potential for savings = 3,305 MW (27.54 MW x 120 (multiplier to scale from one plant to the whole industry sector) = $868 M @ $0.03 per kWh

From respondent information, the internal loss in a typical petrochemical complex can be assumed to be 20% of the calorific value of the fuel used.

From [11] process energy use is 2,221 trillion Btu per year. The total energy can then be calculated by estimating the losses.

Losses are equivalent to 20% of energy used = 2,221 trillion Btu x 0.2 (20%) trillion Btu per year

= 444.2 trillion Btu per year

Hence for the U.S. petrochemical industry as a whole, the potential for energy savings using advanced control systems = 444.2 trillion Btu per year x 0.1 (10%)

Potential for Energy Savings = 44.42 trillion Btu per year

= (44.42 trillion Btu per year / 8,760 hours per year) Btu per hour

= 0.005072 trillion Btu per hour

Potential for Energy Savings = 5,072 MBtu per hour

Potential Power Saving = 5,072 MBtu per hour x 0.2928 (MW hour per MBtu) MW

= 1,484 MW

Value of the savings calculated at 3 cents per kWh = 1,482 MW x $ 0.03 (3 cents) x 8,760 hrs/yr

= $390M per year

For U.S. petrochemical companies, the savings from advanced control are predicted to be 1,484 MW. This is equivalent to an annual saving of $390M. (Assuming power cost = 3 cents per kWh.)

The above calculations show the basic energy savings' numbers. Further real benefits for the U.S. will be derived from reduced waste heat and improved yields through better process control, when advanced control is introduced. Implementation of advanced power technology will lessen environmental impacts. Problems associated with control valve stems will not be completely eliminated. However, movement and continued wear will be reduced to a negligible rate. The service and repair costs for the petrochemical plant will be reduced. Control of fluid flow will reduce pump impellor wear and tear and eliminate cavitation failures. The changes will permit more process improvement and avoid the need for unnecessary governmental intervention.

A summary of this analysis, as applied to U.S. petrochemical companies, is provided below, assuming 100% control and 50% power penetration:

- Annual energy procurement costs would be reduced by $390M
- Annual hydraulic power consumed would be reduced 914 MW, which is equivalent to $240M, assuming a power cost of 3 cents per kWh
- Annual fuel savings from converting steam turbines to electric drives = $868M
- The total fuel related cost savings = $1,498M

A summary of benefits, as applied to the U.S. petrochemical industry, is provided below, assuming 100% control and 100% power penetration:

- Annual energy procurement costs would be reduced by $390M
- Throttle conversion benefit = $480M (2 x $240M)
- Steam turbine conversion to electric drives = $868M
- The total fuel related cost savings = $1,738M

Total U.S. petrochemical costs and savings were developed using published statistics [11][14] in conjunction with the projected improved conversion efficiency expected from the implementation of advanced control and power technologies as calculated above.

Including energy related annual savings, it is estimated that the annual operational benefits shown in Table 4-4 would accrue. The methodology used to estimate the non-fuel related savings in the petrochemical industry was the same as that used for the refining industry.

Table 4-4
Potential Annual Savings from Implementing Advanced Control and Power Technologies in the U.S. Petrochemical Industry, Assuming 100% Penetration

Opportunity	Annual Savings (Millions of Dollars)
Waste due to utility power related causes would be reduced	$295
Operations and maintenance costs would be reduced	$1,725
There would a reduced environmental impact cost	$520
There would be increased electricity cost of	($60)
Total fuel related cost savings as estimated above	$ 1,738
Total potential annual savings	$4,218

This would provide a predicted total annual savings for U.S. petrochemical plants of $4.2 Billion. Based on an estimated investment cost of $7.5 Billion, savings of $4.2 Billion/year would yield a simple payback of 1.8 years ($7.5 Billion $4.2 Billion /year).

It should be noted that the scope of this report does not address potential increases in petrochemical capacity that could result from implementing advanced control and power technologies. It is recommended that this additional benefit be the subject of further investigation.

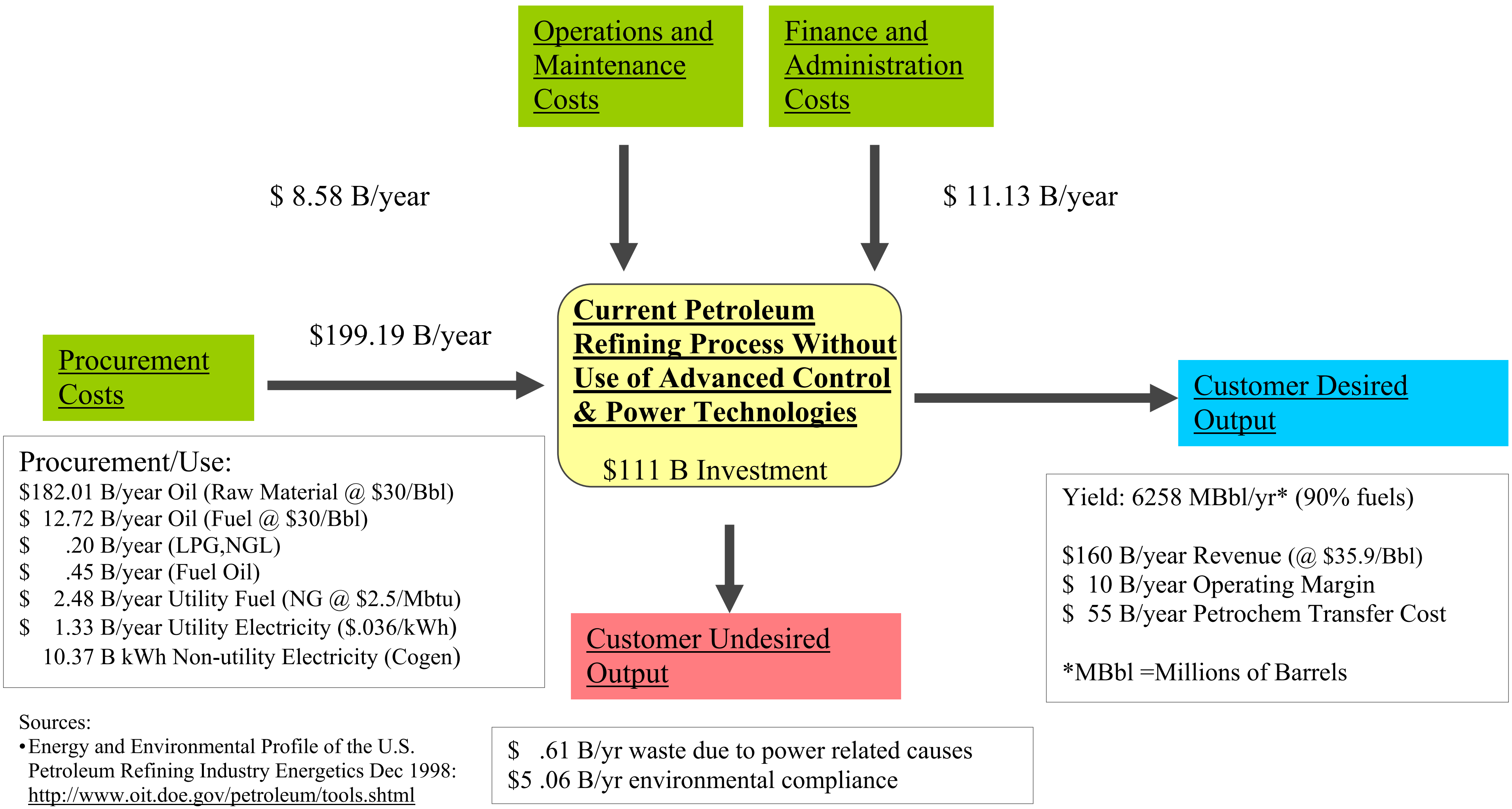
Potential for Energy Savings

Potential savings in energy are measured as an improvement of 7,203 MW for control and an improvement of 6,267 MW for power. This is equivalent to eliminating, and thereby saving, 13,470 MW of generation which can be made available for use elsewhere. This is the same as a continuous electricity supply for 3,367,500 houses, assuming 4 kW usage per house.

Energy Savings, Increased Productivity, and Increased Reliability

Energy savings, increased productivity, and increased reliability could be achieved based on alternate control and power technologies by fully implementing multivariable control on refinery and petrochemical subsections, implementing fuzzy neural self learning control as soon as this control is proven work hardened, producing more output for each unit of energy used in the process, and optimizing operations across entire complexes. Using the opportunities offered by technology to create full variable speed controlled areas of the refineries and petrochemical plants would reduce emissions and expand the capacity of plants

Once advanced control and power technologies are implemented, the U.S. refining and petrochemical industries will have improved immunity from external power events, reduced maintenance and operations costs, and reduced environmental impact.



Sources:
- Energy and Environmental Profile of the U.S. Petroleum Refining Industry Energetics Dec 1998: http://www.oit.doe.gov/petroleum/tools.shtml
- EIA : http://www.eia.doe.gov/fuelelectric.html
- Oil & Gas Journal 12/2002

Figure 4-1
U.S. Petroleum Refining (SIC 29/NAICS 324110)
2002 Industry Baseline (133 Refineries)

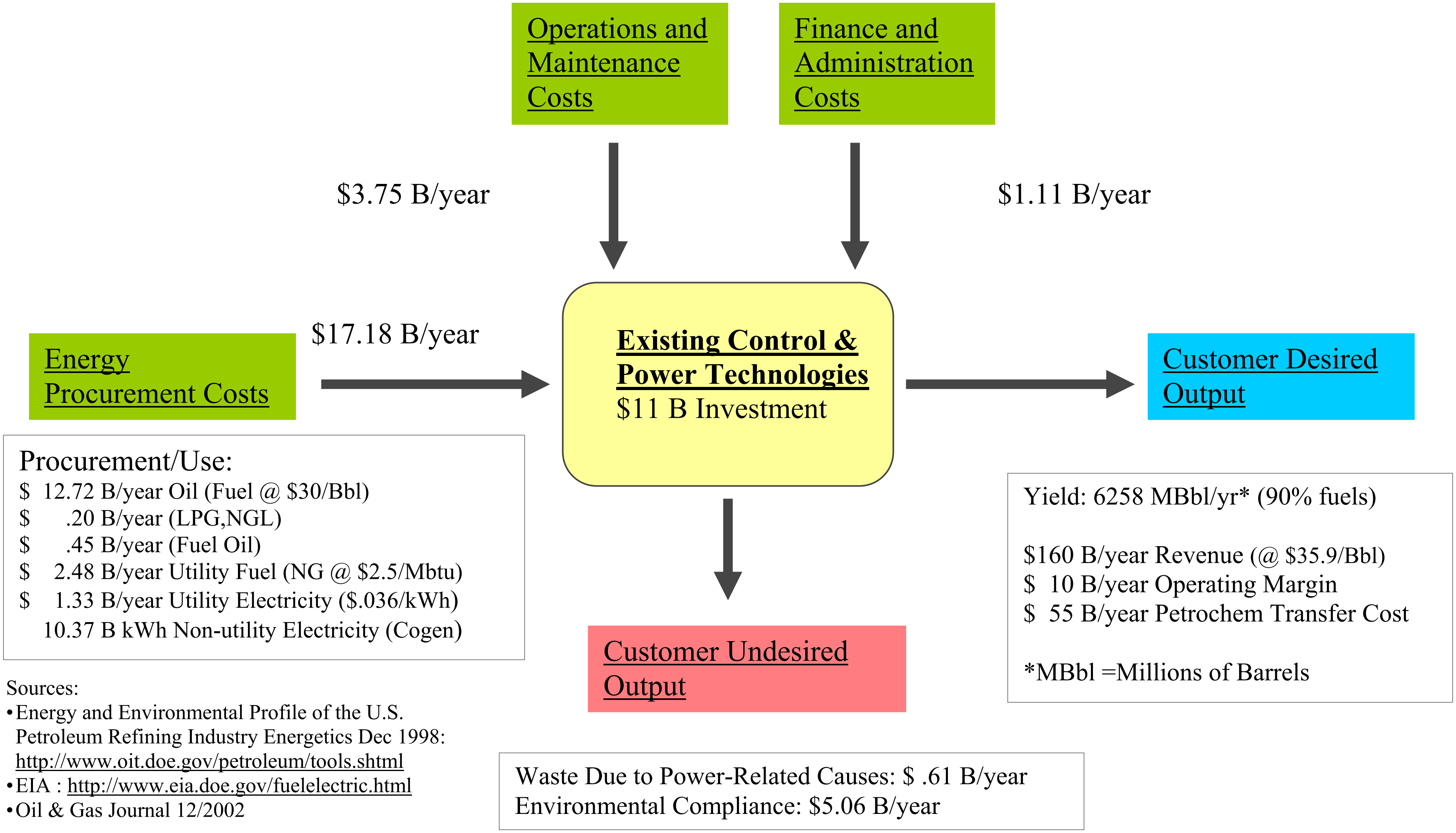


Figure 4-2
U.S. Petroleum Refining (SIC 29/NAICS 324110)
2002 Industry Baseline (133 Refineries)
Existing Control & Power Technologies

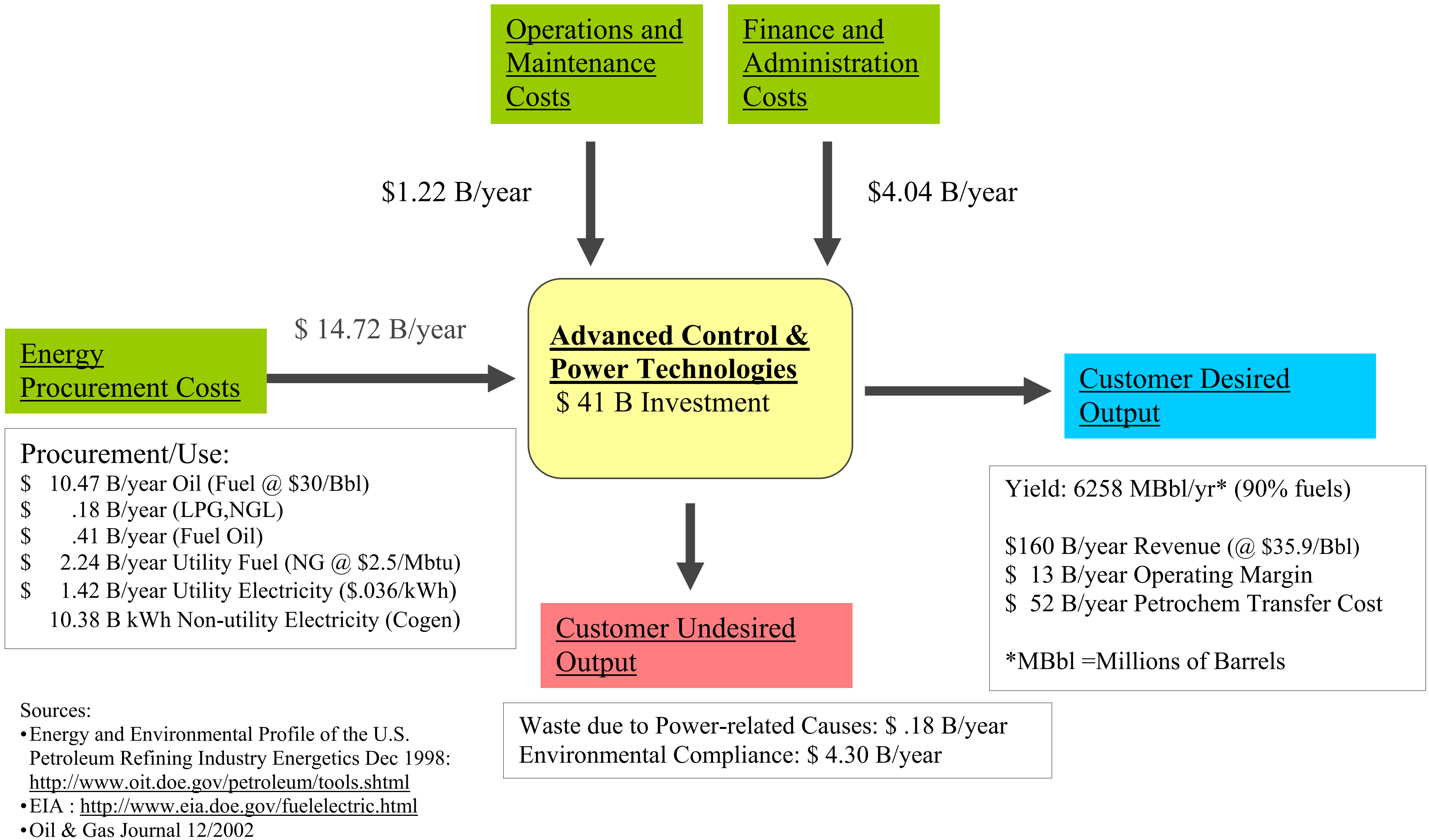


Figure 4-3
U.S. Petroleum Refining (SIC 29/NAICS 324110)
Proforma for Year 2015 (133 Refineries)
Advanced Control & Power Technologies

5
BARRIERS TO IMPLEMENTING ADVANCED CONTROL AND POWER TECHNOLOGIES FOR PROCESS OPTIMIZATION

Technical, Environmental, and Regulatory Barriers

The refining and petrochemical industries are structured around a particular energy source and are largely focused on steam. They operate using steam for convenience combined with electricity and there is a combination of steam with fixed speed pumps and fixed speed motors. This infrastructure, already in place, is the most significant single barrier to the implementation of advanced control and power technology.

U.S. refineries and petrochemical companies are faced with environmental and regulatory challenges. Those stringent environmental and regulatory constraints already faced by California are now penetrating other states across the U.S.. "There are 16 major federal statutes as well as numerous state laws that impose significant compliance and reporting requirements on the (chemical) industry" [12]. In Washington, the NW Environmental Agency reported a very cooperative relationship. They acknowledged favorable responses to requests made and voluntary adoption of acceptable standards by individual companies. In other areas too, safety and environmental issues are accorded priority by "responsible care" companies. This laudable cooperative spirit can only be beneficial in achieving positive results. Environmental regulations impact refineries and petrochemical plants in areas of fugitive emissions, flare gas, leakages from valve stems and flanges, and emissions collection domes atop storage containers. Valves are used widely and integrally in a variety of applications within refineries and petrochemical companies. They are associated with pumps and compressors. Valves are bar coded in order to monitor problems and their solutions.

The U.S. refining and petrochemical industries are under economic pressure. They are facing some or all consequences of reduced exports, reduced domestic demand, increased feedstock prices, personnel reduction and plant closures. In order to calculate the quantitative benefits that can be obtained from the implementation of advanced control and power technologies, data needs to be collected specifically from the process side of the industry. Several attempts to complete the collection of technical data for this study were well supported at the highest technical levels only to be brought to a halt by a manager who had ultimate authority.

Technically, there is in place optimization of sub systems but there is no plant wide optimization. From several sources there have been reports that neural network self-learning algorithms did not work in this environment and most of those algorithms have been removed. They have not yet proven themselves to have achieved the necessary level of maturity. They are not yet sufficiently "hardened" for application in the refining and petrochemical industry. One respondent said he would have to constrain the operation of neural net. Unconstrained operation of neural net must be the ultimate goal for optimized control.

The technical challenge is greater than implementing the necessary changes for improvement; it is to introduce those changes successfully within the limitations of the conditions that presently exist. A company needs to run as efficiently, reliably and cost effectively as possible currently, as well as plan for improvements in efficiency and cost effectiveness for the future. There is a delicate balance between maintaining the status quo and making changes for perceived future benefits. A reconfiguration from steam to electricity would be a costly major upheaval.

