Using Advanced Control and Power Technologies to Improve the Reliability and Energy Efficiency of Petroleum Refining and Petrochemical Manufacturing in California

Technical Report

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Using Advanced Control and Power Technologies to Improve the Reliability and Energy Efficiency of Petroleum Refining and Petrochemical Manufacturing in California

1007415

Final Report, May 2004

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This report describes research jointly sponsored by EPRI and the California Energy Commission.

The report is a corporate document that should be cited in the literature in the following manner:

Using Advanced Control and Power Technologies to Improve the Reliability and Energy Efficiency of Petroleum Refining and Petrochemical Manufacturing in California, EPRI, Palo Alto, CA, California Energy Commission, Sacramento, CA: 2004. 1007415.

PRODUCT DESCRIPTION

Full implementation of advanced control and power technologies could save U.S. refineries and petrochemical plants an estimated $7.14 Billion/year. California refineries process 1,893,020 barrels of crude per day—about 11% of the total U.S. crude. Implementation of advanced control and power technologies could provide California refineries and petrochemical plants significant savings from increased energy efficiency and productivity. This report identifies these savings opportunities for California refineries.

Results & Findings

The judicious implementation of advanced control and power technologies could achieve energy savings, increased productivity, and increased reliability in California refineries. Measurable and significant improvements can be made by extending the implementation of advanced control and power technologies from the existing limited installations to refinery-wide control optimization schemes. 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.

California refineries could save $815 million per year from the implementation of advanced control and power technologies. An estimated investment cost of $980 Million could be paid off by the savings realized in just 1.2 years.

Challenges & Objectives

Collecting the data for this project was not a straightforward task. This assessment of the effectiveness of the advanced power and control technologies currently in use at California refineries depended upon the cooperation of refining industry personnel, particularly electrical and process engineers. Motor list data, cogeneration ratings and electricity usage data were available from electrical engineering. However, data for heat exchangers, furnaces, and boilers were not readily available from process engineering. The process-engineering group expressed a desire to become more familiar with new control technologies, but their interest was tempered by the practical constraints of having to get the job done. There was also concern about sharing proprietary information.

Applications, Values & Use

This Phase 1 report evaluates the current effectiveness of control and power technologies at California refineries and identifies opportunities for energy savings, increased productivity, and increased reliability that could be achieved by alternative control and power technologies. A second Phase 1 study will determine the current effectiveness of control and power technologies in U.S. refineries and petrochemical plants outside California and identify opportunities for energy savings, increased productivity, and increased reliability that could be achieved based by alternative control and power technologies. This second Phase 1 study will be completed in July 2004. The results from these two Phase 1 studies will provide the basis for proceeding with further phases of the project.

In a potential Phase 2, suitable demonstration sites would 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, advanced control and power technologies would be implemented at selected sites.

EPRI Perspective

End users report concerns that are preventing the application of advanced control and power technologies in petroleum refining and petrochemical manufacturing facilities. These concerns explain why older process control techniques and maintenance prone hydraulic couplings and steam turbines are still being used instead of 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. Unfortunately, currently used 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.

Approach

In work cosponsored by the California Energy Commission (CEC) and EPRI, the project team assembled a collaborative of utilities, state/federal agencies, and refineries to document the reliability and energy efficiency benefits of advanced control and power technologies and to find ways to transfer new technology to refining and petrochemical industries. Phase 1 of this project addresses the effectiveness of the control and power technologies in current use in California refineries and evaluates the opportunities for energy savings, increased productivity and increased reliability that could be achieved by alternative control and power technologies. The results of this report will later be integrated into a report that will address the status and prospects of control and power technologies in the U.S. refinery and petrochemical industries.

Keywords

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

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1
INTRODUCTION

Background

Energy savings, increased productivity, and increased reliability can be achieved by the use of advanced control and power technologies in California refineries. In order to assess the effectiveness of advanced control and power technologies currently being used, approaches were made to a representative number of refineries in the state that together accounted for over 90% of California's production volume. 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 a refinery. 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 a refinery 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 refinery.

A second survey was developed that addressed the effectiveness of control and power technologies in refineries. 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 twelve California refineries. An information package and a confidentiality agreement for contributors were developed, together with a letter of invitation that was revised in conjunction with refinery 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 four site visits was completed that covered three major refinery sites: ChevronTexaco Richmond Refinery, Shell Wilmington Refinery, and Valero Benicia Refinery. 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, Shell, Valero, ExxonMobil, ConocoPhillips, BP, Tesoro, Apex, and Kern.