The challenge is to maintain reliability of production whilst improving control and energy intensity in conjunction with reducing emissions, maintenance, and corrosion. This places a significant burden on limited resources. "Resources" is used, here, as a broad term that includes manpower, land, available time, available knowledge, education level, industrial experience, as well as money. An illustration of circumstances coming together that influenced benefits overall and further extended them follows. Market conditions, and in particular increasing feedstock prices, have caused refinery operators to search for lower cost crude. Refining previously untried crude resulted in unexpected consequences for one respondent, namely corrosion, and necessitated repair. The repairs resulted in an upgraded installation of stainless steel vessel reactor liners that in turn led to savings from refining cheaper crude and in addition to better control and a wider range of efficient operation.

The refining and petrochemical industries in the U.S. are constrained in their ability to implement advanced technical changes by limitations in resources, as described. In refining there has been a trend towards outsourcing technical specifications and installations. Petrochemical companies are also considering this route. Such situations give rise to a dilution in commitment or a lack of "ownership". Faced with the narrow focus of contractual terms, the result can be doing the best job for the money rather than doing an excellent job. Success depends upon the capability of the contractor and the education level and industrial engineering experience of those who are contracted to do the work. Dealing with subcontractors may result in poor engineering, the correction of which may take weeks and threaten the overall output of the refinery.

There was acknowledgement that a refinery could be ten years behind a typical petrochemical plant in utilization of control and power technology.

Experiences with control and power technology differed across the industries from favorable to patchy to poor. In general experiences were more favorable in the petrochemical industry. Reservations were expressed over the reliability of drives, their cost, their size, being able to protect them from the environment, and integration and compatibility issues associated with them. Reports ranged from component failure through to early obsolescence. Even recently installed drives by a company that was very well versed in drive issues had exhibited audio noise problems. Re-commissioning experiences did not go smoothly either. Such experiences need not be the norm and there were notable exceptions. Two refineries had successfully introduced large horsepower drives on critical applications. Control technology draws criticism, too, when it falls short of achieving its potential. The maturity of advanced control is questioned when trips occur. Reliability for both control and power technologies is an ongoing issue to be faced.

Technical challenges, business challenges, environmental challenges, and regulatory challenges are considerable in the U.S. refining and petrochemical industry. These challenges are met with commitment, competence, experience, and ability and the industries are powerfully efficient in production, particularly petrochemical companies that are electrically driven. The desire to implement advanced control and power technologies for further energy savings, increased productivity, and improved reliability is apparent at all levels of management and is dependent upon available capital and knowledge. These technologies, applied correctly, can enable this industry that is already functioning well in the face of great change, to function even better in the future.

Physical, Human, and Financial Barriers

Physically there is an extensive existing structure that needs to be reliable and well maintained for continuous production and for the safety of the infrastructure as well as for the people involved. The maturity level of the technology itself is paramount. There are considerations of previous track records. Changes that have been made in the past may have worked badly or not at all. Making necessary changes to complex infrastructure can be a formidable and expensive task. It requires commitment and long term planning.

Human influences are complex and revolve around personalities, motivation, perception, and previous experiences. People must want to make changes and believe in them. There is an important and tangible consideration of human ability levels that depends directly upon levels of knowledge, relevant industrial experience, and training available. “Twenty years experience” must equate to knowledge accumulated and validated as relevant experience over twenty years, rather than to twenty accumulated single years of working that contribute little to in-depth knowledge and relevant experience. People work better, more effectively, and are more open to change if they are confident in their knowledge and their abilities. There needs to be an understanding of and an appreciation for the change from pressure to speed control and for the change from steam to electricity.

Management structure and attitude may tend towards an isolated management philosophy or an integrated management philosophy. Involvement of corporate management at all levels of the organization and free-flowing active communication within and between all levels of the corporation seems to have beneficial results in efficient plant operation. Common focus and shared information worked for the common good. Experienced technical, management and corporate personnel working cooperatively are building blocks that together make for a strong structure and knowledge of the several facets of power engineering is key.

Financial considerations can be as straightforward as having capital available for use and using it wisely. Available capital has a direct bearing on the availability of manpower. It has a direct bearing on being able to make changes. Perceptions of value come into play, as well as the need to be profitable. Short-term Wall Street inspired management goals can be an impediment to long-term projects. Utility generated rebates and financing were offered and accepted at two refineries, and drives were successfully installed. The cost of equipment has to be balanced against expected returns. One respondent at corporate level in a refinery acknowledged that there is huge value to be obtained through advanced technology and that the single factor that restricts implementation is available capital. He said that the task is always to get the highest value from the lowest cost and that, given the necessary capital, changes could be implemented within a year.

6 CONCLUSIONS

1. The power infrastructure that presently serves refineries and petrochemical companies in the U.S. is set up for steam rather than electricity.
2. Improvements can be achieved relatively easily, short term, and within the existing infrastructure, by the implementation of advanced control technologies.
3. Some degree of improvement can be achieved relatively easily, short term, and within the existing infrastructure, by the implementation of advanced power technologies.
4. The effective full introduction of control and power technologies is dependent upon investment in and a long-term commitment to a changed infrastructure.
5. The potential for improved productivity and reduced energy consumption through the dedicated use of advanced techniques is substantial for both refineries and petrochemical plants in the U.S.
6. Petrochemical plants that operate electrically are more efficient than refineries and petrochemical companies that do not.
7. Petrochemical plants that have already invested in a complete electrical infrastructure are in the best position to make further improvements economically and with less risk using advanced controls.
8. Production continuity is important. Therefore refineries, particularly, and petrochemical companies are very conservative in their acceptance and implementation of new control and power technologies.
9. There is a lack of comfort in the process arena where speed control is introduced. No adequate training has been provided in the concept of hydraulic energy control.
10. The adoption of speed control instead of throttle control is not on the horizon for most process engineers.
11. Power technologies will only be adopted when they provide the same system reliability as fixed speed equipment.
12. A judicious application of a combination of advanced control and power technologies will contribute to expansion of capacity even in the face of increased regulation.

13. Poor experiences with early power equipments have affected and still affect adoption of speed control on critical applications.

14. Power technologies are at a very early stage of adoption.

15. In general overall plant wide refinery and petrochemical control optimization has not been tackled.

16. The implementation of advanced control and power must be done well or the consequences will be substantial.

17. Control of the process using sticking control valves hinders optimization.

18. Advanced optimal control has not been adopted and may be 10 to 15 years from implementation.

19. Subcontracting work has proven harmful to efficiency and operating costs.

20. Conditions in reactors are not fully known.

21. Exothermic energy is not extracted optimally in the majority of refineries and petrochemical plants.

22. Attention should be focused on developing methods to recover wasted heat in the process in both refineries and petrochemical companies. Typically 30% of the energy used in the process is wasted as low-grade heat energy.

23. The application of advanced control and power technologies will facilitate closer tolerances that result in improved safety margins, greater reliability, improved stability, and enhanced energy savings.

24. Throttling valves, tight control valves, dampers, wrongly dimensioned furnace burners, and clogged heat exchangers all waste energy.

25. Machines under throttle control should be considered for speed control.

26. The potential for energy savings due to advanced control and power technologies in U.S. refineries and petrochemical companies is 13,470 MW. This is a conservative projection calculated from the limited process data available for this report.

27. Compressors, furnace ID fans, fin fans, blowers, extruders, and pumps with existing throttle control will all benefit from alternative technologies.

28. There are examples of startlingly good performances from power equipments that have been matched to process requirements.

29. Minimal sophisticated electrical control has been adopted to some degree in both U.S. refineries and petrochemical companies.

30. Local and Federal physical, environmental and legislative constraints may significantly impact the operation of refineries and petrochemical companies.

31. Recent amalgamation within companies to form large corporate groups has brought increased pressure on individual units.

32. The commercial climate surrounding refineries and petrochemical companies is presently undergoing great change.

7 RECOMMENDATIONS

1. In order to achieve energy savings, increased productivity and increased reliability in U.S. refineries and petrochemical companies, prudent implementation of advanced control and power technologies is recommended.

2. In order to prepare to introduce changes it is strongly recommended that detailed control inventory be obtained from process engineers and that a survey of at least one U.S. site is completed using the model created for this study. In order to do this the various barriers that were encountered that prevented such collection of information need to be overcome.

3. Information contained in this report should be confirmed by field measurements taken at a U.S. site in cooperation with process engineering.

4. Develop specific applications of advanced control and power technologies at demonstration sites.

5. Develop training workshops for control and power technology implementation.

6. Develop system oriented control and power standards for suitable equipment for the refining and petrochemical industries.

7. Encourage and foster a systematic approach to address infrastructure issues.

8. Every effort should be made to further good communication within companies and, in turn, between companies and institutions in order that information may be truly representative of real situations. In this way accurate information can be used to full extent to promote the best and most effective outcomes for the future.

9. There should be a melding of disciplines towards the common goal of reliability. Electrical reliability should take precedence over electrical, mechanical and process constraints.

10. It is recommended that this report be considered in conjunction with a similar study, already completed, of refineries and petrochemical plants in California.

11. It should be noted that the scope of this report does not address potential increases in capacity that could result from implementing advanced control and power technologies. It is recommended that this additional benefit be the subject of further investigation.

8
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A
REFINERY/PETROCHEMICAL INFORMATION OUTLINE

1. Statistics and Physical Layout
2. Utilities
   - Electrical
   - Natural Gas
   - Petroleum
   - Fuel Gas
   - Other
3. Hydraulic Power
   - Electric
   - Mechanical
4. Electric Motor Inventory
   - Type
   - Speed
5. Control Inventory
   - Type
   - Range
   - Shafts and Flanges
6. Environmental Issues
   - Flare Gas
   - Waste Heat
   - Waste Mechanical Energy
   - Sludge
7. Maintenance
8. Operations
9. Investment
10. Quality

B

CEC/DOE PETROLEUM REFINERY/PETROCHEMICAL PROJECT SITE DATA REQUEST

Contributor Organization __________________

Site __________________

Contact __________________

Date initiated __________________

Data required by February 20 2004

Objectives of the program:

- Identify process optimization currently hindered by control and power technologies
- Identify conditions in the process that currently allow energy to be wasted
- Identify areas where energy savings could be made in existing applications
- Estimate potential energy savings
- Identify fixed speed equipment applications that could benefit from alternative technologies
- Summarize opportunities for energy savings, increased productivity and increased reliability that could be achieved based on alternative control and power technologies

Program Data

In order to fulfill the program objectives the data listed in the following pages is requested.

Each section contains data request and an area for personal observations and comment. There may be specific conditions known only to the responding site that if reported would allow the CEC and DOE to improve their support of the refining industry. Please add extra pages if the space provided is not sufficient.

General Statistics

Raw material		bbl / day
Delivered product	1	bbl / day
	2	bbl / day
	3	bbl / day
	4	bbl / day
	5	bbl / day
	6	bbl / day

Comments

Utilities

- Electricity delivered by electrical company MW
- Electricity generated on site from natural gas MW
- Electricity generated from __________ MW
- Natural gas used by the process Mm Btu
- Crude Oil Used for process energy bbl / day
- Fuel Gas used for process energy Mm Btu
- Other sources of energy Quantity

Hydraulic Power

The object of this section is to identify all sources and drains of hydraulic power (other than pipe loss).

Input Power

List all electrical motors. Obtain from a motor rating list containing speed and type (induction or synchronous)

List all steam turbines rating and speed range data from rating plate.

List all significant steam heat exchangers data from rating plate

Let down turbines rating and speed data from rating plate

Other sources of input hydraulic power:

Output Power

List all cooling towers rating and type water or air open or closed

Flare fuel gas produced:

Exothermic energy not harnessed:

Product temperature at delivery to storage.

Other hydraulic power issues:

Control Inventory

For each of the items in the hydraulic power source and sink section provide information on the method of control.

Select from the following:

Throttled regulating

Throttled wide open

Speed control

Bypass control

Other

Are there control issues that could benefit from advanced control and power techniques?

For example:

Non-invasive process condition measurement of power, flow

Control tolerances

Multivariable modeling, optimization and self-learning

Comments:

Environmental Issues

Leaks potentially occur at control valve spindles and connecting flanges

Are these a problem at your location?

Are there control or production conditions that cause flare gas to be released?

Are there compliance issues that could be address through the implementation of advanced control and power technologies?

Could the production of flare gas, waste heat, waste mechanical energy and sludge be reduced through system wide control?

Additional aspects that are important

Maintenance

What is the annual maintenance budget. $________

In relative terms much time is spent on the maintenance of:

	Little	Acceptable	Unacceptable	Causes Unscheduled Loss
• Fixed speed pump impellors				
• Throttle control surfaces				
• Bypass systems				
• Flanges				
• Pipe work				
• Steam Generators				
• Steam turbines				
• Steam heat exchangers				
• Electric motors				
• Electric distribution				
• Cooling towers				

Other important issues:

Operations

Would the use of advanced control and power technologies reduce operations cost? Identify areas:

Investment

What level of investment is committed to the improvement of the process equipment?
$__________year__________
$__________year__________

Quality

Does the shear action of the throttling valve damage or degrade product?

Are there any times when the quality of the products delivered from the refinery needs to be optimized to meet customer requirements?

Is there a demand for new products that could improve the refinery operating revenue?

Could production of new products be facilitated through the use of advanced control and power technologies?

Additional Resources

Please describe the additional resources that would positively impact the revenue generated by the refinery.

Equipment

Information

Trained Engineers

Other:

Many thanks for your time and efforts. Information that you have will be only be published in the final report with your consent.

C
ADVANCED CONTROL AND POWER TECHNOLOGIES SURVEY

UNIT/ PROCESS	DESCRIPTION	REFINERY/ PETROCHEM DESCRIPTOR	HP	SPEED	TYPE (IND, SYNC or ST)	VOLTAGE	DRIVEN EQUIPMENT	CONTROL	POTENTIAL FOR IMPROVEMENT	PREVIOUSLY INVESTIGATED FOR ENERGY SAVINGS

D
SAMPLE PHONE QUESTIONNAIRE FOR REFINERY/PETROCHEMICAL PARTICIPANTS

The questions followed the list below:

1. Where are you on the spectrum of control: pneumatic through to neural net?
2. As changes were made to upgrade sections of the plant did you realize measurable energy benefits?
3. How much, in percentage terms, was the energy benefit?
4. What are your plans for the future of the control system?
5. How many adjustable speed drives are in use in the process system?
6. What has been your experience with adjustable speed drives? Give any examples for illustration.
7. Are you planning to change progressively from pump throttle control to speed control?
8. What is the co-generation plant rating?
9. Do you out source control and drive project specifications and how satisfied are you with the process?

There may be follow up clarification after each question is answered. This is an objective study, the findings of which will be directed to the benefit of petrochemical refineries through a report presented to the CEC.

E
DESCRIPTION OF CONTROL TECHNOLOGIES

Pneumatic Control was the primary method of controlling industrial processes until the 1950s. Conventional pneumatic controllers had limited range and linearity of control. For these reasons pneumatically controlled industrial systems were energy inefficient.

Analog Control, introduced in the 1950s, was the first attempt to control industrial processes using electrical techniques. It provided accurate set point control and process feedback of a single process variable. This single loop used proportional-integral-derivative (PID) control to provide reliability and range that could not be achieved with pneumatic control. It was cumbersome and wasteful of space and the displays could extend across an entire wall. Each individual loop had to be monitored in the control room by an operator skilled in the dynamic control of the refinery and who gave it intensive attention during any change. The energy efficiency of analog control was considerably better than that of pneumatic and set the scene for the introduction of even more electrical control.

A Distributed Control System (DCS) is one in which digital computing power is distributed throughout the process. Digital computers were cautiously introduced in the mid 1970s. At first, analog control continued to be made available to back up the fledgling DCS equipment that was perceived to be very unreliable. By the early 1980s second generation DCS equipment was in use and a central computer screen was used by the operators. The perception of unreliability had evaporated. Control advantages became apparent as well as the physical advantage of having one screen monitor all the main parameters in the refinery. Duplicate screens could be installed anywhere in the plant. The large instrument control room became a thing of the past. By the mid 1980s the DCS system had became the host for much more than simple control operations. Basic digital control was supplemented by:

- Expert systems
- Plant wide information systems
- Statistical Process Control (SPC)
- Accounting data
- System modeling

By the early 1990s the extended capability of DCS was appreciated and pressures were exerted on the controls community to use “open architecture” that would allow new functional control logic to be added to the DCS system. These additions included:

- Product information
- SPC

- Intelligent alarms
- Expert systems
- Scheduling information
- Predictive maintenance

The DCS system continues to be expanded to incorporate more features.

Multivariable Control

Multivariable control uses the architecture of DCS to incorporate sophisticated software that enables the control of interactions among a number of control loops or variables. The process engineer skillfully derives algorithms from many variables that may be or may appear to be unrelated. The newly constructed variable is used as a substitute for information that is unavailable practically.

Neural Net

Neural net control systems extend the capability of multivariable systems by introducing control algorithms that will deal with incomplete information. This enables the neural control system to reach new optimized control states that meet the combined goals of:

- Refinery product output performance against the variability of crude oil
- Refinery operating stability
- Extension of time between refinery turnarounds
- Maximizing refinery financial results

F
2002 U.S. REFINING CAPACITY

Table F-1
2002 U.S. Refining Capacity (BCD)* [1]

Company and Location	Crude	Vacuum Distillation	Coking	Alkylation	Catalytic Cracking	Catalytic Reforming	Catalytic Hydrocracking	Catalytic Hydrotreating
ALABAMA								
Coastal ExxonMobil Refining Mobile Bay	20,000	15,000	0	0	0	0	0	0
Hunt Refining Co. Tuscaloosa	43,225	14,250	12,600	0	0	6,480	0	31,500
Shell Chemical Co. Saraland	85,000	28,000	0	0	0	21,000	0	43,000
Total Alabama (3 refineries)	**148,225**	**57,250**	**12,600**	**0**	**0**	**27,480**	**0**	**74,500**
ALASKA								
BP PLC Prudhoe Bay	15,000	0	15,000	0	0	0	0	0
BP PLC Kuparuk	14,500	0	14,500	0	0	0	0	0
Petro Star Inc. North Pole	15,000	0	0	0	0	0	0	0
Petro Star Inc. Valdez	48,000	0	0	0	0	0	0	0
Tesoro Alaska Co. Kenai	72,000	19,000	0	0	0	12,000	12,500	12,500
Williams Alaska Petroleum Inc. North Pole	220,000	8,000	0	0	0	0	0	0
Total Alaska (6 refineries)	**384,500**	**27,000**	**29,500**	**0**	**0**	**12,000**	**12,500**	**12,500**
ARKANSAS								
Cross Oil Refining Co. Inc. Smackover	7,000	3,000	0	0	0	0	0	24,500
Lion Oil Co. El Dorado	64,000	26,500	0	4,900	19,700	14,000	0	29,500
Total Arkansas (2 refineries)	**71,000**	**29,500**	**0**	**4,900**	**19,700**	**14,000**	**0**	**54,000**
CALIFORNIA								
BP PLC Carson	260,000	130,000	65,000	15,000	96,000	52,000	43,000	187,000

Company and Location	Crude	Vacuum Distillation	Coking	Alkylation	Catalytic Cracking	Catalytic Reforming	Catalytic Hydrocracking	Catalytic Hydrotreating
Chevron Texaco El Segundo	260,000	120,000	64,000	21,000	62,000	40,000	45,000	193,000
Chevron Texaco Corp. Richmond	225,000	110,000	0	20,000	65,000	45,000	109,000	144,000
ConocoPhillips Carson/Wilmington	130,500	78,000	48,000	14,200	45,000	35,200	24,750	135,850
ConocoPhillips San Fran. Rodeo	107,920	78,309	47,502	0	0	30,600	32,400	45,963
ExxonMobil Refinery Torrance	149,000	98,000	51,500	23,500	90,500	19,000	23,000	141,000
Kern Oil & Refining Bakersfield	25,000	0	0	0	0	3,000	0	12,500
San Joaquin Refining Bakersfield	24,300	14,300	0	0	0	0	0	3,000
Shell Oil Products Bakersfield	65,000	39,000	22,000	0	0	14,700	23,500	41,900
Shell Oil Products Martinez	154,800	102,400	44,600	10,200	68,700	28,200	33,800	189,600
Shell Oil Products Wilmington	98,500	58,000	41,000	8,700	35,000	31,000	29,000	92,000
Tesoro Petroleum Golden Eagle	161,000	144,000	42,000	14,000	66,500	42,000	32,000	145,500
Valero Energy Corp. Benicia	148,000	80,500	29,000	15,000	72,000	36,000	35,000	167,000
Valero Energy Corp. Wilmington	84,000	49,700	28,000	15,000	54,000	16,000	0	182,000
Total California (14 refineries)	**1,893,020**	**1,102,209**	**482,602**	**156,600**	**654,700**	**392,700**	**430,450**	**1,680,813**
COLORADO								
ConocoPhillips Commerce City	60,000	25,000	0	0	19,000	9,600	0	34,100
Valero Energy Corp. Denver	28,000	9,500	0	0	8,000	9,000	0	9,000
Total Colorado (2 refineries)	**88,000**	**34,500**	**0**	**0**	**27,000**	**18,600**	**0**	**43,100**
DELAWARE								
Motiva Enterprises LLC Delaware City	175,000	91,000	47,000	8,190	73,000	39,000	18,000	119,000
Total Delaware (1 refinery)	**175,000**	**91,000**	**47,000**	**8,190**	**73,000**	**39,000**	**18,000**	**119,000**

Company and Location	Crude	Vacuum Distillation	Coking	Alkylation	Catalytic Cracking	Catalytic Reforming	Catalytic Hydrocracking	Catalytic Hydrotreating
HAWAII								
ChevronTexaco Corp. Barber's Point	54,000	30,000	0	4,000	21,000	0	0	3,000
Tesoro Hawaii Corp. Kapolei	93,700	39,500	0	0	0	12,800	17,600	10,800
Total Hawaii (2 refineries)	**147,700**	**69,500**	**0**	**4,000**	**21,000**	**12,800**	**17,600**	**13,800**
ILLINOIS								
Citgo Petroleum Corp. Lemont	158,650	71,250	35,100	18,900	60,300	28,080	0	103,410
ConocoPhillips Wood River	286,400	107,000	0	20,500	90,000	85,000	28,500	178,100
ExxonMobil Refining & Supply Co. Joliet	238,000	113,000	55,500	27,000	93,000	42,000	0	176,000
Marathon Ashland Petroleum LLC Robinson	192,000	61,900	27,600	12,400	50,400	71,300	25,700	123,500
Total Illinois (4 refineries)	**875,050**	**353,150**	**118,200**	**78,800**	**293,700**	**226,380**	**54,200**	**581,010**
INDIANA								
BP PLC Whiting	410,000	242,000	34,200	34,200	156,800	85,500	0	299,800
Countrymark Cooperative Inc. Mount Vernon	23,500	7,400	0	1,700	7,850	6,500	0	10,000
Total Indiana (2 refineries)	**433,500**	**249,400**	**34,200**	**35,900**	**164,650**	**92,000**	**0**	**309,800**
KANSAS								
Farmland Industries Coffeyville	95,000	50,000	17,000	7,000	29,000	17,000	0	59,300
Frontier Oil Corp. El Dorado	110,000	39,000	18,000	12,500	37,200	29,500	0	122,900
National Cooperative Refining Assoc. McPherson	79,000	31,600	20,400	6,300	20,900	20,900	11,200	67,300
Total Kansas (3 refineries)	**284,000**	**120,600**	**55,400**	**25,800**	**87,100**	**67,400**	**11,200**	**249,500**

Company and Location	Crude	Vacuum Distillation	Coking	Alkylation	Catalytic Cracking	Catalytic Reforming	Catalytic Hydrocracking	Catalytic Hydrotreating
KENTUCKY								
Marathon Ashland Petroleum LLC Catlettsburg	222,000	91,200	0	12,400	96,000	45,600	0	195,300
Somerset Refinery Inc. Somerset	5,500	0	0	0	0	1,500	0	2,000
Total Kentucky (2 refineries)	**227,500**	**91,200**	**0**	**12,400**	**96,000**	**47,100**	**0**	**197,300**
LOUISIANA								
American International Refining Inc. Lake Charles	30,000	15,000	0	0	0	0	0	0
Calcasieu Refining Co. Lake Charles	15,680	0	0	0	0	0	0	0
Calumet Lubricants Co. Cotton Valley	8,500	0	0	0	0	0	0	4,000
Calumet Lubricants Co. Princeton	9,500	8,500	0	0	0	0	8,000	0
Calumet Lubricants Co. Shreveport	15,000	10,000	0	0	0	0	7,200	1,100
Canal Refining Co. Church Point	30,000	2,500	0	0	0	0	0	8,000
Cit-Con Oil Corp. Lake Charles		36,100	00	0	0	0	0	
Citgo Petroleum Corp. Lake Charles	336,801	79,800	88,200	20,700	126,000	103,500	37,800	229,950
ConocoPhillips Belle Chasse	250,000	92,000	25,200	38,000	104,000	42,000	0	112,000
ConocoPhillips Westlake	232,000	110,000	60,000	75,000	40,000	42,000	29,000	153,220
ExxonMobil Refining & Supply Co. Baton Rouge	491,500	220,500	108,000	35,000	227,000	72,000	23,000	308,500
ExxonMobil Refining & Supply Co. Chalmette	182,500	102,000	33,000	12,500	68,000	46,000	18,500	124,000
Marathon Ashland Petroleum LLC Garyville	232,000	118,800	32,800	29,500	109,300	46,600	0	209,000
Motiva Enterprises LLC Convent	235,000	100,000	0	13,050	85,000	36,000	45,000	162,000

Company and Location	Crude	Vacuum Distillation	Coking	Alkylation	Catalytic Cracking	Catalytic Reforming	Catalytic Hydrocracking	Catalytic Hydrotreating
Motiva Enterprises LLC Norco	220,000	78,000	21,300	14,800	105,000	57,300	31,500	73,300
Murphy Oil USA Inc. Meraux	95,000	47,500	0	7,650	34,200	0	0	58,050
Orion Refining Corp. Norco	155,000	124,000	75,000	0	85,000	12,000	0	90,000
Placid Refining Co. LLC Port Allen	48,000	20,000	0	3,800	19,000	9,700	0	21,700
Shell Chemical Co. St. Rose	55,000	28,000	0	0	0	0	0	0
Valero Energy Corp. Krotz Springs	78,000	29,500	0	0	30,500	12,000	0	16,250
Total Louisiana (20 refineries)	**2,719,481**	**1,222,200**	**443,500**	**250,000**	**1,033,000**	**479,100**	**200,000**	**1,571,070**
MICHIGAN								
Marathon Ashland Petroleum LLC Detroit	74,000	36,100	0	3,900	28,500	20,000	0	48,600
Total Michigan (1 refinery)	**74,000**	**36,100**	**0**	**3,900**	**28,500**	**20,000**	**0**	**48,600**
MINNESOTA								
Koch Petroleum Group Rosemount	270,750	171,000	61,200	10,980	77,400	44,100	0	272,700
Marathon Ashland Petroleum LLC St. Paul Park	70,000	30,400	0	5,200	24,700	20,000	0	71,300
Total Minnesota (2 refineries)	**340,750**	**201,400**	**61,200**	**16,180**	**102,100**	**64,100**	**0**	**344,000**
MISSISSIPPI								
ChevronTexaco Corp. Pascagoula	295,000	231,000	71,000	14,800	63,000	71,000	142,000	140,000
Ergon Refining Inc. Vicksburg	23,000	10,200	0	0	0	0	0	8,600
Total Mississippi (2 refineries)	**318,000**	**241,200**	**71,000**	**14,800**	**63,000**	**71,000**	**142,000**	**148,600**
MONTANA								
Cenex Harvest States Laurel	56,000	28,000	0	4,200	13,100	11,800	0	44,100
ConocoPhillips Billings	57,950	28,500	17,325	6,489	18,090	12,150	0	54,792

Company and Location	Crude	Vacuum Distillation	Coking	Alkylation	Catalytic Cracking	Catalytic Reforming	Catalytic Hydrocracking	Catalytic Hydrotreating
ExxonMobil Refining & Supply Co. Billings	58,000	27,500	8,000	4,000	20,000	12,000	5,000	43,500
Montana Refining Co. Great Falls	7,000	3,350	0	0	2,300	1,000	0	0
Total Montana (4 refineries)	**178,950**	**87,350**	**25,325**	**14,689**	**53,490**	**36,950**	**5,000**	**142,392**
NEW JERSEY								
Coastal Eagle Point Oil Co. Westville	150,000	47,500	0	4,000	55,000	28,000	0	29,000
ConocoPhillips Linden	250,000	62,000	0	16,000	138,000	28,000	0	238,000
Valero Energy Corp. Paulsboro	166,000	85,000	26,600	11,100	52,000	24,500	0	111,250
Total New Jersey (3 refineries)	**566,000**	**194,500**	**26,600**	**31,100**	**245,000**	**80,500**	**0**	**378,250**
NEW MEXICO								
Giant Refining Co. Bloomfield	18,600	0	0	0	6,000	4,800	0	7,800
Giant Refining Co. Gallup	26,000	0	0	1,800	8,500	7,300	0	11,500
Navajo Refining Co. Artesia	60,000	20,000	0	7,800	18,500	12,500	0	50,500
Total New Mexico (3 refineries)	**104,600**	**20,000**	**0**	**9,600**	**33,000**	**24,600**	**0**	**69,800**
NORTH DAKOTA								
Tesoro West Coast Co. Mandan	58,000	0	0	4,200	24,700	11,500	0	12,000
Total North Dakota (1 refinery)	**58,000**	**0**	**0**	**4,200**	**24,700**	**11,500**	**0**	**12,000**
OHIO								
BP PLC Toledo	152,000	66,000	34,200	10,900	57,000	40,800	28,500	90,300
Marathon Ashland Petroleum LLC Canton	73,000	30,000	0	6,700	22,800	18,100	0	57,100
Premcor Refining Group Lima	165,000	52,000	22,500		40,000	55,500	26,000	63,000

Company and Location	Crude	Vacuum Distillation	Coking	Alkylation	Catalytic Cracking	Catalytic Reforming	Catalytic Hydrocracking	Catalytic Hydrotreating
Sunoco Inc. Toledo	140,000	30,000	0	9,000	60,000	45,600	28,200	48,000
Total Ohio (4 refineries)	**530,000**	**178,000**	**56,700**	**26,600**	**179,800**	**160,000**	**82,700**	**258,400**
OKLAHOMA								
ConocoPhillips Ponca City	189,620	68,970	24,210	14,580	58,815	47,160	0	121,680
Gary-Williams Energy Corp. Wynnewood	52,500	15,500	0	4,000	18,500	13,000	5,000	12,000
Sinclair Oil Corp. Tulsa	50,000	25,175	0	2,700	16,200	10,800	0	26,300
Sunoco Inc. Tulsa	85,000	30,000	8,500	0	0	17,500	0	34,500
Valero Energy Corp. Ardmore	85,000	62,000	0	6,400	27,500	20,000	0	90,200
Total Oklahoma (5 refineries)	**462,120**	**171,645**	**32,710**	**27,680**	**121,015**	**108,460**	**5,000**	**284,680**
PENNSYLVANIA								
American Refining Group Bradford	10,000	0	0	0	0	1,800	0	3,500
ConocoPhillips Trainer	186,200	75,430	0	11,790	48,420	48,780	19,890	110,610
Sunoco Inc. Marcus Hook	175,000	26,400	0	10,000	93,000	15,600	0	48,000
Sunoco Inc. Philadelphia	330,000	157,400	0	16,700	113,500	68,000	0	163,600
United Refining Co. Warren	66,700	27,000	0	3,500	23,000	16,000	0	40,000
Total Pennsylvania (5 refineries)	**767,900**	**286,230**	**0**	**41,990**	**277,920**	**150,180**	**19,890**	**365,710**
TENNESSEE								
Williams Energy Services Memphis	190,000	0	0	12,000	68,000	36,000	0	123,000
Total Tennessee (1 refinery)	**190,000**	**0**	**0**	**12,000**	**68,000**	**36,000**	**0**	**123,000**
TEXAS								
AGE Refining & Manufacturing San Antonio	10,000	0	0	0	0	0	0	0

Company and Location	Crude	Vacuum Distillation	Coking	Alkylation	Catalytic Cracking	Catalytic Reforming	Catalytic Hydrocracking	Catalytic Hydrotreating
AGE Refining & Manufacturing Alon USA Big Spring	61,000	24,000	0	4,500	23,000	21,000	0	56,900
Atofina Petrochemicals, Inc. Port Arthur	176,000	49,900	0	5,700	62,800	36,100	10,500	110,700
BP PLC Texas City	437,000	228,000	40,400	58,900	209,000	137,800	114,000	363,900
ChevronTexaco Corp. El Paso	90,000	34,700		8,200	28,000	17,700	0	37,800
Citgo Petroleum Corp. Corpus Christi	156,750	73,625	37,800	18,090	72,450	47,250	0	169,380
Coastal Refining & Marketing Inc. Corpus Christi	100,000	56,000	17,500	3,000	20,000	30,000	11,000	82,000
ConocoPhillips Borger	142,785	0	0	17,100	58,320	27,810	0	157,950
ConocoPhillips Sweeny	215,650	111,150	59,310	14,940	94,050	32,400	0	193,590
Crown Central Petroleum Corp. Pasadena	100,000	42,000	12,500	13,000	56,000	0	0	36,000
ExxonMobil Refining & Supply Co. Baytown	523,000	252,500	78,000	30,000	202,500	122,000	25,500	503,000
ExxonMobil Refining & Supply Co. Beaumont	348,500	141,000	48,000	15,500	108,000	147,000	60,000	292,500
Flint Hills Resources Corpus Christi	297,000	104,500	13,680	11,700	104,500	57,600	10,530	188,100
LaGloria Oil & Gas Co. Tyler	60,000	15,000	6,500	4,750	20,200	17,500	0	32,000
Lyondell-Citgo Refining LP Houston	268,850	187,625	87,300	18,810	89,100	60,300	0	281,070
Marathon Ashland Petroleum LLC Texas City	72,000	0	0	10,500	41,800	10,500	0	0
Motiva Enterprises LLC Port Arthur	250,000	110,000	49,500	18,000	86,000	45,000	17,820	194,000
Premcor Refining Group Port Arthur	225,000	130,000	80,000	17,000	77,000	50,000	3,500	212,000
Shell Deer Park Refining Co. Deer Park	333,800	181,600	80,200	16,500	67,500	67,800	62,600	211,900

Company and Location	Crude	Vacuum Distillation	Coking	Alkylation	Catalytic Cracking	Catalytic Reforming	Catalytic Hydrocracking	Catalytic Hydrotreating
Valero Energy Corp. Corpus Christi	140,000	86,700	17,500	16,500	107,000	68,500	47,000	184,000
Valero Energy Corp. Houston	83,000	39,000	0	8,500	62,000	10,500	0	44,500
Valero Energy Corp. Sunray	155,000	47,000	0	9,000	54,500	46,000	30,000	65,500
Valero Energy Corp. Texas City	210,000	100,000	0	11,500	78,500	13,500	0	182,600
Valero Energy Corp. Three Rivers	97,000	29,000	0	5,800	23,000	30,500	29,000	80,750
Total Texas (24 refineries)	**4,552,335**	**2,043,300**	**628,190**	**337,490**	**1,745,220**	**1,096,760**	**421,450**	**3,680,140**
UTAH								
ChevronTexaco Corp. Salt Lake City	45,000	25,600	7,200	4,500	13,000	7,000	0	24,000
ConocoPhillips Woods Cross	25,000	5,500	0	2,400	7,680	7,200	0	13,700
Flying J Inc. Salt Lake City	25,000	5,500	0	1,800	10,000	5,500	0	14,000
Silver Eagle Refining Inc. Woods Cross	12,500	6,000	0	0	0	2,200	0	6,200
Tesoro West Coast Co. Salt Lake City	60,000	0	0	5,600	23,000	11,300	0	11,700
Total Utah (5 refineries)	**167,500**	**42,600**	**7,200**	**14,300**	**53,680**	**33,200**	**0**	**69,600**
VIRGINIA								
Giant Refining Yorktown	58,900	33,000	17,100	0	26,700	10,800	0	29,300
Total Virginia (1 refinery)	**58,900**	**33,000**	**17,100**	**0**	**26,700**	**10,800**	**0**	**29,300**
WASHINGTON								
BP PLC Ferndale	222,720	96,960	59,520	0	0	60,480	54,720	79,680
ConocoPhillips Ferndale	90,250	46,360	0	4,950	28,080	15,597	0	53,280
Shell Oil Products U.S. Anacortes	148,600	62,300	25,400	11,600	57,300	32,200	0	83,500
Tesoro West Coast Co. Anacortes	114,500	45,000	0	11,500	42,000	24,300	0	31,800

Company and Location	Crude	Vacuum Distillation	Coking	Alkylation	Catalytic Cracking	Catalytic Reforming	Catalytic Hydrocracking	Catalytic Hydrotreating
U.S. Oil Refining Co. Tacoma	44,350	23,700	0	0	0	5,500	0	12,900
Total Washington (5 refineries)	**620,420**	**274,320**	**84,920**	**28,050**	**127,380**	**138,077**	**54,720**	**261,160**
WEST VIRGINIA								
Ergon-West Virginia Inc. Newell	18,600	8,050	0	0	0	4,300	0	10,000
Total West Virginia (1 refinery)	**18,600**	**8,050**	**0**	**0**	**0**	**4,300**	**0**	**10,000**
WISCONSIN								
Murphy Oil USA Inc. Superior	33,250	19,500	0	1,350	9,900	7,200	0	20,620
Total Wisconsin (1 refinery)	**33,250**	**19,500**	**0**	**1,350**	**9,900**	**7,200**	**0**	**20,620**
WYOMING								
Frontier Refining Inc. Cheyenne	46,000	26,000	10,000	4,200	12,000	7,600	0	25,400
Sinclair/Little America Casper	22,500	6,000	0	0	10,000	5,500	0	16,000
Sinclair Oil Corp. Sinclair	54,000	29,500	0	4,000	20,600	14,200	0	46,200
Wyoming Refining Co. Newcastle	12,500	1,500	0	1,300	5,500	2,750	0	7,500
Total Wyoming (4 refineries)	**135,000**	**63,000**	**10,000**	**9,500**	**48,100**	**30,050**	**0**	**95,100**
Total U.S. (133 refineries)	**16,623,301**	**7,347,704**	**2,243,947**	**1,107019**	**5,677,355**	**3,512,237**	**1,474,710**	**11,247,745**

* Barrels per calendar day

Implementing Advanced Control and Power Technologies to Improve Energy Efficiency and Reduce Operating Costs for U.S. Petroleum Refining and Petrochemical Manufacturing

Technical Report

Implementing Advanced Control and Power Technologies to Improve Energy Efficiency and Reduce Operating Costs for U.S. Petroleum Refining and Petrochemical Manufacturing

Product ID: Global Project #1136 for AICHE

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PRODUCT DESCRIPTION

Assessing the effectiveness of advanced control and power technologies currently being used in U.S refineries and petrochemical plants was a task dependent upon cooperation from a variety of disciplines within the refining industry, particularly from electrical and process engineers. It was not a straightforward task of collecting data on which to base calculations. Responses to the concept of the introduction of advanced control and power technologies to refineries were varied and depended upon an individual's knowledge of those technologies and his experiences of them, either personal or vicarious. Reactions varied widely from a certain and definite resistance to change to a readiness to accept advanced control and power. The variety of these human responses paralleled the variety of the technical applications already in use. This investigation revealed dedicated and hard working people with little time and energy to spare. They were focused on efficient and uninterrupted production within the limits of business, environmental and regulatory constraints. The process-engineering group seemed to have the ultimate authority and although they expressed a desire to become more familiar with these technologies, that interest was tempered by the practical constraints of having to get the job done. There was concern about sharing proprietary information and self-exposure.