There was universal support for the project. However, for some companies the levels of contribution were limited or curtailed owing to corporate pressures, 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 shows the current use of control and power technologies in California refineries.

Contributors of information for this report described a very wide range of control techniques currently in use. 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 widely. The overall average energy savings was 25% for this refinery under multivariable control.

Table 2-1
Use of Control and Power Technologies in Californian 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

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

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.

Control using throttling valves presents special performance issues in California because there are stringent monitoring and correction requirements for throttling valves throughout the state. 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.

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 in refining 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 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 by-products of the refining 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 refining 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 some refineries there is little enthusiasm for the introduction of variable speed control as a method of optimizing energy delivered to the hydraulic system. There have been a number of poor experiences associated with adjustable speed drives and this overshadows the possibility of installing new drive systems. However, where there has been successful implementation of variable speed control it has been met with enthusiasm and proved to be an asset. Successful application of variable speed control can only be accomplished through careful specification of equipment and diligent follow up.

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 were avoided and the heat were reused. For the safety of equipment and workers, safety margins are always necessarily in place. Excessive safety margins, employed for increased process stability, result in 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.

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. Implementing refinery wide control optimization will facilitate refinery wide energy savings. When speed control is added, along with a 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.

Opportunities for Advanced Control Technologies

The potential for advanced control technology in California Refineries is significant. Table 3-1 shows the present state of adoption of control technologies in California refineries. 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 state of California. 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 refinery. 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]

Table 3-1
Present State of Adoption of Control Technology

Present Control Technology	Sub Section of the Refinery	Whole Refinery
Move to DCS	90%	90%
Move to Multivariable	40%	0%
Move to Neural Net	5%	0%
Future Control	0%	0%

Opportunities for Advanced Power Technologies

The implementation of advanced power technology in California offers much potential. Table 3-2 shows the present state of power technology adoption in California. It will afford 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.

Table 3-2
Present State of Adoption of Power Technology

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 %

4
ANALYSIS OF SAVINGS FOR A TYPICAL CALIFORNIA REFINERY

Basis for Analysis

In order to extrapolate from the 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] that is shown in Table 4-1 on the next page.

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 = 3835 Trillion Btu [2]

For one average sized U.S. refinery

The supply of heat and power = 3835 / 133 = 28.8346 Trillion Btu per year

Converting to MW = 28.8346 / 8760 = 3.292×10^9 Btu per hr
= $(3.292 \times 10^9) \times (2.928 \times 10^{-7})$ MW
= 963 MW

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

The average sized refinery in the US = 124,987 Bpd

In California, 14 refineries use 1,893,020 Bpd of crude oil [1]

The average sized refinery in California = 135,215 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. California refineries represent 10.5% of the total number of refineries in the US and they use 11% of the total crude oil refined [1]. Here the similarity ends. California Refineries, when compared with refineries in the rest of the US, show a series of different characteristics as shown in Table 4-1.

Table 4-1
2002 California Refining Capacity (BCD)* [1]

Company and Location	Crude	Vacuum Distillation	Coking	Alkylation	Catalytic Cracking	Catalytic Reforming	Catalytic Hydrocracking	Catalytic Hydrotreating
BP PLC Carson	260,000	130,000	65,000	15,000	96,000	52,000	43,000	187,000
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	***	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**
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
% of U.S. in California	**11.0**	**15.0**	**21.5**	**13.0**	**11.0**	**11.0**	**29.0**	**14.9**

* Barrels per calendar day

Savings for a Typical California Refinery

The information collected from one refinery was scaled to represent an average Californian refinery. The average sized refinery in California utilizes 135,215 Bpd. A refinery of this size, from the study data, requires 151 MW of electric power. Most commonly, a large proportion of this electrical energy is produced by co-generation. 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 175,500 kW were included in the power distribution shown in Table 4-2. 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 4-2
Typical Electric Motor Use from Study Respondent Scaled to Match the Average Californian Refinery

	Proportion	kW	Quantity
Low voltage motors (based on 50 hp)	38%	66,200	1324
Medium voltage motors 100 to 1000 hp	26%	46,050	165
Medium voltage motors 1000 to 15,000 hp	36%	63,250	30

The following analysis considers a typical Californian refinery [1, 10] that uses the array of process technology set out in Table 4-1.

From survey information received from one respondent and scaled to match the California average of 135,215 Bpd, the electric power consumed in the refinery = 151 MW.

Loss in the electric motor driven systems:

Motor loss (6%) = 9,060 kW (6% of 151MW)

Pump loss (25%) = 35,485 kW (25% of 151x 0.94)

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

Throttle loss (Assume 20%) = 21,291 **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 = (21.291 kW) x (0.5) x (0.75) kW

= 7984 kW = 7.984 **MW**

Thus, 14 Californian refineries will save potentially: 14 x 7.984 MW = **112 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 16 such drives in each refinery would alone provide 112 MW. (16 drives x 0.5 MW/drive x 14 refineries = **112 MW = $30 M @ $0.03 per kWh**)

Calculating total energy converted by the average Californian refinery:

Using the calorific value of 5.6M Btu per barrel, the rate of energy flowing through an average California refinery = 13.5215 x 5.6 x 2.928/24kW

= **9,237 MW**

From respondent information, the internal loss in a typical refinery can be assumed to be 5% of the calorific value of the fuel used i.e. 462 MW.

The internal loss for a typical complex refinery is 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. 46 MW. For the 14 Californian refineries, the savings from advanced control are predicted to be **644 MW**.

The above calculations show the basic energy savings' numbers. Further real benefits for California 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 14 Californian refineries, the savings from advanced control are predicted to be 644 MW. This is equivalent to an annual saving of $ 170 M. (Assuming power cost = 3 cents per kWhr)

A summary of this analysis, as applied to the 14 Californian refineries, is provided below, assuming 100% control and 50% power penetration:

- Annual energy procurement costs would be reduced by $ 170 M
- Annual hydraulic power consumed would be reduced by 5% or 112 MW, which is equivalent to $ 30 M, assuming a power cost of 3 cents per kWhr.
- Annual fuel savings from converting steam turbines to electric drives =$30 M
- The total fuel related cost savings = $ 230 M

A summary of benefits, as applied to the 14 Californian refineries, is provided below, assuming 100% control and 100% power penetration:

- Annual energy procurement costs would be reduced by $170 M
- Throttle conversion benefit = $60 M (2 x $ 30 M)
- Steam turbine conversion to electric drives = $55 M (30/16 x $30 M)
- The total fuel related cost savings = $285 M

Total refinery costs and savings [Figures 4-1, 4-2 and 4-3] were developed using published statistics 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 4-3 would accrue.

Table 4-3
Potential Annual Savings from Implementing Advanced Control and Power Technologies in California Refineries, Assuming 100% Penetration

Opportunity	Annual Savings (Millions of Dollars)
Waste due to utility power related causes would be reduced	$ 50
Operations and maintenance costs would be reduced	$ 400
There would a reduced environmental impact cost	$ 90
There would be increased electricity usage of	($ 10)
Total fuel related cost savings	$ 285
Total potential annual savings	**$ 815**

This would provide a predicted total annual savings for California refineries of $ 815 M. Based on an estimated investment cost of $980 Million, savings of $815 Million/year would yield a simple payback of 1.2 years ($980 Million/$815 Million/year).

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.