Results & Findings

The variety of control and power technologies that has penetrated refineries and petrochemical plants in the U.S. is wide ranging. Its success and acceptance was dependent upon the knowledge, experience, and technical expertise of the installers and the operators. Motor list data, cogeneration ratings and electricity usage data was available from electrical engineering. However, there was no readily available data for heat exchangers, furnaces or boilers from process engineering.

The judicial implementation of advanced control and power technologies could achieve energy savings, increased productivity, and increased reliability in U.S. refineries and petrochemical plants. The present situation is such that there is ample opportunity to make measurable and significant improvements based on the implementation of advanced control and power technologies from modest and limited installations to site-wide control optimization schemes. The achievable benefits include reduction of costs, less maintenance, freeing up of manpower, reduced environmental impact, additional headroom to develop sites, and a potential to export power on a net metering basis.

Based on the findings in this Report, U.S. refineries and petrochemical plants could save $10.4 Billion per year from the implementation of advanced control and power technologies. For an estimated investment cost of $18.5 Billion, savings of $10.4 Billion /year would yield a simple payback of 1.8 years ($18.5 Billion/ $10.4 Billion /year). These savings are summarized in the following Table.

Potential Annual Savings from Implementing Advanced Control and Power Technologies in U.S. Refineries and Petrochemical Plants, Assuming 100% Penetration

Opportunity	Annual Savings (Millions of Dollars)
Waste due to utility power related causes would be reduced	$725
Operations and maintenance costs would be reduced	$4,255
There would a reduced environmental impact cost	$1280
There would be increased electricity cost of	($150)
Total fuel related cost savings	$ 4,284
Total potential annual savings	$10,394

Challenges & Objectives

Successful implementation of these technologies is dependent upon understanding its principles, knowledgeable and detailed specification of equipment, expert installation, and a willingness to educate for change.

Applications, Values & Use

The work described in this Phase 1 Report determined the effectiveness of control and power technologies currently being used in U.S. refineries and petrochemical plants and identified opportunities for energy savings, increased productivity, and increased reliability that could be achieved based on alternative control and power technologies. A previous Phase 1 study determined the effectiveness of control and power technologies currently being used in California refineries and identified opportunities for energy savings, increased productivity, and increased reliability that could be achieved based on alternative control and power technologies [13]. The results from these two Phase 1 studies will provide the basis for proceeding with Phase 2 of this project.

In Phase 2 (potential future project), suitable demonstration sites will be selected for the implementation of advanced control and power technologies to improve reliability and energy efficiency in petroleum refining and petrochemical manufacturing.

In Phase 3 (potential future project), advanced control and power technologies will be implemented at Selected Sites.

EPRI/Global Energy Partners Perspective

End user feedback suggests that there are serious concerns that are preventing the application of advanced control and power technologies in petroleum refining and petrochemical manufacturing facilities. These concerns are so serious that older process control techniques and maintenance prone, hydraulic couplings and steam turbines are still being used to maintain control over the process, rather than expert systems and advanced power conversion techniques. Additional maintenance costs and energy inefficiencies associated with mechanical variable speed devices are accepted as a trade off against the risk of unknown performance by advanced power electronic alternatives. Speed devices are accepted as a trade off against the risk of unknown performance by advanced power electronic alternatives.

Thus, current older process control techniques result in energy losses in existing applications and prevent advanced power electronic controllers from being implemented in areas of the refineries and petrochemical plants where considerable savings from increased energy efficiency and productivity could be achieved. These older process control techniques also reduce the overall reliability of refineries and petrochemical plants and do not provide a method to achieve energy optimization over the entire site.

Full implementation of advanced control and power technologies could save U.S. refineries and petrochemical plants an estimated $10.4 Billion/year. This report identifies these savings opportunities for U.S. refineries and petrochemical plants.

Approach

The California Energy Commission (CEC) and the U. S. Department of Energy (DOE) contracted with Global Energy Partners to assemble a collaborative of utilities, state/federal agencies, and refineries and petrochemical plants to document the reliability and energy efficiency benefits of advanced control and power technologies and transfer technology to refining and petrochemical industries. The project will be approached in three phases. The decision to fund each phase is independent and can be based on the relevance and applicability for the participant.

This Phase 1 Report addresses only the effectiveness of control and power technologies currently being used and opportunities for energy savings, increased productivity and increased reliability that could be achieved based on alternative control and power technologies in U. S refineries and petrochemical plants.

Keywords

Petroleum refining
Petrochemical manufacturing
Control technologies
Power technologies
Electric drives
Electric motors
Energy efficiency
Self-learning controls
Reliability

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1 INTRODUCTION

Background

A study, "Using Advanced Control and Power Technologies to Improve the Reliability and Energy Efficiency of Petroleum Refining and Petrochemical Manufacturing in California," was completed in March 2004. This study expands the scope of the study already completed for California to petroleum refineries and petrochemical manufacturers across the United States. Energy savings, increased productivity, and increased reliability can be achieved by the use of advanced control and power technologies in refineries and petrochemical companies throughout the United States. In order to assess the effectiveness of advanced control and power technologies currently being used, approaches were made to a representative number of U.S. refineries and petrochemical companies. Personnel at various levels of seniority were contacted within both large and small companies.

The investigation considered the present state of use of both control and power technologies and the expectations for these technologies for the future. Technical, environmental and regulatory challenges were examined along with business challenges. Technical data was gathered and analyzed when it was made available. Credence was given to observations, experiences, and opinions that were expressed. Electrical data was readily made available. Data associated with the process was more difficult to obtain.

Methodology

The methodology used during this investigation evolved substantially as a practical and necessary response to obstacles that became apparent as the study got underway. The initial survey was composed to gather data relating to all hydraulic energy used in refineries and petrochemical companies. The electrical engineers had data. It was possible to get motor lists. However, the process engineers did not have data available in a single source. In addition they were unable to cite the performance of the heat exchangers. This was unexpected but understandable because the complexity of refineries and petrochemical companies is extremely high and the individual components are not instrumented for economic reasons. A willingness to contribute was often tempered by lack of readily available data and no time to devote to collecting it from scratch, or by corporate, industrial, regulatory and government constraints. Important contributions were gathered from one-on-one conversations and not limited only to research fact sheets gathered from the respondents.

A second survey was developed that addressed the effectiveness of control and power technologies in refineries and petrochemical companies. A quantitative calculation of specific energy savings was not possible because of a lack of quantitative data. However, a qualitative assessment of areas where substantial energy could be saved was feasible.

Contact was made with a total of twenty refineries and seven petrochemical plants across the U.S., including California. An information package and a confidentiality agreement for contributors were developed, together with a letter of invitation that was revised in conjunction with respondents. A letter of support from the DOE was solicited that was used to encourage and foster participation.

An Information Summary (Appendix A) was composed that was further developed to form the Refinery and Petrochemical Survey (Appendix B). The survey was sent to willing respondents. Telephone interviews were conducted. A total of six site visits was completed that covered four major refinery sites and one petrochemical site: ChevronTexaco Richmond Refinery, California, Chevron Texaco Pascagoula Refinery, Mississippi, Shell Wilmington Refinery, California, Valero Benicia Refinery, California and Equistar Chemicals, Houston, Texas. Documented replies were reviewed for completeness. An MS Excel spread sheet (Appendix C) was used to enter information for early respondents and included in the package for subsequent respondents. The scope of the survey was amended and reduced in order to retain contributors and a new survey was developed for phone interviews (Appendix D). Results were analyzed and information from research, telephone conversations, site visits, and data provided by respondents was summarized.

Contributors to this report include ChevronTexaco, Pascagoula, Mississippi, Chevron Texaco, Barber's Point, Hawaii, Chevron Texaco Richmond Refinery, California, Chevron Texaco, El Segundo, California, Shell, Norco, Louisiana, Shell, Wilmington, California, Shell, Bakersfield, California, Shell, Martinez, California, Valero, Benicia, California, ExxonMobil, Joliet, Illinois, Exxon Mobil, Torrance, California, ConocoPhillips, Sweeny, Texas, ConocoPhillips, Ponca City, Oklahoma, ConocoPhillips, Wood River, Illinois, ConocoPhillips, Rodeo, California. ConocoPhillips, Wilmington, California, BP, Carson, California, BP, Cherry Point, Washington, BP Chemicals, Lima, Ohio, Tesoro, Martinez, California, Apex, Long Beach, California, Kern, Bakersfield, California, DOW Chemicals, Freeport, Texas, Equistar Chemicals, Houston, Texas, BASF, Houston, Texas, Solutia, Greenwood, South Carolina, Dupont, Old Hickory, Kentucky.

There was universal support for the project. However, for many companies the levels of contribution were limited or curtailed owing to corporate pressures, staff reductions, plant closures, time constraints, and the number of personnel available either to answer questions or to complete the survey provided.

2
PRESENT USE OF CONTROL AND POWER TECHNOLOGIES

Present Use of Control Technologies

Control Technology is an enabling technology. It facilitates the translation of physical requirements into an automated process. To what extent and to what effect it is used depends upon the acceptance of current electronic advances. Table 2-1 and Table 2-2 show the current use of control and power technologies in U.S. refineries and petrochemical plants. In general, control technology has penetrated more uniformly into petrochemical companies. This is understandable as many petrochemical plants were constructed at a time when these technologies were becoming available, whereas the majority of refineries were already established.

Contributors of information for this report described a very wide range of control techniques currently in use in refineries. They ranged from 50's style pneumatic control, through single loop analog control, distributed control systems (DCS) and multi variable control, to the most advanced neural net sub systems. A brief definition of these terms is described in Appendix E. The speed of penetration of more advanced control did not seem to be directly attributable solely to a company but rather more influenced by the drive and persistence of an individual involved in any particular site. One company, for example, used a majority of pneumatic control at one plant and yet had considerable neural net application in another. The success of any move to advanced control is very much dependent on the refinery engineer taking ownership once the subcontractor's work is complete.

Refinery research indicated that specific improvements had been recorded as a result of changes made. A move from pneumatic control to DCS control provided savings of 10% to 25% in total energy with possibly another 5% to 10% that could still be obtained. Survey responses indicated that operators of manual control systems use safety margins that result in wasted energy. Such conservative operation ensures process stability, although this does not foster peak economic efficiency. Steam heater efficiency, in particular, can be considerably enhanced by the use of automatic multivariable control. In a case where a move to DCS did not produce a noticeable reduction in energy usage, the process efficiency was improved in that there were fewer upsets and problems. The result was more continuous production time and therefore more opportunity to take advantage of any changes in the marketplace. Basic DCS is not an advanced control technology. This term is used fairly loosely and may include some elements of predictive control, and even multi variable control. Very specific savings of 30% to 40% have been recorded as savings in certain distillation columns. However, in the same plant, savings of only 2% to 3% have also been recorded under similar circumstances, indicating that results may vary

Table 2-1
Use of Control and Power Technologies in U.S. Refineries

Refinery*	Control**	MV Penetration	Considering Advanced Control	Electric Penetration	ASD Penetration	Considering Advanced Power	Operating Margin	Cogen	Remarks
1	All MV units	100%	No	95%	5%	Yes	Tight	Yes	Information via corporate
2									Not contacted
3	DCS and MV	80%	Yes	85%	1%	No	Tight	NA	Information via corporate
4	DCS few on MV	30%	Yes	85%	1%	No	Tight	Yes	Process engineer
5									Closing, not able to contribute
6	Single loop electric	0%	No	95%	0%	No	Tight	Yes	Process engineer
7	Fully DCS some MV	20%	Yes	85%	1%	Yes	Tight	Yes	Process engineer
8	All MV units	100%	No	95%	5%	Yes	Very tight	Yes	Information via corporate
9								Yes	Energy engineer study not completed
10	Single loop electric	0%	Yes	85%	1%	No	Tight	Yes	Information via corporate
11	DCS some MV	20%	Yes	85%	1%	Yes		Yes	Process engineer
12	DCS	0	Yes	95%	1%	No		Yes	Process engineer
13								Yes	Declined to contribute
14	DCS	0	Yes		1%	No	Tight	Yes	Electrical engineer
15	MV	95	Yes	90%	4%	Yes	Tight	Future	Maintenance engineer and via corporate

Table 2-1
Use of Control and Power Technologies in U.S. Refineries, Continued

Refinery*	Control**	MV Penetration	Considering Advanced Control	Electric Penetration	ASD Penetration	Considering Advanced Power	Operating Margin	Cogen	Remarks
16	MV	80%	Yes	80%	1%	Yes	Tight	Yes	Information via corporate
17									Unable to contribute
18	MV	90%	Yes	85%	2%	Yes	Tight	Yes	Process engineer
19	MV	90%	Yes	85%	1%	Yes	Tight	Yes	Information via corporate
20	DCS	90%	Yes	90%	1%	Yes	Tight	Yes	Information via corporate
21	MV	100%	Yes	95%	5%	No	Tight	No	Information via corporate

* Refinery random reference
** MV = Multivariable Control, DCS = Distributed Control System

Table 2-2
Use of Control and Power Technologies in U.S. Petrochemical Plants

Petrochemical Company*	Control**	MV Penetration	Considering Advanced Control	Electric Penetration	ASD Penetration	Considering Advanced Power	Operating Margin	Cogen	Remarks
1	MV	95%	Yes	80%	6%	Yes	Improving	Yes	Energy engineer
2	DCS	5%	No	100%	96%	No	Chapter 11	No	Maintenance engineer
3	MV	90%	Yes	80%	4%	Yes	Improving	NA	Process engineer
4	MV	90%	Yes	80%	3%	No	Very tight	Yes	Electrical engineer
5	DCS	10%	No	96%	90%	No	Closing	Yes	Utility engineer
6	MV	90%	Yes	80%	3%	Yes	Tight	Yes	Electrical engineer and Process engineer
7	MV	90%	Yes	80%	5%	No	Very tight	Yes	Electrical engineer

* Petrochemical random reference
** MV = Multivariable Control, DCS = Distributed Control System

widely. The overall average energy savings was 25% for this refinery under multivariable control.

The most difficult challenge in the refining process is the control of the rate of output, in particular, control of the CAT Cracker. A number of CAT Crackers operate under the control of a multivariable system. There are cases where capital equipment is obsolete and funds are neither available nor justifiable for investment in the most up to date units. Even pumps having adjustable speed control are considered too expensive. The most important consideration is keeping a refinery running. Reducing production rates in order to maintain equipment needs careful management. Any process disruption may result in delays and a reluctance to revert to multivariable control after a manual start up.

The petrochemical industry differs from the refining industry in that it produces a wide range of products for the marketplace and its position in the delivery chain is complex. The refinery process is more easily defined compared with the petrochemical process. The petrochemical industry is ahead of the refining industry in process control, having pioneered the DCS system, and it is now widely utilizing multivariable predictive control. Respondents had great difficulty in tying economic payback to the level of control because there was no information available on which to base these calculations. However, they were very aware of the positive impact of control on the process and are now considering what the next step should be in the evolution of control schemes. Presently, the problems associated with existing control applications that need improvement are robustness, control uptime and, for some applications, the range of control. Range of control is particularly important as applied to catalysts. To date, multivariable controllers have been applied to sections of plants, although not to complexes as a whole. The goal of petrochemical plants is to achieve quality and consistency from their plants. They audit the process for suitability of optimum performance quite separately from energy auditing. Pinch technology was reported as being utilized to good effect by one respondent. It should be noted that respondents that produced final product, such as extruded manmade fiber, saw no need for more sophisticated control at this time. Based on industrial trends for improved quality and output and energy intensity it seems evident that this attitude will change. Further advanced control will afford improvements for the petrochemical industry.

Control using throttling valves presents special performance issues for both refineries and petrochemical plants because there are stringent monitoring and correction requirements for throttling valves in place. In the past only California had to face such issues. Now these regulatory constraints are penetrating other states. Problems for refineries are further increased by regional requirements for “boutique” gasoline tailored to meet regional requirements. Control valve stems are a major source of fugitive gasses. To minimize this problem the valve stem packing is tightened down. The control schemes associated with this require 0.25% to 0.5% accuracy. Sticking valve stems prevent this. Advanced power control could alleviate the problem. Both the EPA and the Texas Commission on Environmental Quality have recently lowered thresholds on reportable release to one pound.

There is an understanding that real energy benefits can be achieved by using advanced control and there is a perception that the challenge to be faced is not technology itself but rather operator confidence in technology. In terms of energy efficiency, the focus is to decrease energy intensity or to reduce energy usage per unit of output.

Present Use of Power Technologies

Power Technology, like Control Technology, is enabling. It facilitates the translation of energy from one form to another. A key example of this transference is the introduction of hydraulic power to the process under control. This technology covers both the introduction of energy and the extraction of energy. Both mechanical and electrical techniques are represented. Hydraulic power is associated with changes as related to fluid and gases. It covers heating, cooling, pumping, compressing, converting, condensing, and the extraction of kinetic energy.

To understand the full impact of electrical power technologies as applied to refineries and petrochemical plants in U.S. it is essential to understand the current methods of energy transfer from utility source to process material. Energy is applied to basic raw material in the form of heat. This heat is predominantly produced from the combustion of natural gas and by-products of the process, namely fuel gas. The heat from the combustion is converted into steam that is used in four ways: generation of electricity, heating process material, direct injection into the process material, and powering of steam turbines. Owing to the exothermic nature of sections of the process, certain stages of the gas flow require that energy be removed from the hydraulic system. This energy may be wasted or converted into steam or into electrical energy. Historically, this element of the energy has not been optimally controlled.

Research has shown that in a number of refineries nationwide there is little enthusiasm for the introduction of variable speed control as a method of optimizing energy delivered to the hydraulic system. There is a reluctance to move from pressure control to speed control. There have been a number of poor experiences associated with adjustable speed drives, in particular large units, where expectations have not been met and this overshadows the possibility of installing new large drive systems. Feedback indicates that, in the case of a particular large drive application, reliability was poor and it was felt that the complexity of the equipment installed necessitated specific expertise in dealing with it for success. Availability of relevant education and training was a factor and it was felt also that the number of people who understood it and could work on it limited the drive’s performance. Economic justification was difficult to endorse in such a situation. However, where there has been successful implementation of variable speed control in refineries, for example on smaller unit installations on fans, it has been met with enthusiasm and proved to be an asset. Reliability is not an issue in such applications largely because there are multiple smaller units and no single unit would significantly impair the throughput of the refinery. Contrast this with a single 4000hp drive application for variable control on a hydrocracker compressor that is singly critical to plant refinery output. One petrochemical respondent reported the successful use of two modern concept permanent magnet couplings. These devices provided the full speed control necessary for the pump whilst avoiding the size and environmental constraints of adjustable frequency drives. This method of controlling pump output eliminated throttling losses. Successful application of variable speed control can only be accomplished through careful specification of equipment and diligent follow up. Successful installations of large drives for variable speed control are best achieved by a total systems approach to engineering; equipment installations need to work together as a whole. In the refinery industry no new refineries are being built and retrofits are not being done and therefore the penetration for larger electrical drives for variable speed control is very small.