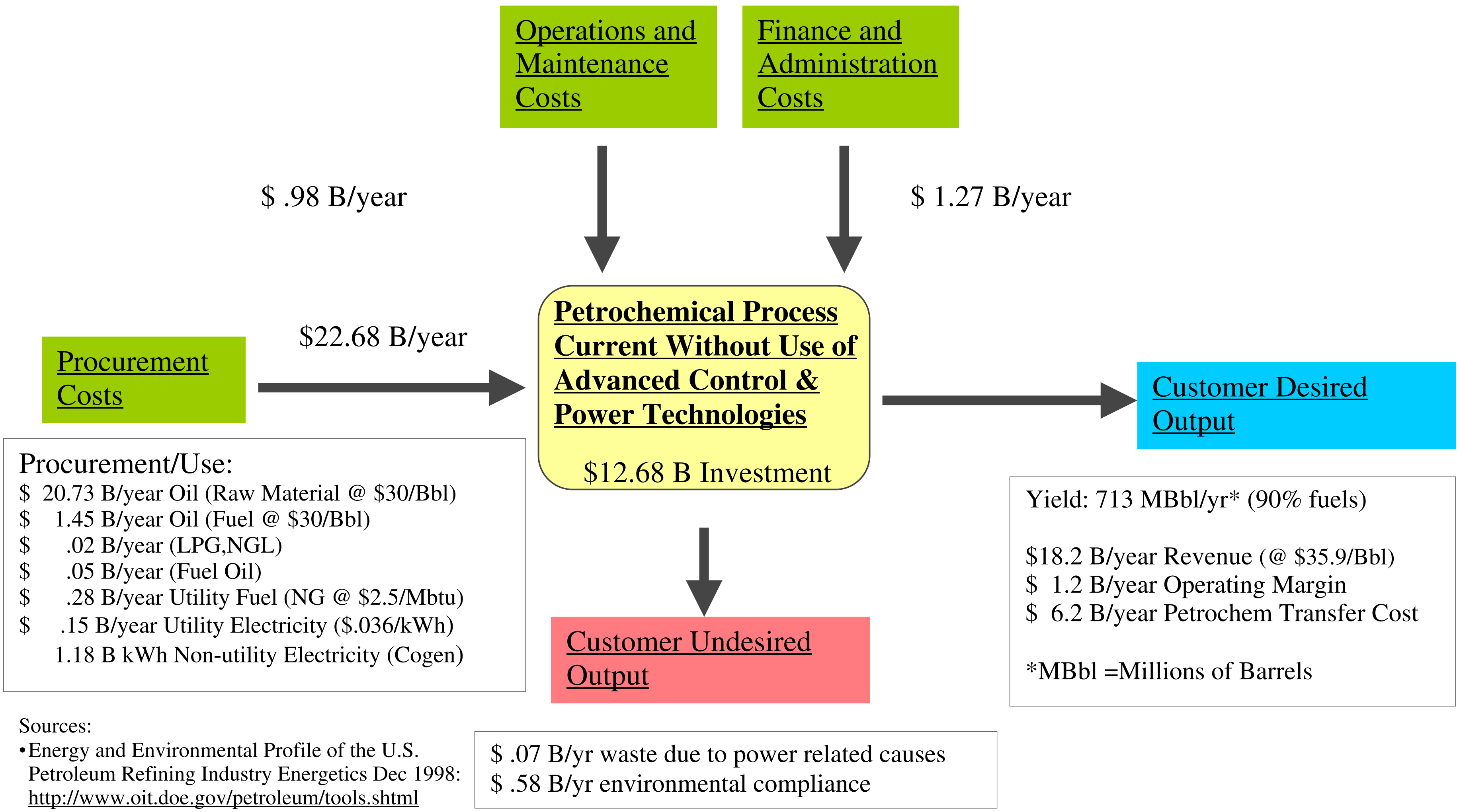
Potential for Energy Savings

Potential savings in energy are measured as an improvement of 644 MW for control and an improvement of 112 MW for power. This is equivalent to eliminating, and thereby saving, 756 MW of generation which can be made available for use elsewhere. This is the same as a continuous electricity supply for 189,000 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 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 the whole refinery. Using the opportunities offered by technology to create full variable speed controlled areas of the refinery would reduce emissions and expand the capacity of the plant even under the stringent existing conditions that apply in California.

Once advanced control and power technologies are implemented, California refineries will benefit from 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
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Figure 4-1
California Petroleum Refining (SIC 29/NAICS 324110). 2002 Industry Baseline (14 Refineries). U.S Data Normalized by California Crude Charge

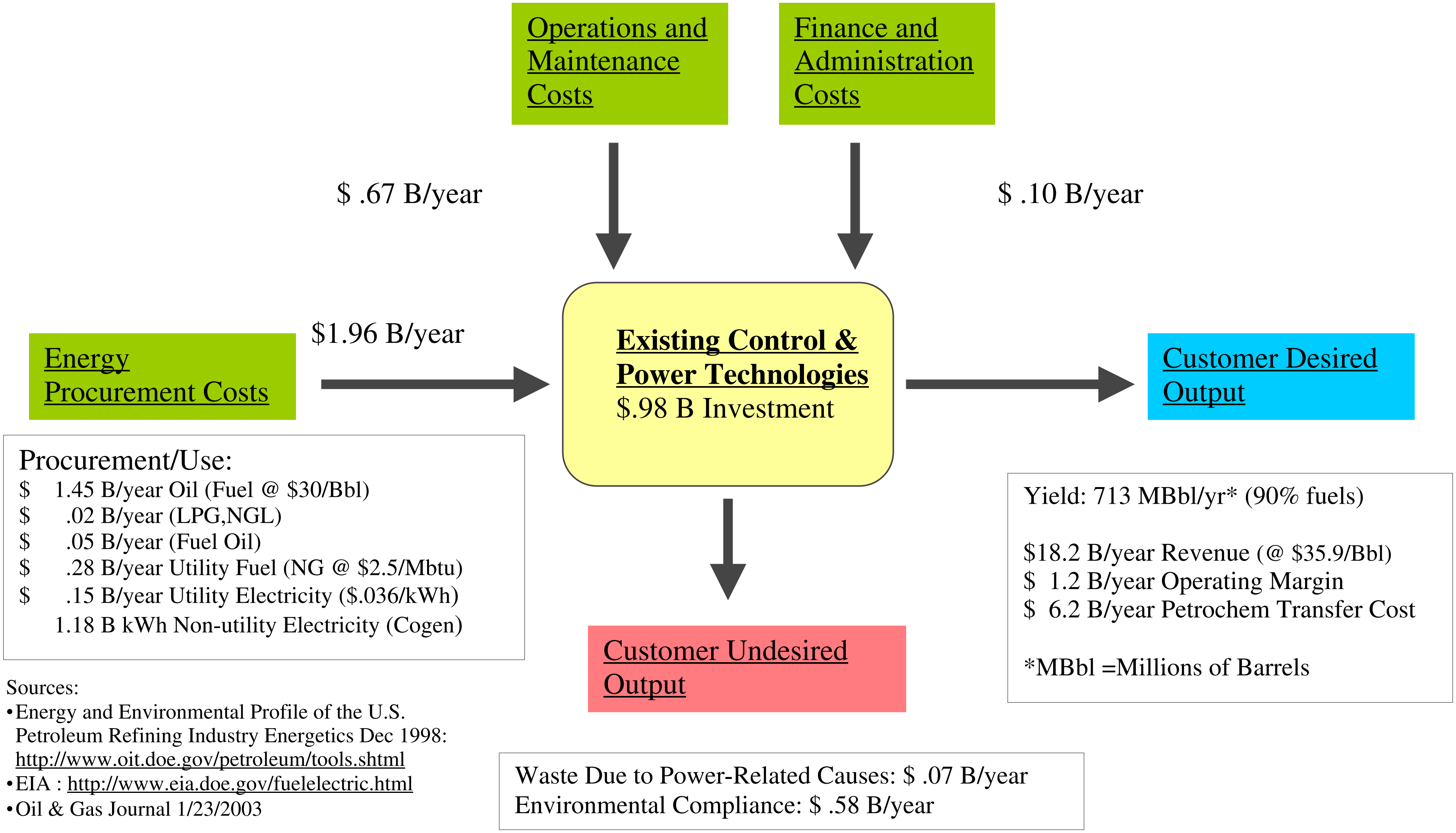
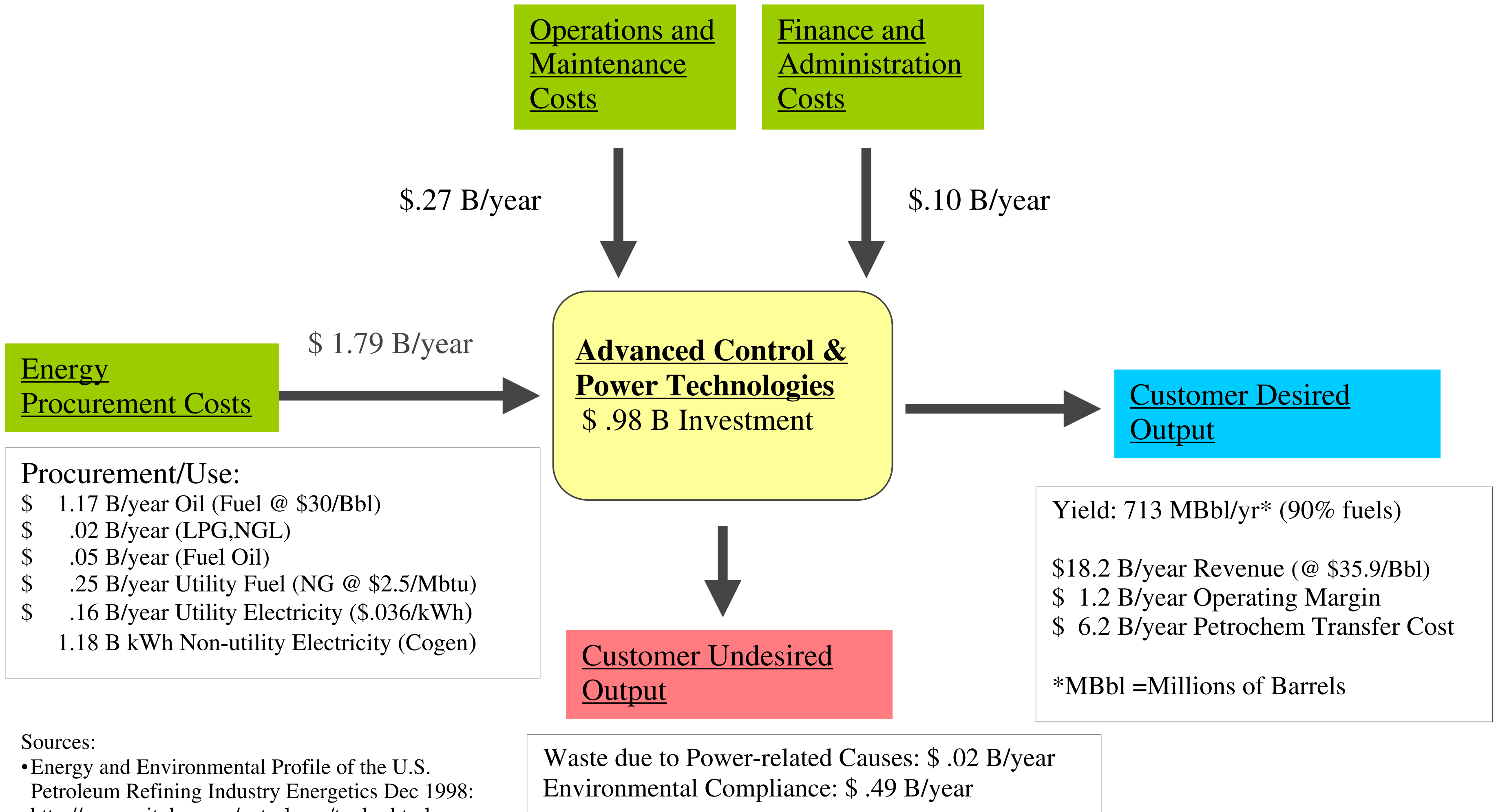