There are two entirely different characteristics of petrochemical plants. There are those that are almost indistinguishable from refineries in that they are physically close to a refinery, probably right next door, and they use similar equipment. They may use the product from that refinery. There is a symbiotic relationship. These petrochemical plants tend to manufacture chemicals, often unrecognizable to the layperson, that in turn are used by other remote petrochemical plants. These other remote petrochemical plants are geographically separate from refineries and they manufacture end products that are more recognizable to the layperson as, for example, pesticides or nylon. These two groups of companies use technology in different ways. Petrochemical plants geographically close to a refinery use similarly styled processes to those in refineries. For example, a petrochemical facility and a refinery could both have alkylation processes and catalytic reforming. Remote petrochemical plants, however, tend to be product specific and need dedicated specialized process equipment. Within the petrochemical industry there are different rates of acceptance and penetration of power technology.

Petrochemical plants closely associated with refineries have accepted small adjustable speed drives and found them to be successful in the following applications: cooling towers, product blending, extruding, dosing, cooling fans, and fin fans. Steam turbines are widely used where speed variation is required for fan, pump and compressor applications and they have been found to be robust and reliable.

Petrochemical plants remote from refineries reported extensive use of electrical variable speed control on process equipment. This use of speed control has been successfully applied to pumps, fans, and air washers and has been driven by improved energy conservation. Productivity itself hasn’t improved but energy has been conserved by the elimination of throttle valves.

Advanced power control techniques are more readily accepted as smaller applications in both petrochemical plants and refineries. They have been explored more widely in petrochemical applications. Where larger applications have been implemented they are more likely to be used in the petrochemical industry at this point, and as such they may also be part of petrochemical production within a refinery.

3
OPPORTUNITIES FOR CONTROL AND POWER TECHNOLOGIES

Process Conditions that Currently Allow Energy to Be Wasted

Conditions in the process that currently allow energy to be wasted need to be addressed by applying the Laws of Thermodynamics to best advantage. Respondents explained that between 30% and 40% of all energy used in the refining process goes into the distillation of crude oil. Most of this energy escapes as low-grade heat. Refinery efficiency and air quality would be improved if this was avoided and the heat was reused. For the safety of equipment and workers in refineries and associated petrochemical plants, safety margins are always necessarily in place. Excessive safety margins employed for increased process stability leads to wasted energy. A clogged heat exchanger uses excessive energy, as do throttling valves, tight control valves, and using two pumps instead of one. Ambient temperature changes cause energy to be wasted. Fixed speed pumps and fin fans cannot adequately compensate for variable ambient conditions. Exothermic energy, when it is changed into steam instead of being converted directly to electricity, absorbs energy that could be used elsewhere in the process. Steam loops typically waste 66% of energy. Using steam where an electrical drive could be used is wasteful also and scant knowledge of the capabilities of process components leads to over consumption of energy. Respondents believed that tighter control of process variables would result in better product and energy savings.

Energy Savings Opportunities in Existing Applications

Energy savings could be made in existing applications by implementing an improved level of control which, when combined with advanced power technologies, will reduce wastage associated with valves, pumps, furnaces, reactors, and heat exchangers. It can also reduce wastage from excessive safety margins while maintaining security. For the refining and petrochemical industries implementing plant wide control optimization will facilitate substantial energy savings. When variable speed control is implemented, along with an appropriate range of advanced technology, to a variety of applications, the outcome will be decreased energy intensity. Changing from steam turbines to electric motors wherever possible will also provide favorable energy savings.

Fixed Speed Equipment Applications that Could Benefit from Alternate Technologies

Fixed speed equipment applications that could benefit from alternate technologies are compressors; furnace ID fans, fin fans, blowers, and pumps with existing throttle control. There are additional applications that are two-speed controlled that could benefit from comprehensive variable control. In situations where one pump supplies many throttle valves, alternate technologies could provide significant improved control and energy benefits.

Opportunities for Advanced Control Technologies

The potential for advanced control technology in U.S. refineries and petrochemical companies is significant. Table 3-1 shows the present state of adoption of control technologies in U.S. refineries. Table 3-2 shows the present state of adoption of control technologies in U.S. petrochemical companies. Completion of the evolution towards distributed control systems (DCS) and multivariable control needs to be encouraged because it offers a potentially large benefit to the U.S. This initial evolutionary stage must be succeeded by the use of the next generation of self-learning tools that have the capability to optimize control of a complete facility. This progression will require investment, but it is a vital and necessary step in order to take full advantage of every aspect of advanced control algorithms. [5,6,7,8,9] Future control [tables 3-1 and 3-2] refers to the most advanced features of control … that which can be achieved using a combination of available advanced technology. This chapter deals with opportunities. 0% indicates that the refineries have not implemented these aspects of advanced control owing to a variety of constraints described in this report. Refineries are conservative. Refineries and petrochemical plants operate as sub-sections that each complete identifiable products and together comprise a total plant. Thus it is possible for a subsection (an entity in itself) to be 60% multivariable while the refinery as a whole has made no moves at all toward integrating the sub sections into a control system that would optimize the operations of the whole refinery. Tables 3-1 and 3-2 summarize the extent that control technology has been utilized in refineries and petrochemical plants, and illustrates the potential for future improved control.

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Table 3-1
Present State of Adoption of Control Technology in U.S. Refineries

Present Control Technology	Sub Section of the Refinery	Whole Refinery
Move to DCS	98%	98%
Move to Multivariable	60%	0%
Move to Neural Net	5%	0%
Future Control	0%	0%

Table 3-2
Present State of Adoption of Control Technology in U.S. Petrochemical Plants

Present Control Technology	Sub Section of the Petrochemical Company	Whole Petrochemical Company
Move to DCS	100%	100%
Move to Multivariable	80%	0%
Move to Neural Net	10%	0%
Future Control	0%	0%

Opportunities for Advanced Power Technologies

The implementation of advanced power technology in U.S. refineries and petrochemical companies offers much potential. Table 3-3 shows the present state of power technology adoption in U.S. Refineries. Table 3-4 shows the present state of power technology adoption in U.S. Petrochemical Companies. Adopting advanced power technology will afford refineries and petrochemical plants more time between outages, immunity from power transients, reduced heat load, reduced wear on pipes and flanges, reduced bearing failure rates, reduced steam load, and reduced electrical load. More energy will be able to be extracted from the fluid. There will be potential for increased accuracy in flow control, potential for exporting electrical power, and a more effectively integrated total system. Tables 3-3 and 3-4 illustrate that subsections within refineries and petrochemical plants have made similar moves towards power technologies, as have the plants as a whole. Tables 3-3, and 3-4 show that the move to fixed speed electric drives is advanced whilst the implementation of speed control has barely started. Tables 3-3 and 3-4 illustrate the potential for future improved power control.

It is worth noting the comparison between tables 3-1 and 3-2 that deals with control technology, and tables 3-3 and 3-4 that deal with power technology. Both the sub sections of plants and plants have adopted power technology equally as a whole whereas control technology has penetrated subsections of plants to some degree but not whole plants. This illustrates the potential penetration of control and power technologies for the future.

Table 3-3
Present State of Adoption of Power Technology in U.S. Refineries

Electric Drives	Sub Part of Refinery	Whole Refinery
Move to fixed speed electric motor	90%	90%
Move to variable speed electric motor	2%	2%
Move to advanced power control	< 1%	< 1%
Fully optimized control	0 %	0 %

Table 3-4
Present State of Adoption of Power Technology in U.S. Petrochemical Plants

Electric Drives	Sub Part of Petrochemical Company	Whole Petrochemical Company
Move to fixed speed electric motor	60%	60%
Move to variable speed electric motor	3%	3%
Move to advanced power control	< 1%	< 1%
Fully optimized control	0 %	0 %

4
ANALYSIS OF SAVINGS FOR A TYPICAL U.S. REFINERY AND A TYPICAL U.S. PETROCHEMICAL PLANT

In order to extrapolate from refinery data collected during the study, two reference documents were used: a recent energy balance for petroleum refineries [2] and information published in the Oil and Gas Journal [1].

From reference [1] it is possible to calculate the average power consumed by an average sized petroleum refinery in the United States:

There are a total of 133 refineries in the U.S.

Total supply for heat and power for all 133 refineries for one year = 3,478 Trillion Btu [2]

For one average sized U.S. refinery

The supply of heat and power = 3,478 Trillion Btu/ 133 Refineries

= 26.1503 Trillion Btu per year

Converting to MW = 26.1503Trillion Btu per year / 8,760 Hours per year

= 2.985×10^9 Btu per hr
= (2.985×10^9) Btu per hr x (2.928×10^{-7}) MW hr/Btu
= 874 MW

In the U.S., 133 refineries use 16,623,301 Bpd of crude oil [1]

The average sized refinery in the U.S. = 124,987 Bpd

The efficient refinery can be recognized by the presence of the following features: vacuum distillation, coking, alkylation, catalytic cracking, catalytic reforming, catalytic hydrocracking, and catalytic hydrotreating. The more of these features there are, the more committed the refinery is to technologies that enable the extraction of more gasoline from crude oil.

Savings for a Typical U.S. Refinery

The information collected from one refinery was scaled to represent an average U.S. refinery. The average sized refinery in the U.S. utilizes 124,987 Bpd. A refinery of this size, from the study data, requires 140 MW of electric power. Most commonly an average 29% of electrical power is produced by cogeneration [2]. This arrangement not only provides flexibility, but an economic advantage to the refinery. Both the cost and the reliability of such an electrical supply are important.

All motors that together have nameplate ratings of 162,225 kW were included in the power distribution shown in Table 4-1. Output throttles controlled 75% of these motors. It was not possible to complete a control audit at the site due to a turnaround condition.

Table 4-1
Typical Electric Motor Use from Study Respondent Scaled to Match the Average U.S. Refinery

	Proportion	kW	Quantity
Low voltage motors (based on 50 hp)	38%	61,190	1224
Medium voltage motors 100 to 1000 hp	26%	42,567	152
Medium voltage motors 1000 to 15,000 hp	36%	58,468	28

The following analysis considers a typical U.S. refinery [1, 10]

From survey information received from one respondent refinery that used vacuum distillation, coking, alkylation, catalytic cracking, catalytic reforming, catalytic hydrocracking, and catalytic hydrotreating and was scaled to match the U.S. average of 124,987 Bpd, the electric power consumed in the refinery = 140 MW. (Note: the refinery selected also provided a complete and accurate motor list)

Loss in the electric motor driven systems:

Motor loss (6%) = 8,400 kW (6% of 140MW)

Pump loss, from PSAT [16] is in the range 25%-40%

Pump loss (Assume 25%) = 0.25 (25%) x (140,000 kW – 8,400 kW)

= 32,900 kW

Throttle loss, from EPRI research is in the range 20%-50%,

Throttle loss (Assume 20%) = 0.20 (20%) of (140,000 kW – 8,400 kW – 32,900 kW)

= 19,740 kW

Calculating the potential for energy savings that could be made from eliminating throttle loss with the implementation of advanced power control:

From the study refinery, 75 % of the electric motors were throttled.

Assume that there is a 50 % penetration rate of drives displacing throttle losses.

Potential savings for one average refinery = (19.740 kW) x (0.5) (50% penetration) x (0.75) (75% motors throttled) kW

= 7403 kW = 7.403 MW

Thus, 133 U.S. refineries will save potentially: 133 (refineries) x 7.403 MW = **984 MW**

Additionally, consider the potential for energy savings by converting a steam turbine to an electric drive:

Reference [3] and [4] both indicate that a single turbine to electric drive conversion will save 0.5 MW in energy. Such a conversion will also conserve 600psig steam and coolant water. Extrapolating from these two case histories, it is possible to see that for the 16 such drives present in the typical refinery requiring 140 MW of electrical power described above would alone provide 1064 MW of energy savings. (16 drives x 0.5 MW/drive x 133 refineries = **1,064 MW = $280 M @ $0.03 per kWh**)

Calculating total energy converted by the average U.S. refinery:

Using the calorific value of 5.6M Btu per barrel, the rate of energy flowing through an average U.S. refinery = 124,987 (bpd) x 5.6 (MBtu per barrel) x .2928 (MW hr per MBtu) /24hrs

= **8,539 MW**

From respondent information for a group of major refineries, the internal loss in a typical refinery was estimated to be 5% of the calorific value of the crude oil input used i.e. 8,539 MW x 0.05 (5%) = 427 MW. This is a very conservative figure as the internal loss for a typical complex refinery is commonly stated as 10% [10].

Coordinated refinery control will conservatively be able to save a further 10% of the current loss or 0.5% of the average refinery throughput, i.e. 427 MW x 0.1 (10%) = 43 MW. For the 133 U.S. refineries, the savings from advanced control are predicted to be 43 MW x 133 (refineries) = **5,719 MW**.

The above calculations show the basic energy savings' numbers. Further real benefits for the U.S. will be derived from reduced waste heat and improved yields through sharper cuts, when advanced control is introduced. Implementation of advanced power technology will lessen environmental impacts. Problems associated with control valve stems will not be completely eliminated. However, movement and continued wear will be reduced to a negligible rate. The service and repair costs for the refinery will be reduced. Control of fluid flow will reduce pump impellor wear and tear and eliminate cavitation failures. The changes will permit more process improvement and avoid the need for unnecessary governmental intervention.

For 133 U.S. refineries, the savings from advanced control are predicted to be 5,719 MW. This is equivalent to an annual saving of 5719 MW x $0.03 per kWh = $1,503 Million. (Assuming power cost = 3 cents per kWh). A summary of this analysis, as applied to the 133 U.S. refineries, is provided below, assuming 100% control and 50% power penetration:

- Annual energy losses would be reduced by $1,503M
- Annual hydraulic power consumed would be reduced by 5% or 984 MW, which is equivalent to $259M, assuming a power cost of 3 cents per kWh.
- Annual fuel savings from converting steam turbines to electric drives =$280M
- The total fuel related cost savings = $2,042M

A summary of benefits, as applied to the 133 U.S. refineries, is provided below, assuming 100% control and 100% power penetration:

- Annual energy losses would be reduced by $1,503M
- Throttle conversion benefit = $518 M (2 x $259M)
- Steam turbine conversion to electric drives = $525 M (30/16 x $280M)
- The total fuel related cost savings = $2,546M

Total U.S. refinery costs and savings [Figure 4-1, Figure 4-2, and Figure 4-3] were developed using published statistics [1], [11], [15] in conjunction with the projected improved conversion efficiency expected from the implementation of advanced control and power technologies as calculated above.

Including energy related annual savings, it is estimated that the annual operational benefits shown in Table 4-2 would accrue. The savings shown in Table 4-2 were calculated by subtracting the "opportunity" items in Figure 4-3 from the corresponding values in Figure 4-2.

Table 4-2
Potential Annual Savings from Implementing Advanced Control and Power Technologies in U.S. Refineries, Assuming 100% Penetration

Opportunity	Annual Savings (Millions of Dollars)
Waste due to utility power related causes would be reduced	$430
Operations and maintenance costs would be reduced	$2,530
There would a reduced environmental impact cost	$760
There would be increased electricity cost of	($90)
Total fuel related cost savings	$ 2,546
Total potential annual savings	$6,176

This would provide a predicted total annual savings for U.S. refineries of $6.2 Billion. Based on an estimated investment cost of $11 Billion, savings of $6.2 Billion/year would yield a simple payback of 1.8 years ($11 Billion/$6.2 Billion/year). Note: Payback does not include financing cost.

It should be noted that the scope of this report does not address potential increases in refining capacity that could result from implementing advanced control and power technologies. It is recommended that this additional benefit be the subject of further investigation.

Savings for a Typical U.S. Petrochemical Plant

In order to extrapolate from petrochemical data collected during the study, two reference documents were used: a recent energy balance for chemical plants [11] and information published in the OIT/ Profiles and Partnerships [12]

From [11] it is possible to calculate the energy delivered as utility supplies to operate all of the chemical plants in the United States and convert this energy to equivalent power

Total energy used = 3,729 trillion Btu / year

= 3,729 trillion Btu / (365 days / year) / (24 hr / day) Btu/hour

= 0.4257 trillion Btu / hour

= 0.42 trillion Btu / hour x 0.2928 (W per Btu) trillion watts

= 122,967 MW

From [12] this energy is delivered by energy sources

Energy source = 122,967 MW equivalent

From [13]: Of this equivalent power used in the chemical industry, according to MECs, 60% is used in petrochemicals

Equivalent Power used in petrochemical plants = 122,967 MW x 0.60 (60%) = 73,780 MW

Assume the 5% of petrochemical plants (those remote from refineries and delivering final product) have fully implemented speed control

Then 95% of petrochemical plants are potential candidates for the implementation of advanced control and power technologies

Total equivalent power =73,780 MW x 0.95 (95%) = 70,091 MW

The respondent petrochemical plant (an acrylonitrile unit within a large petrochemical complex was selected because a detailed motor list was available) used as an example has been scaled to fit the typical plant size in the U.S.

Respondent plant energy input:

Natural gas volume = 850,000 scf per hour

Natural gas energy = 850,000 scf per hour / 1000 scf per MBtu

= 850 MBtu per hour

Natural gas equivalent power = 850 MBtu x 0.2928 (W per Btu) MW

= 249 MW

Off gas volume = 690,000 scf per hour

Off gas energy = 690,000 scf per hour / 1000 scf per MBtu

= 690 MBtu per hour

Off gas equivalent power = 690 Mbtu/hour x 0.2928 (MW hour per MBtu) MW

= 202 MW

Electricity = 135 MW

Total energy = 249 MW (natural gas equivalent) + 202 MW (off gas equivalent) + 135 MW (electricity)

= 586 MW

From above, the total power supplied to U.S. petrochemical plants = 70,091 MW

In order to extrapolate from energy savings calculated in the typical petrochemical plant to savings predicted for the whole U.S. petrochemical industry, the multiplier = 70,091 MW petrochemical industry total / 586 MW per petrochemical plant = 120

All motors that together have nameplate ratings of 195,060 kW were included in the power distribution shown in Table 4-3. Output throttles controlled 80% of these motors. It was not possible to complete a control audit at the site due to time pressure.

Table 4-3
Typical Electric Motor Use from a Study Respondent Petrochemical Plant Scaled to Match a Typical U.S. Petrochemical Plant

	Power range	Number of Motors
Low voltage motors	1-10 hp	1,587
Low voltage motors	10-100 hp	1,194
Low voltage motors	100-1,000 hp	429
Medium voltage motors	1,000-10,000 hp	117

From survey information received from one respondent and scaled to match a typical U.S. petrochemical plant, the electric power consumed in the plant = 135 MW.

Loss in the electric motor driven systems:

Motor loss (6%) = 8,100 kW (6% of 135 MW)

Pump loss, from PSAT [16] is in the range 25%-40%

Pump loss (Assume 25%) = 0.25 (25%) x (135,000 kW – 8,100 kW)

= 31,729 kW

Throttle loss, from EPRI research is in the range 20%-50%,

Throttle loss (Assume 20%) = 0.20 (20%) x (135,000 kW – 8,100 kW – 31,729kW)

= 19,034 kW

Calculating the potential for energy savings that could be made from eliminating throttle loss with the implementation of advanced power control:

From the study petrochemical complex, 80 % of the electric motors were throttled

Assume that there is a 50 % penetration rate of drives displacing throttle losses

Potential for savings for one typical petrochemical complex = (19,034 kW)(throttle loss) x (0.5)(penetration rate) x (0.8)(proportion of motors presently throttled) kW = 7,614 kW = 7.614 **MW**

Thus, using the multiplier 120 to scale from one plant to the whole US petrochemical industry, U.S. petrochemical plants will save potentially 120 (multiplier) x 7.614 MW (potential savings from throttle losses at each typical plant) = **914 MW** = $240 M @ $0. 03 per kWh

Assume that there is 100% penetration rate of drives replacing throttle losses

Potential for savings for U.S. petrochemical industry = $480M ($240M x 2) (increase from 50% to 100%)

Additionally, consider the potential for energy savings by converting a steam turbine to an electric drive:

Reference [3] indicates that a single turbine to electric drive conversion will save 0.5 MW in energy. Such a conversion will also conserve 600psig steam and coolant water. Extrapolating from this case history, 17% of steam turbine power can be conserved by converting to an electric drive. The typical petrochemical plant contains 162 MW of steam turbines.

Therefore the potential for energy savings for the typical plant containing an acrylonitrile unit referenced previously = 27.54 MW (162 MW x 0.17 (17%))

Hence, for the U.S. petrochemical industry as a whole potential for savings = 3,305 MW (27.54 MW x 120 (multiplier to scale from one plant to the whole industry sector) = $868 M @ $0.03 per kWh

From respondent information, the internal loss in a typical petrochemical complex can be assumed to be 20% of the calorific value of the fuel used.

From [11] process energy use is 2,221 trillion Btu per year. The total energy can then be calculated by estimating the losses.

Losses are equivalent to 20% of energy used = 2,221 trillion Btu x 0.2 (20%) trillion Btu per year

= 444.2 trillion Btu per year

Hence for the U.S. petrochemical industry as a whole, the potential for energy savings using advanced control systems = 444.2 trillion Btu per year x 0.1 (10%)

Potential for Energy Savings = 44.42 trillion Btu per year

= (44.42 trillion Btu per year / 8,760 hours per year) Btu per hour

= 0.005072 trillion Btu per hour

Potential for Energy Savings = 5,072 MBtu per hour

Potential Power Saving = 5,072 MBtu per hour x 0.2928 (MW hour per MBtu) MW

= 1,484 MW

Value of the savings calculated at 3 cents per kWh = 1,482 MW x $ 0.03 (3 cents) x 8,760 hrs/yr

= $390M per year

For U.S. petrochemical companies, the savings from advanced control are predicted to be 1,484 MW. This is equivalent to an annual saving of $390M. (Assuming power cost = 3 cents per kWh.)

The above calculations show the basic energy savings' numbers. Further real benefits for the U.S. will be derived from reduced waste heat and improved yields through better process control, when advanced control is introduced. Implementation of advanced power technology will lessen environmental impacts. Problems associated with control valve stems will not be completely eliminated. However, movement and continued wear will be reduced to a negligible rate. The service and repair costs for the petrochemical plant will be reduced. Control of fluid flow will reduce pump impellor wear and tear and eliminate cavitation failures. The changes will permit more process improvement and avoid the need for unnecessary governmental intervention.

A summary of this analysis, as applied to U.S. petrochemical companies, is provided below, assuming 100% control and 50% power penetration:

- Annual energy procurement costs would be reduced by $390M
- Annual hydraulic power consumed would be reduced 914 MW, which is equivalent to $240M, assuming a power cost of 3 cents per kWh
- Annual fuel savings from converting steam turbines to electric drives = $868M
- The total fuel related cost savings = $1,498M

A summary of benefits, as applied to the U.S. petrochemical industry, is provided below, assuming 100% control and 100% power penetration:

- Annual energy procurement costs would be reduced by $390M
- Throttle conversion benefit = $480M (2 x $240M)
- Steam turbine conversion to electric drives = $868M
- The total fuel related cost savings = $1,738M

Total U.S. petrochemical costs and savings were developed using published statistics [11][14] in conjunction with the projected improved conversion efficiency expected from the implementation of advanced control and power technologies as calculated above.

Including energy related annual savings, it is estimated that the annual operational benefits shown in Table 4-4 would accrue. The methodology used to estimate the non-fuel related savings in the petrochemical industry was the same as that used for the refining industry.

Table 4-4
Potential Annual Savings from Implementing Advanced Control and Power Technologies in the U.S. Petrochemical Industry, Assuming 100% Penetration

Opportunity	Annual Savings (Millions of Dollars)
Waste due to utility power related causes would be reduced	$295
Operations and maintenance costs would be reduced	$1,725
There would a reduced environmental impact cost	$520
There would be increased electricity cost of	($60)
Total fuel related cost savings as estimated above	$ 1,738
Total potential annual savings	$4,218

This would provide a predicted total annual savings for U.S. petrochemical plants of $4.2 Billion. Based on an estimated investment cost of $7.5 Billion, savings of $4.2 Billion/year would yield a simple payback of 1.8 years ($7.5 Billion $4.2 Billion /year).

It should be noted that the scope of this report does not address potential increases in petrochemical capacity that could result from implementing advanced control and power technologies. It is recommended that this additional benefit be the subject of further investigation.

Potential for Energy Savings

Potential savings in energy are measured as an improvement of 7,203 MW for control and an improvement of 6,267 MW for power. This is equivalent to eliminating, and thereby saving, 13,470 MW of generation which can be made available for use elsewhere. This is the same as a continuous electricity supply for 3,367,500 houses, assuming 4 kW usage per house.

Energy Savings, Increased Productivity, and Increased Reliability

Energy savings, increased productivity, and increased reliability could be achieved based on alternate control and power technologies by fully implementing multivariable control on refinery and petrochemical subsections, implementing fuzzy neural self learning control as soon as this control is proven work hardened, producing more output for each unit of energy used in the process, and optimizing operations across entire complexes. Using the opportunities offered by technology to create full variable speed controlled areas of the refineries and petrochemical plants would reduce emissions and expand the capacity of plants

Once advanced control and power technologies are implemented, the U.S. refining and petrochemical industries will have improved immunity from external power events, reduced maintenance and operations costs, and reduced environmental impact.

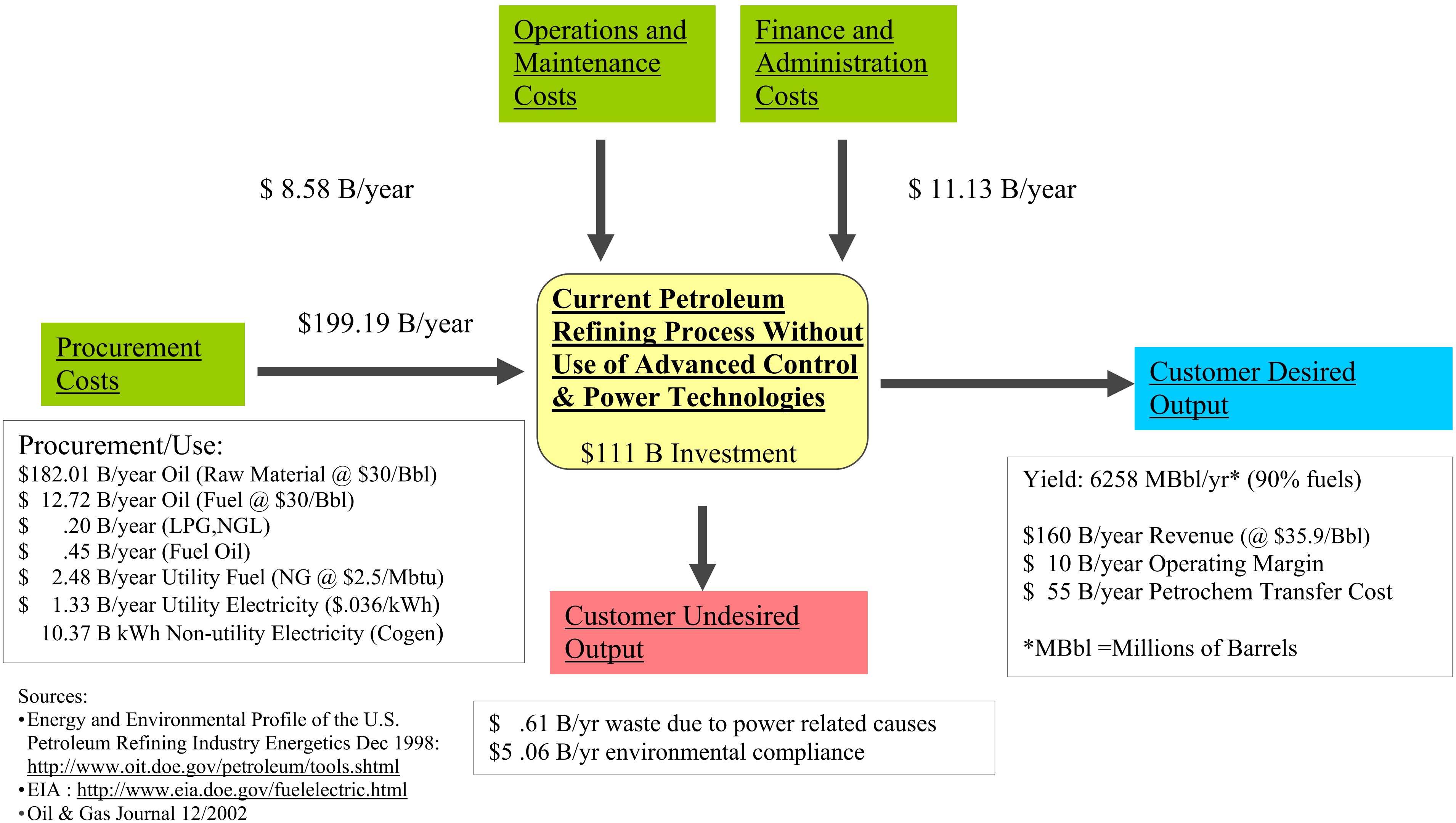

Figure 4-1
U.S. Petroleum Refining (SIC 29/NAICS 324110)
2002 Industry Baseline (133 Refineries)

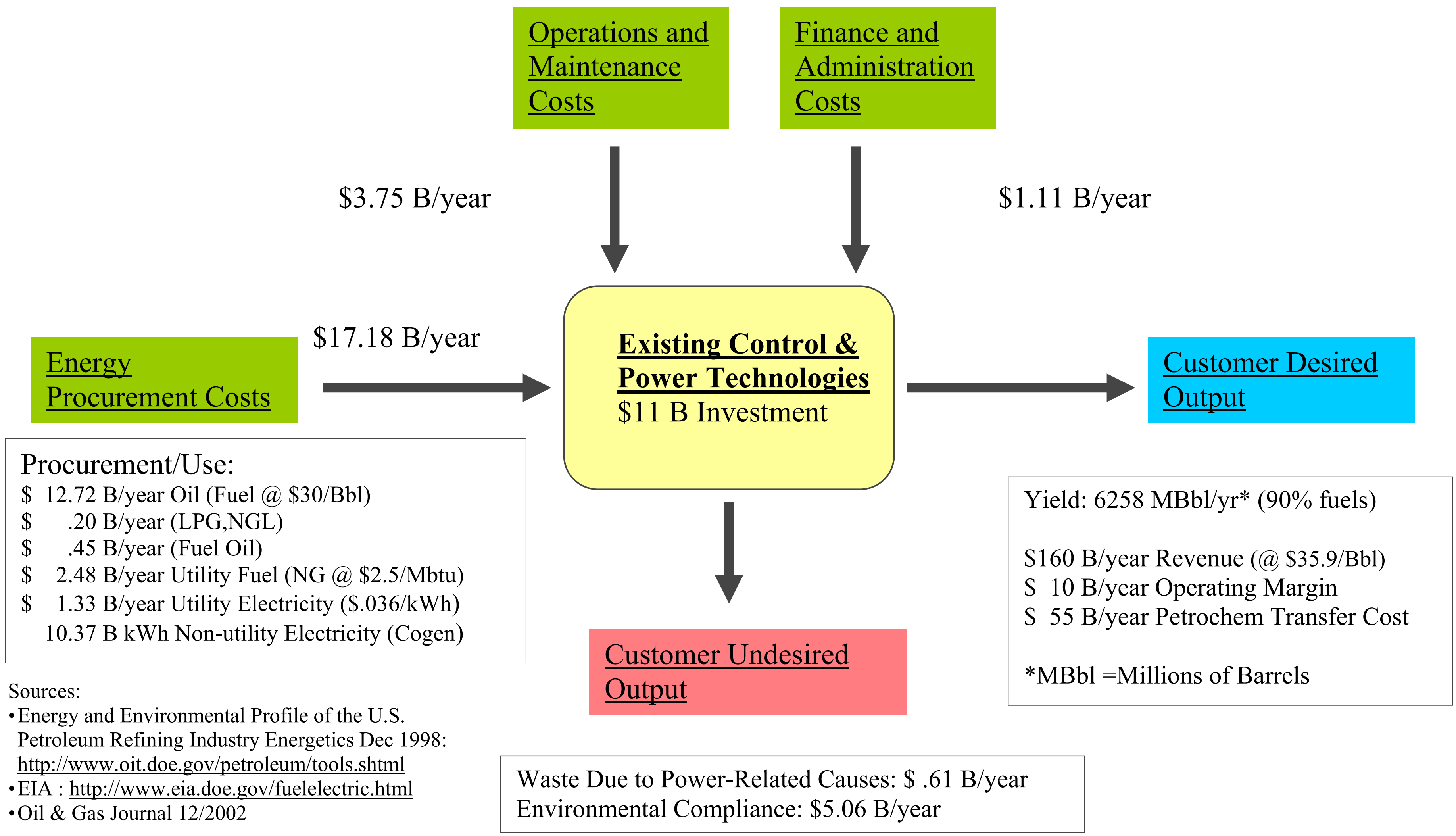

Figure 4-2
U.S. Petroleum Refining (SIC 29/NAICS 324110)
2002 Industry Baseline (133 Refineries)
Existing Control & Power Technologies

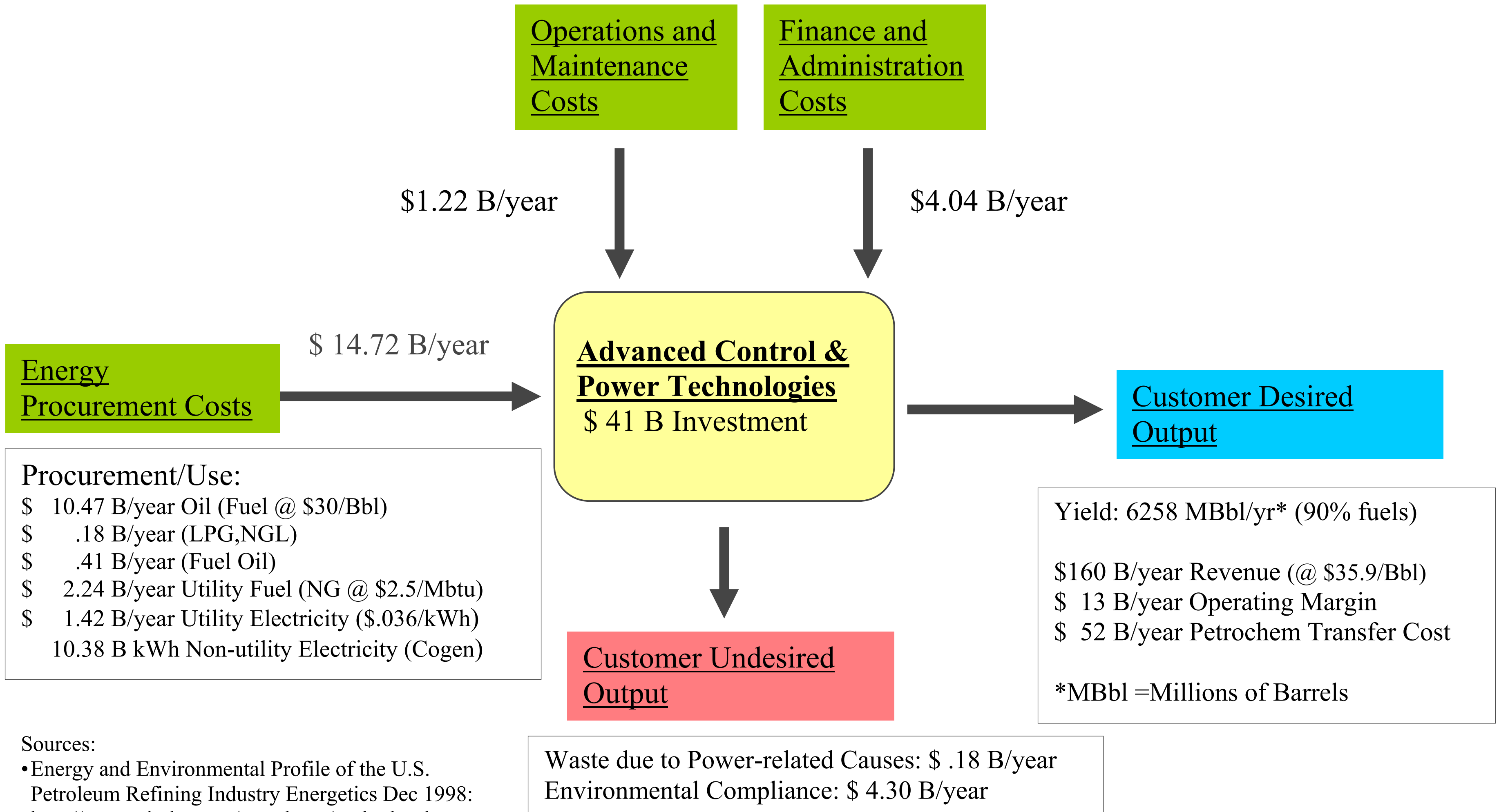

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Figure 4-3
U.S. Petroleum Refining (SIC 29/NAICS 324110)
Proforma for Year 2015 (133 Refineries)
Advanced Control & Power Technologies

5

BARRIERS TO IMPLEMENTING ADVANCED CONTROL AND POWER TECHNOLOGIES FOR PROCESS OPTIMIZATION

Technical, Environmental, and Regulatory Barriers

The refining and petrochemical industries are structured around a particular energy source and are largely focused on steam. They operate using steam for convenience combined with electricity and there is a combination of steam with fixed speed pumps and fixed speed motors. This infrastructure, already in place, is the most significant single barrier to the implementation of advanced control and power technology.

U.S. refineries and petrochemical companies are faced with environmental and regulatory challenges. Those stringent environmental and regulatory constraints already faced by California are now penetrating other states across the U.S.. "There are 16 major federal statutes as well as numerous state laws that impose significant compliance and reporting requirements on the (chemical) industry" [12]. In Washington, the NW Environmental Agency reported a very cooperative relationship. They acknowledged favorable responses to requests made and voluntary adoption of acceptable standards by individual companies. In other areas too, safety and environmental issues are accorded priority by "responsible care" companies. This laudable cooperative spirit can only be beneficial in achieving positive results. Environmental regulations impact refineries and petrochemical plants in areas of fugitive emissions, flare gas, leakages from valve stems and flanges, and emissions collection domes atop storage containers. Valves are used widely and integrally in a variety of applications within refineries and petrochemical companies. They are associated with pumps and compressors. Valves are bar coded in order to monitor problems and their solutions.

The U.S. refining and petrochemical industries are under economic pressure. They are facing some or all consequences of reduced exports, reduced domestic demand, increased feedstock prices, personnel reduction and plant closures. In order to calculate the quantitative benefits that can be obtained from the implementation of advanced control and power technologies, data needs to be collected specifically from the process side of the industry. Several attempts to complete the collection of technical data for this study were well supported at the highest technical levels only to be brought to a halt by a manager who had ultimate authority.

Technically, there is in place optimization of sub systems but there is no plant wide optimization. From several sources there have been reports that neural network self-learning algorithms did not work in this environment and most of those algorithms have been removed. They have not yet proven themselves to have achieved the necessary level of maturity. They are not yet sufficiently "hardened" for application in the refining and petrochemical industry. One respondent said he would have to constrain the operation of neural net. Unconstrained operation of neural net must be the ultimate goal for optimized control.

The technical challenge is greater than implementing the necessary changes for improvement; it is to introduce those changes successfully within the limitations of the conditions that presently exist. A company needs to run as efficiently, reliably and cost effectively as possible currently, as well as plan for improvements in efficiency and cost effectiveness for the future. There is a delicate balance between maintaining the status quo and making changes for perceived future benefits. A reconfiguration from steam to electricity would be a costly major upheaval.

The challenge is to maintain reliability of production whilst improving control and energy intensity in conjunction with reducing emissions, maintenance, and corrosion. This places a significant burden on limited resources. "Resources" is used, here, as a broad term that includes manpower, land, available time, available knowledge, education level, industrial experience, as well as money. An illustration of circumstances coming together that influenced benefits overall and further extended them follows. Market conditions, and in particular increasing feedstock prices, have caused refinery operators to search for lower cost crude. Refining previously untried crude resulted in unexpected consequences for one respondent, namely corrosion, and necessitated repair. The repairs resulted in an upgraded installation of stainless steel vessel reactor liners that in turn led to savings from refining cheaper crude and in addition to better control and a wider range of efficient operation.

The refining and petrochemical industries in the U.S. are constrained in their ability to implement advanced technical changes by limitations in resources, as described. In refining there has been a trend towards outsourcing technical specifications and installations. Petrochemical companies are also considering this route. Such situations give rise to a dilution in commitment or a lack of "ownership". Faced with the narrow focus of contractual terms, the result can be doing the best job for the money rather than doing an excellent job. Success depends upon the capability of the contractor and the education level and industrial engineering experience of those who are contracted to do the work. Dealing with subcontractors may result in poor engineering, the correction of which may take weeks and threaten the overall output of the refinery.

There was acknowledgement that a refinery could be ten years behind a typical petrochemical plant in utilization of control and power technology.

Experiences with control and power technology differed across the industries from favorable to patchy to poor. In general experiences were more favorable in the petrochemical industry. Reservations were expressed over the reliability of drives, their cost, their size, being able to protect them from the environment, and integration and compatibility issues associated with them. Reports ranged from component failure through to early obsolescence. Even recently installed drives by a company that was very well versed in drive issues had exhibited audio noise problems. Re-commissioning experiences did not go smoothly either. Such experiences need not be the norm and there were notable exceptions. Two refineries had successfully introduced large horsepower drives on critical applications. Control technology draws criticism, too, when it falls short of achieving its potential. The maturity of advanced control is questioned when trips occur. Reliability for both control and power technologies is an ongoing issue to be faced.

Technical challenges, business challenges, environmental challenges, and regulatory challenges are considerable in the U.S. refining and petrochemical industry. These challenges are met with commitment, competence, experience, and ability and the industries are powerfully efficient in production, particularly petrochemical companies that are electrically driven. The desire to implement advanced control and power technologies for further energy savings, increased productivity, and improved reliability is apparent at all levels of management and is dependent upon available capital and knowledge. These technologies, applied correctly, can enable this industry that is already functioning well in the face of great change, to function even better in the future.

Physical, Human, and Financial Barriers

Physically there is an extensive existing structure that needs to be reliable and well maintained for continuous production and for the safety of the infrastructure as well as for the people involved. The maturity level of the technology itself is paramount. There are considerations of previous track records. Changes that have been made in the past may have worked badly or not at all. Making necessary changes to complex infrastructure can be a formidable and expensive task. It requires commitment and long term planning.

Human influences are complex and revolve around personalities, motivation, perception, and previous experiences. People must want to make changes and believe in them. There is an important and tangible consideration of human ability levels that depends directly upon levels of knowledge, relevant industrial experience, and training available. “Twenty years experience” must equate to knowledge accumulated and validated as relevant experience over twenty years, rather than to twenty accumulated single years of working that contribute little to in-depth knowledge and relevant experience. People work better, more effectively, and are more open to change if they are confident in their knowledge and their abilities. There needs to be an understanding of and an appreciation for the change from pressure to speed control and for the change from steam to electricity.

Management structure and attitude may tend towards an isolated management philosophy or an integrated management philosophy. Involvement of corporate management at all levels of the organization and free-flowing active communication within and between all levels of the corporation seems to have beneficial results in efficient plant operation. Common focus and shared information worked for the common good. Experienced technical, management and corporate personnel working cooperatively are building blocks that together make for a strong structure and knowledge of the several facets of power engineering is key.

Financial considerations can be as straightforward as having capital available for use and using it wisely. Available capital has a direct bearing on the availability of manpower. It has a direct bearing on being able to make changes. Perceptions of value come into play, as well as the need to be profitable. Short-term Wall Street inspired management goals can be an impediment to long-term projects. Utility generated rebates and financing were offered and accepted at two refineries, and drives were successfully installed. The cost of equipment has to be balanced against expected returns. One respondent at corporate level in a refinery acknowledged that there is huge value to be obtained through advanced technology and that the single factor that restricts implementation is available capital. He said that the task is always to get the highest value from the lowest cost and that, given the necessary capital, changes could be implemented within a year.

6 CONCLUSIONS

1. The power infrastructure that presently serves refineries and petrochemical companies in the U.S. is set up for steam rather than electricity.
2. Improvements can be achieved relatively easily, short term, and within the existing infrastructure, by the implementation of advanced control technologies.
3. Some degree of improvement can be achieved relatively easily, short term, and within the existing infrastructure, by the implementation of advanced power technologies.
4. The effective full introduction of control and power technologies is dependent upon investment in and a long-term commitment to a changed infrastructure.
5. The potential for improved productivity and reduced energy consumption through the dedicated use of advanced techniques is substantial for both refineries and petrochemical plants in the U.S.
6. Petrochemical plants that operate electrically are more efficient than refineries and petrochemical companies that do not.
7. Petrochemical plants that have already invested in a complete electrical infrastructure are in the best position to make further improvements economically and with less risk using advanced controls.
8. Production continuity is important. Therefore refineries, particularly, and petrochemical companies are very conservative in their acceptance and implementation of new control and power technologies.
9. There is a lack of comfort in the process arena where speed control is introduced. No adequate training has been provided in the concept of hydraulic energy control.
10. The adoption of speed control instead of throttle control is not on the horizon for most process engineers.
11. Power technologies will only be adopted when they provide the same system reliability as fixed speed equipment.
12. A judicious application of a combination of advanced control and power technologies will contribute to expansion of capacity even in the face of increased regulation.

13. Poor experiences with early power equipments have affected and still affect adoption of speed control on critical applications.

14. Power technologies are at a very early stage of adoption.

15. In general overall plant wide refinery and petrochemical control optimization has not been tackled.

16. The implementation of advanced control and power must be done well or the consequences will be substantial.

17. Control of the process using sticking control valves hinders optimization.

18. Advanced optimal control has not been adopted and may be 10 to 15 years from implementation.

19. Subcontracting work has proven harmful to efficiency and operating costs.

20. Conditions in reactors are not fully known.

21. Exothermic energy is not extracted optimally in the majority of refineries and petrochemical plants.

22. Attention should be focused on developing methods to recover wasted heat in the process in both refineries and petrochemical companies. Typically 30% of the energy used in the process is wasted as low-grade heat energy.

23. The application of advanced control and power technologies will facilitate closer tolerances that result in improved safety margins, greater reliability, improved stability, and enhanced energy savings.

24. Throttling valves, tight control valves, dampers, wrongly dimensioned furnace burners, and clogged heat exchangers all waste energy.

25. Machines under throttle control should be considered for speed control.

26. The potential for energy savings due to advanced control and power technologies in U.S. refineries and petrochemical companies is 13,470 MW. This is a conservative projection calculated from the limited process data available for this report.

27. Compressors, furnace ID fans, fin fans, blowers, extruders, and pumps with existing throttle control will all benefit from alternative technologies.

28. There are examples of startlingly good performances from power equipments that have been matched to process requirements.

29. Minimal sophisticated electrical control has been adopted to some degree in both U.S. refineries and petrochemical companies.

30. Local and Federal physical, environmental and legislative constraints may significantly impact the operation of refineries and petrochemical companies.

31. Recent amalgamation within companies to form large corporate groups has brought increased pressure on individual units.

32. The commercial climate surrounding refineries and petrochemical companies is presently undergoing great change.

7 RECOMMENDATIONS

1. In order to achieve energy savings, increased productivity and increased reliability in U.S. refineries and petrochemical companies, prudent implementation of advanced control and power technologies is recommended.

2. In order to prepare to introduce changes it is strongly recommended that detailed control inventory be obtained from process engineers and that a survey of at least one U.S. site is completed using the model created for this study. In order to do this the various barriers that were encountered that prevented such collection of information need to be overcome.

3. Information contained in this report should be confirmed by field measurements taken at a U.S. site in cooperation with process engineering.

4. Develop specific applications of advanced control and power technologies at demonstration sites.

5. Develop training workshops for control and power technology implementation.

6. Develop system oriented control and power standards for suitable equipment for the refining and petrochemical industries.

7. Encourage and foster a systematic approach to address infrastructure issues.

8. Every effort should be made to further good communication within companies and, in turn, between companies and institutions in order that information may be truly representative of real situations. In this way accurate information can be used to full extent to promote the best and most effective outcomes for the future.

9. There should be a melding of disciplines towards the common goal of reliability. Electrical reliability should take precedence over electrical, mechanical and process constraints.

10. It is recommended that this report be considered in conjunction with a similar study, already completed, of refineries and petrochemical plants in California.

11. It should be noted that the scope of this report does not address potential increases in capacity that could result from implementing advanced control and power technologies. It is recommended that this additional benefit be the subject of further investigation.

8
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A
REFINERY/PETROCHEMICAL INFORMATION OUTLINE

1. Statistics and Physical Layout
2. Utilities
   - Electrical
   - Natural Gas
   - Petroleum
   - Fuel Gas
   - Other
3. Hydraulic Power
   - Electric
   - Mechanical
4. Electric Motor Inventory
   - Type
   - Speed
5. Control Inventory
   - Type
   - Range
   - Shafts and Flanges
6. Environmental Issues
   - Flare Gas
   - Waste Heat
   - Waste Mechanical Energy
   - Sludge
7. Maintenance
8. Operations
9. Investment
10. Quality

B

CEC/DOE PETROLEUM REFINERY/PETROCHEMICAL PROJECT SITE DATA REQUEST

Contributor Organization __________________

Site __________________

Contact __________________

Date initiated __________________

Data required by February 20 2004

Objectives of the program:

- Identify process optimization currently hindered by control and power technologies
- Identify conditions in the process that currently allow energy to be wasted
- Identify areas where energy savings could be made in existing applications
- Estimate potential energy savings
- Identify fixed speed equipment applications that could benefit from alternative technologies
- Summarize opportunities for energy savings, increased productivity and increased reliability that could be achieved based on alternative control and power technologies

Program Data

In order to fulfill the program objectives the data listed in the following pages is requested.

Each section contains data request and an area for personal observations and comment. There may be specific conditions known only to the responding site that if reported would allow the CEC and DOE to improve their support of the refining industry. Please add extra pages if the space provided is not sufficient.

General Statistics

Raw material		bbl / day
Delivered product	1	bbl / day
	2	bbl / day
	3	bbl / day
	4	bbl / day
	5	bbl / day
	6	bbl / day

Comments

Utilities

- Electricity delivered by electrical company MW
- Electricity generated on site from natural gas MW
- Electricity generated from __________ MW
- Natural gas used by the process Mm Btu
- Crude Oil Used for process energy bbl / day
- Fuel Gas used for process energy Mm Btu
- Other sources of energy Quantity

Hydraulic Power

The object of this section is to identify all sources and drains of hydraulic power (other than pipe loss).

Input Power

List all electrical motors. Obtain from a motor rating list containing speed and type (induction or synchronous)

List all steam turbines rating and speed range data from rating plate.

List all significant steam heat exchangers data from rating plate

Let down turbines rating and speed data from rating plate

Other sources of input hydraulic power:

Output Power

List all cooling towers rating and type water or air open or closed

Flare fuel gas produced:

Exothermic energy not harnessed:

Product temperature at delivery to storage.

Other hydraulic power issues:

Control Inventory

For each of the items in the hydraulic power source and sink section provide information on the method of control.

Select from the following:

Throttled regulating

Throttled wide open

Speed control

Bypass control

Other

Are there control issues that could benefit from advanced control and power techniques?

For example:

Non-invasive process condition measurement of power, flow

Control tolerances

Multivariable modeling, optimization and self-learning

Comments:

Environmental Issues

Leaks potentially occur at control valve spindles and connecting flanges

Are these a problem at your location?

Are there control or production conditions that cause flare gas to be released?

Are there compliance issues that could be address through the implementation of advanced control and power technologies?

Could the production of flare gas, waste heat, waste mechanical energy and sludge be reduced through system wide control?

Additional aspects that are important

Maintenance

What is the annual maintenance budget. $________

In relative terms much time is spent on the maintenance of:

	Little	Acceptable	Unacceptable	Causes Unscheduled Loss
• Fixed speed pump impellors				
• Throttle control surfaces				
• Bypass systems				
• Flanges				
• Pipe work				
• Steam Generators				
• Steam turbines				
• Steam heat exchangers				
• Electric motors				
• Electric distribution				
• Cooling towers				

Other important issues:

Operations

Would the use of advanced control and power technologies reduce operations cost? Identify areas:

Investment

What level of investment is committed to the improvement of the process equipment?
$__________year__________
$__________year__________

Quality

Does the shear action of the throttling valve damage or degrade product?

Are there any times when the quality of the products delivered from the refinery needs to be optimized to meet customer requirements?

Is there a demand for new products that could improve the refinery operating revenue?

Could production of new products be facilitated through the use of advanced control and power technologies?

Additional Resources

Please describe the additional resources that would positively impact the revenue generated by the refinery.

Equipment

Information

Trained Engineers

Other:

Many thanks for your time and efforts. Information that you have will be only be published in the final report with your consent.

C
ADVANCED CONTROL AND POWER TECHNOLOGIES SURVEY

UNIT/ PROCESS	DESCRIPTION	REFINERY/ PETROCHEM DESCRIPTOR	HP	SPEED	TYPE (IND, SYNC or ST)	VOLTAGE	DRIVEN EQUIPMENT	CONTROL	POTENTIAL FOR IMPROVEMENT	PREVIOUSLY INVESTIGATED FOR ENERGY SAVINGS

D
SAMPLE PHONE QUESTIONNAIRE FOR REFINERY/PETROCHEMICAL PARTICIPANTS

The questions followed the list below:

1. Where are you on the spectrum of control: pneumatic through to neural net?
2. As changes were made to upgrade sections of the plant did you realize measurable energy benefits?
3. How much, in percentage terms, was the energy benefit?
4. What are your plans for the future of the control system?
5. How many adjustable speed drives are in use in the process system?
6. What has been your experience with adjustable speed drives? Give any examples for illustration.
7. Are you planning to change progressively from pump throttle control to speed control?
8. What is the co-generation plant rating?
9. Do you out source control and drive project specifications and how satisfied are you with the process?

There may be follow up clarification after each question is answered. This is an objective study, the findings of which will be directed to the benefit of petrochemical refineries through a report presented to the CEC.

E
DESCRIPTION OF CONTROL TECHNOLOGIES

Pneumatic Control was the primary method of controlling industrial processes until the 1950s. Conventional pneumatic controllers had limited range and linearity of control. For these reasons pneumatically controlled industrial systems were energy inefficient.

Analog Control, introduced in the 1950s, was the first attempt to control industrial processes using electrical techniques. It provided accurate set point control and process feedback of a single process variable. This single loop used proportional-integral-derivative (PID) control to provide reliability and range that could not be achieved with pneumatic control. It was cumbersome and wasteful of space and the displays could extend across an entire wall. Each individual loop had to be monitored in the control room by an operator skilled in the dynamic control of the refinery and who gave it intensive attention during any change. The energy efficiency of analog control was considerably better than that of pneumatic and set the scene for the introduction of even more electrical control.

A Distributed Control System (DCS) is one in which digital computing power is distributed throughout the process. Digital computers were cautiously introduced in the mid 1970s. At first, analog control continued to be made available to back up the fledgling DCS equipment that was perceived to be very unreliable. By the early 1980s second generation DCS equipment was in use and a central computer screen was used by the operators. The perception of unreliability had evaporated. Control advantages became apparent as well as the physical advantage of having one screen monitor all the main parameters in the refinery. Duplicate screens could be installed anywhere in the plant. The large instrument control room became a thing of the past. By the mid 1980s the DCS system had became the host for much more than simple control operations. Basic digital control was supplemented by:

- Expert systems
- Plant wide information systems
- Statistical Process Control (SPC)
- Accounting data
- System modeling

By the early 1990s the extended capability of DCS was appreciated and pressures were exerted on the controls community to use “open architecture” that would allow new functional control logic to be added to the DCS system. These additions included:

- Product information
- SPC

- Intelligent alarms
- Expert systems
- Scheduling information
- Predictive maintenance

The DCS system continues to be expanded to incorporate more features.

Multivariable Control

Multivariable control uses the architecture of DCS to incorporate sophisticated software that enables the control of interactions among a number of control loops or variables. The process engineer skillfully derives algorithms from many variables that may be or may appear to be unrelated. The newly constructed variable is used as a substitute for information that is unavailable practically.

Neural Net

Neural net control systems extend the capability of multivariable systems by introducing control algorithms that will deal with incomplete information. This enables the neural control system to reach new optimized control states that meet the combined goals of:

- Refinery product output performance against the variability of crude oil
- Refinery operating stability
- Extension of time between refinery turnarounds
- Maximizing refinery financial results

F
2002 U.S. REFINING CAPACITY

Table F-1
2002 U.S. Refining Capacity (BCD)* [1]

Company and Location	Crude	Vacuum Distillation	Coking	Alkylation	Catalytic Cracking	Catalytic Reforming	Catalytic Hydrocracking	Catalytic Hydrotreating
ALABAMA								
Coastal ExxonMobil Refining Mobile Bay	20,000	15,000	0	0	0	0	0	0
Hunt Refining Co. Tuscaloosa	43,225	14,250	12,600	0	0	6,480	0	31,500
Shell Chemical Co. Saraland	85,000	28,000	0	0	0	21,000	0	43,000
Total Alabama (3 refineries)	**148,225**	**57,250**	**12,600**	**0**	**0**	**27,480**	**0**	**74,500**
ALASKA								
BP PLC Prudhoe Bay	15,000	0	15,000	0	0	0	0	0
BP PLC Kuparuk	14,500	0	14,500	0	0	0	0	0
Petro Star Inc. North Pole	15,000	0	0	0	0	0	0	0
Petro Star Inc. Valdez	48,000	0	0	0	0	0	0	0
Tesoro Alaska Co. Kenai	72,000	19,000	0	0	0	12,000	12,500	12,500
Williams Alaska Petroleum Inc. North Pole	220,000	8,000	0	0	0	0	0	0
Total Alaska (6 refineries)	**384,500**	**27,000**	**29,500**	**0**	**0**	**12,000**	**12,500**	**12,500**
ARKANSAS								
Cross Oil Refining Co. Inc. Smackover	7,000	3,000	0	0	0	0	0	24,500
Lion Oil Co. El Dorado	64,000	26,500	0	4,900	19,700	14,000	0	29,500
Total Arkansas (2 refineries)	**71,000**	**29,500**	**0**	**4,900**	**19,700**	**14,000**	**0**	**54,000**
CALIFORNIA								
BP PLC Carson	260,000	130,000	65,000	15,000	96,000	52,000	43,000	187,000

Company and Location	Crude	Vacuum Distillation	Coking	Alkylation	Catalytic Cracking	Catalytic Reforming	Catalytic Hydrocracking	Catalytic Hydrotreating
Chevron Texaco El Segundo	260,000	120,000	64,000	21,000	62,000	40,000	45,000	193,000
Chevron Texaco Corp. Richmond	225,000	110,000	0	20,000	65,000	45,000	109,000	144,000
ConocoPhillips Carson/Wilmington	130,500	78,000	48,000	14,200	45,000	35,200	24,750	135,850
ConocoPhillips San Fran. Rodeo	107,920	78,309	47,502	0	0	30,600	32,400	45,963
ExxonMobil Refinery Torrance	149,000	98,000	51,500	23,500	90,500	19,000	23,000	141,000
Kern Oil & Refining Bakersfield	25,000	0	0	0	0	3,000	0	12,500
San Joaquin Refining Bakersfield	24,300	14,300	0	0	0	0	0	3,000
Shell Oil Products Bakersfield	65,000	39,000	22,000	0	0	14,700	23,500	41,900
Shell Oil Products Martinez	154,800	102,400	44,600	10,200	68,700	28,200	33,800	189,600
Shell Oil Products Wilmington	98,500	58,000	41,000	8,700	35,000	31,000	29,000	92,000
Tesoro Petroleum Golden Eagle	161,000	144,000	42,000	14,000	66,500	42,000	32,000	145,500
Valero Energy Corp. Benicia	148,000	80,500	29,000	15,000	72,000	36,000	35,000	167,000
Valero Energy Corp. Wilmington	84,000	49,700	28,000	15,000	54,000	16,000	0	182,000
Total California (14 refineries)	**1,893,020**	**1,102,209**	**482,602**	**156,600**	**654,700**	**392,700**	**430,450**	**1,680,813**
COLORADO								
ConocoPhillips Commerce City	60,000	25,000	0	0	19,000	9,600	0	34,100
Valero Energy Corp. Denver	28,000	9,500	0	0	8,000	9,000	0	9,000
Total Colorado (2 refineries)	**88,000**	**34,500**	**0**	**0**	**27,000**	**18,600**	**0**	**43,100**
DELAWARE								
Motiva Enterprises LLC Delaware City	175,000	91,000	47,000	8,190	73,000	39,000	18,000	119,000
Total Delaware (1 refinery)	**175,000**	**91,000**	**47,000**	**8,190**	**73,000**	**39,000**	**18,000**	**119,000**

Company and Location	Crude	Vacuum Distillation	Coking	Alkylation	Catalytic Cracking	Catalytic Reforming	Catalytic Hydrocracking	Catalytic Hydrotreating
HAWAII								
ChevronTexaco Corp. Barber's Point	54,000	30,000	0	4,000	21,000	0	0	3,000
Tesoro Hawaii Corp. Kapolei	93,700	39,500	0	0	0	12,800	17,600	10,800
Total Hawaii (2 refineries)	**147,700**	**69,500**	**0**	**4,000**	**21,000**	**12,800**	**17,600**	**13,800**
ILLINOIS								
Citgo Petroleum Corp. Lemont	158,650	71,250	35,100	18,900	60,300	28,080	0	103,410
ConocoPhillips Wood River	286,400	107,000	0	20,500	90,000	85,000	28,500	178,100
ExxonMobil Refining & Supply Co. Joliet	238,000	113,000	55,500	27,000	93,000	42,000	0	176,000
Marathon Ashland Petroleum LLC Robinson	192,000	61,900	27,600	12,400	50,400	71,300	25,700	123,500
Total Illinois (4 refineries)	**875,050**	**353,150**	**118,200**	**78,800**	**293,700**	**226,380**	**54,200**	**581,010**
INDIANA								
BP PLC Whiting	410,000	242,000	34,200	34,200	156,800	85,500	0	299,800
Countrymark Cooperative Inc. Mount Vernon	23,500	7,400	0	1,700	7,850	6,500	0	10,000
Total Indiana (2 refineries)	**433,500**	**249,400**	**34,200**	**35,900**	**164,650**	**92,000**	**0**	**309,800**
KANSAS								
Farmland Industries Coffeyville	95,000	50,000	17,000	7,000	29,000	17,000	0	59,300
Frontier Oil Corp. El Dorado	110,000	39,000	18,000	12,500	37,200	29,500	0	122,900
National Cooperative Refining Assoc. McPherson	79,000	31,600	20,400	6,300	20,900	20,900	11,200	67,300
Total Kansas (3 refineries)	**284,000**	**120,600**	**55,400**	**25,800**	**87,100**	**67,400**	**11,200**	**249,500**

Company and Location	Crude	Vacuum Distillation	Coking	Alkylation	Catalytic Cracking	Catalytic Reforming	Catalytic Hydrocracking	Catalytic Hydrotreating
KENTUCKY								
Marathon Ashland Petroleum LLC Catlettsburg	222,000	91,200	0	12,400	96,000	45,600	0	195,300
Somerset Refinery Inc. Somerset	5,500	0	0	0	0	1,500	0	2,000
Total Kentucky (2 refineries)	**227,500**	**91,200**	**0**	**12,400**	**96,000**	**47,100**	**0**	**197,300**
LOUISIANA								
American International Refining Inc. Lake Charles	30,000	15,000	0	0	0	0	0	0
Calcasieu Refining Co. Lake Charles	15,680	0	0	0	0	0	0	0
Calumet Lubricants Co. Cotton Valley	8,500	0	0	0	0	0	0	4,000
Calumet Lubricants Co. Princeton	9,500	8,500	0	0	0	0	8,000	0
Calumet Lubricants Co. Shreveport	15,000	10,000	0	0	0	0	7,200	1,100
Canal Refining Co. Church Point	30,000	2,500	0	0	0	0	0	8,000
Cit-Con Oil Corp. Lake Charles		36,100	00	0	0	0	0	
Citgo Petroleum Corp. Lake Charles	336,801	79,800	88,200	20,700	126,000	103,500	37,800	229,950
ConocoPhillips Belle Chasse	250,000	92,000	25,200	38,000	104,000	42,000	0	112,000
ConocoPhillips Westlake	232,000	110,000	60,000	75,000	40,000	42,000	29,000	153,220
ExxonMobil Refining & Supply Co. Baton Rouge	491,500	220,500	108,000	35,000	227,000	72,000	23,000	308,500
ExxonMobil Refining & Supply Co. Chalmette	182,500	102,000	33,000	12,500	68,000	46,000	18,500	124,000
Marathon Ashland Petroleum LLC Garyville	232,000	118,800	32,800	29,500	109,300	46,600	0	209,000
Motiva Enterprises LLC Convent	235,000	100,000	0	13,050	85,000	36,000	45,000	162,000

Company and Location	Crude	Vacuum Distillation	Coking	Alkylation	Catalytic Cracking	Catalytic Reforming	Catalytic Hydrocracking	Catalytic Hydrotreating
Motiva Enterprises LLC Norco	220,000	78,000	21,300	14,800	105,000	57,300	31,500	73,300
Murphy Oil USA Inc. Meraux	95,000	47,500	0	7,650	34,200	0	0	58,050
Orion Refining Corp. Norco	155,000	124,000	75,000	0	85,000	12,000	0	90,000
Placid Refining Co. LLC Port Allen	48,000	20,000	0	3,800	19,000	9,700	0	21,700
Shell Chemical Co. St. Rose	55,000	28,000	0	0	0	0	0	0
Valero Energy Corp. Krotz Springs	78,000	29,500	0	0	30,500	12,000	0	16,250
Total Louisiana (20 refineries)	**2,719,481**	**1,222,200**	**443,500**	**250,000**	**1,033,000**	**479,100**	**200,000**	**1,571,070**
MICHIGAN								
Marathon Ashland Petroleum LLC Detroit	74,000	36,100	0	3,900	28,500	20,000	0	48,600
Total Michigan (1 refinery)	**74,000**	**36,100**	**0**	**3,900**	**28,500**	**20,000**	**0**	**48,600**
MINNESOTA								
Koch Petroleum Group Rosemount	270,750	171,000	61,200	10,980	77,400	44,100	0	272,700
Marathon Ashland Petroleum LLC St. Paul Park	70,000	30,400	0	5,200	24,700	20,000	0	71,300
Total Minnesota (2 refineries)	**340,750**	**201,400**	**61,200**	**16,180**	**102,100**	**64,100**	**0**	**344,000**
MISSISSIPPI								
ChevronTexaco Corp. Pascagoula	295,000	231,000	71,000	14,800	63,000	71,000	142,000	140,000
Ergon Refining Inc. Vicksburg	23,000	10,200	0	0	0	0	0	8,600
Total Mississippi (2 refineries)	**318,000**	**241,200**	**71,000**	**14,800**	**63,000**	**71,000**	**142,000**	**148,600**
MONTANA								
Cenex Harvest States Laurel	56,000	28,000	0	4,200	13,100	11,800	0	44,100
ConocoPhillips Billings	57,950	28,500	17,325	6,489	18,090	12,150	0	54,792

Company and Location	Crude	Vacuum Distillation	Coking	Alkylation	Catalytic Cracking	Catalytic Reforming	Catalytic Hydrocracking	Catalytic Hydrotreating
ExxonMobil Refining & Supply Co. Billings	58,000	27,500	8,000	4,000	20,000	12,000	5,000	43,500
Montana Refining Co. Great Falls	7,000	3,350	0	0	2,300	1,000	0	0
Total Montana (4 refineries)	**178,950**	**87,350**	**25,325**	**14,689**	**53,490**	**36,950**	**5,000**	**142,392**
NEW JERSEY								
Coastal Eagle Point Oil Co. Westville	150,000	47,500	0	4,000	55,000	28,000	0	29,000
ConocoPhillips Linden	250,000	62,000	0	16,000	138,000	28,000	0	238,000
Valero Energy Corp. Paulsboro	166,000	85,000	26,600	11,100	52,000	24,500	0	111,250
Total New Jersey (3 refineries)	**566,000**	**194,500**	**26,600**	**31,100**	**245,000**	**80,500**	**0**	**378,250**
NEW MEXICO								
Giant Refining Co. Bloomfield	18,600	0	0	0	6,000	4,800	0	7,800
Giant Refining Co. Gallup	26,000	0	0	1,800	8,500	7,300	0	11,500
Navajo Refining Co. Artesia	60,000	20,000	0	7,800	18,500	12,500	0	50,500
Total New Mexico (3 refineries)	**104,600**	**20,000**	**0**	**9,600**	**33,000**	**24,600**	**0**	**69,800**
NORTH DAKOTA								
Tesoro West Coast Co. Mandan	58,000	0	0	4,200	24,700	11,500	0	12,000
Total North Dakota (1 refinery)	**58,000**	**0**	**0**	**4,200**	**24,700**	**11,500**	**0**	**12,000**
OHIO								
BP PLC Toledo	152,000	66,000	34,200	10,900	57,000	40,800	28,500	90,300
Marathon Ashland Petroleum LLC Canton	73,000	30,000	0	6,700	22,800	18,100	0	57,100
Premcor Refining Group Lima	165,000	52,000	22,500		40,000	55,500	26,000	63,000

Company and Location	Crude	Vacuum Distillation	Coking	Alkylation	Catalytic Cracking	Catalytic Reforming	Catalytic Hydrocracking	Catalytic Hydrotreating
Sunoco Inc. Toledo	140,000	30,000	0	9,000	60,000	45,600	28,200	48,000
Total Ohio (4 refineries)	**530,000**	**178,000**	**56,700**	**26,600**	**179,800**	**160,000**	**82,700**	**258,400**
OKLAHOMA								
ConocoPhillips Ponca City	189,620	68,970	24,210	14,580	58,815	47,160	0	121,680
Gary-Williams Energy Corp. Wynnewood	52,500	15,500	0	4,000	18,500	13,000	5,000	12,000
Sinclair Oil Corp. Tulsa	50,000	25,175	0	2,700	16,200	10,800	0	26,300
Sunoco Inc. Tulsa	85,000	30,000	8,500	0	0	17,500	0	34,500
Valero Energy Corp. Ardmore	85,000	62,000	0	6,400	27,500	20,000	0	90,200
Total Oklahoma (5 refineries)	**462,120**	**171,645**	**32,710**	**27,680**	**121,015**	**108,460**	**5,000**	**284,680**
PENNSYLVANIA								
American Refining Group Bradford	10,000	0	0	0	0	1,800	0	3,500
ConocoPhillips Trainer	186,200	75,430	0	11,790	48,420	48,780	19,890	110,610
Sunoco Inc. Marcus Hook	175,000	26,400	0	10,000	93,000	15,600	0	48,000
Sunoco Inc. Philadelphia	330,000	157,400	0	16,700	113,500	68,000	0	163,600
United Refining Co. Warren	66,700	27,000	0	3,500	23,000	16,000	0	40,000
Total Pennsylvania (5 refineries)	**767,900**	**286,230**	**0**	**41,990**	**277,920**	**150,180**	**19,890**	**365,710**
TENNESSEE								
Williams Energy Services Memphis	190,000	0	0	12,000	68,000	36,000	0	123,000
Total Tennessee (1 refinery)	**190,000**	**0**	**0**	**12,000**	**68,000**	**36,000**	**0**	**123,000**
TEXAS								
AGE Refining & Manufacturing San Antonio	10,000	0	0	0	0	0	0	0

Company and Location	Crude	Vacuum Distillation	Coking	Alkylation	Catalytic Cracking	Catalytic Reforming	Catalytic Hydrocracking	Catalytic Hydrotreating
AGE Refining & Manufacturing Alon USA Big Spring	61,000	24,000	0	4,500	23,000	21,000	0	56,900
Atofina Petrochemicals, Inc. Port Arthur	176,000	49,900	0	5,700	62,800	36,100	10,500	110,700
BP PLC Texas City	437,000	228,000	40,400	58,900	209,000	137,800	114,000	363,900
ChevronTexaco Corp. El Paso	90,000	34,700		8,200	28,000	17,700	0	37,800
Citgo Petroleum Corp. Corpus Christi	156,750	73,625	37,800	18,090	72,450	47,250	0	169,380
Coastal Refining & Marketing Inc. Corpus Christi	100,000	56,000	17,500	3,000	20,000	30,000	11,000	82,000
ConocoPhillips Borger	142,785	0	0	17,100	58,320	27,810	0	157,950
ConocoPhillips Sweeny	215,650	111,150	59,310	14,940	94,050	32,400	0	193,590
Crown Central Petroleum Corp. Pasadena	100,000	42,000	12,500	13,000	56,000	0	0	36,000
ExxonMobil Refining & Supply Co. Baytown	523,000	252,500	78,000	30,000	202,500	122,000	25,500	503,000
ExxonMobil Refining & Supply Co. Beaumont	348,500	141,000	48,000	15,500	108,000	147,000	60,000	292,500
Flint Hills Resources Corpus Christi	297,000	104,500	13,680	11,700	104,500	57,600	10,530	188,100
LaGloria Oil & Gas Co. Tyler	60,000	15,000	6,500	4,750	20,200	17,500	0	32,000
Lyondell-Citgo Refining LP Houston	268,850	187,625	87,300	18,810	89,100	60,300	0	281,070
Marathon Ashland Petroleum LLC Texas City	72,000	0	0	10,500	41,800	10,500	0	0
Motiva Enterprises LLC Port Arthur	250,000	110,000	49,500	18,000	86,000	45,000	17,820	194,000
Premcor Refining Group Port Arthur	225,000	130,000	80,000	17,000	77,000	50,000	3,500	212,000
Shell Deer Park Refining Co. Deer Park	333,800	181,600	80,200	16,500	67,500	67,800	62,600	211,900

Company and Location	Crude	Vacuum Distillation	Coking	Alkylation	Catalytic Cracking	Catalytic Reforming	Catalytic Hydrocracking	Catalytic Hydrotreating
Valero Energy Corp. Corpus Christi	140,000	86,700	17,500	16,500	107,000	68,500	47,000	184,000
Valero Energy Corp. Houston	83,000	39,000	0	8,500	62,000	10,500	0	44,500
Valero Energy Corp. Sunray	155,000	47,000	0	9,000	54,500	46,000	30,000	65,500
Valero Energy Corp. Texas City	210,000	100,000	0	11,500	78,500	13,500	0	182,600
Valero Energy Corp. Three Rivers	97,000	29,000	0	5,800	23,000	30,500	29,000	80,750
Total Texas (24 refineries)	**4,552,335**	**2,043,300**	**628,190**	**337,490**	**1,745,220**	**1,096,760**	**421,450**	**3,680,140**
UTAH								
ChevronTexaco Corp. Salt Lake City	45,000	25,600	7,200	4,500	13,000	7,000	0	24,000
ConocoPhillips Woods Cross	25,000	5,500	0	2,400	7,680	7,200	0	13,700
Flying J Inc. Salt Lake City	25,000	5,500	0	1,800	10,000	5,500	0	14,000
Silver Eagle Refining Inc. Woods Cross	12,500	6,000	0	0	0	2,200	0	6,200
Tesoro West Coast Co. Salt Lake City	60,000	0	0	5,600	23,000	11,300	0	11,700
Total Utah (5 refineries)	**167,500**	**42,600**	**7,200**	**14,300**	**53,680**	**33,200**	**0**	**69,600**
VIRGINIA								
Giant Refining Yorktown	58,900	33,000	17,100	0	26,700	10,800	0	29,300
Total Virginia (1 refinery)	**58,900**	**33,000**	**17,100**	**0**	**26,700**	**10,800**	**0**	**29,300**
WASHINGTON								
BP PLC Ferndale	222,720	96,960	59,520	0	0	60,480	54,720	79,680
ConocoPhillips Ferndale	90,250	46,360	0	4,950	28,080	15,597	0	53,280
Shell Oil Products U.S. Anacortes	148,600	62,300	25,400	11,600	57,300	32,200	0	83,500
Tesoro West Coast Co. Anacortes	114,500	45,000	0	11,500	42,000	24,300	0	31,800

Company and Location	Crude	Vacuum Distillation	Coking	Alkylation	Catalytic Cracking	Catalytic Reforming	Catalytic Hydrocracking	Catalytic Hydrotreating
U.S. Oil Refining Co. Tacoma	44,350	23,700	0	0	0	5,500	0	12,900
Total Washington (5 refineries)	**620,420**	**274,320**	**84,920**	**28,050**	**127,380**	**138,077**	**54,720**	**261,160**
WEST VIRGINIA								
Ergon-West Virginia Inc. Newell	18,600	8,050	0	0	0	4,300	0	10,000
Total West Virginia (1 refinery)	**18,600**	**8,050**	**0**	**0**	**0**	**4,300**	**0**	**10,000**
WISCONSIN								
Murphy Oil USA Inc. Superior	33,250	19,500	0	1,350	9,900	7,200	0	20,620
Total Wisconsin (1 refinery)	**33,250**	**19,500**	**0**	**1,350**	**9,900**	**7,200**	**0**	**20,620**
WYOMING								
Frontier Refining Inc. Cheyenne	46,000	26,000	10,000	4,200	12,000	7,600	0	25,400
Sinclair/Little America Casper	22,500	6,000	0	0	10,000	5,500	0	16,000
Sinclair Oil Corp. Sinclair	54,000	29,500	0	4,000	20,600	14,200	0	46,200
Wyoming Refining Co. Newcastle	12,500	1,500	0	1,300	5,500	2,750	0	7,500
Total Wyoming (4 refineries)	**135,000**	**63,000**	**10,000**	**9,500**	**48,100**	**30,050**	**0**	**95,100**
Total U.S. (133 refineries)	**16,623,301**	**7,347,704**	**2,243,947**	**1,107019**	**5,677,355**	**3,512,237**	**1,474,710**	**11,247,745**

* Barrels per calendar day