Figure 4-2
California Petroleum Refining (SIC 29/NAICS 324110). 2002 Industry Baseline (14 Refineries). Existing Control & Power Technologies



Sources:
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Figure 4-3
Petroleum Refining (SIC 29/NAICS 324110). Proforma for Year 2015 (14 Refineries). Advanced Control & Power Technologies

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

Technical, Environmental, and Regulatory Barriers

California refineries are faced with stringent environmental and regulatory challenges. Such challenges impact change and potential change. Environmental regulations affect refineries 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. They are associated with pumps and compressors. Each valve is bar coded in order to monitor problems and their solutions.

There is an aversion to mandated change. One can understand a mind set of, "Why put ourselves to the cost and effort of collecting data that may be used to implement ever more changes that will compound the complexity of a business that is already under siege." Mind set and motivation aside, in order to calculate quantitative benefits, data needs to be collected specifically from the process side of the refinery. Several attempts to complete the collection of technical data for the study were well supported at the highest technical levels only to be brought to a halt by the refinery manager who had ultimate authority.

Technically, there is in place optimization of sub systems within refineries but there is no refinery 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 industry.

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.

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.

The refining industry in California is constrained in its ability to implement advanced technical changes by limitations in resources, as described. Local government regulations can override federal regulations and tend to be more stringent. Corporate structures may be dependent upon outsourcing for technical specifications and technical installations. 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 is a common perception that in California there are so many studies undertaken that fitting in yet another is impossible. Refineries indicated there was no margin being reported in refining. Energy was the second highest cost after labor in running a plant. There was, however, acknowledgement that a refinery could be ten years behind a typical petrochemical plant in utilization of control and power technology.

Experiences with drive technology were at best patchy and at worst poor. Reservations were expressed over the size of drives and being able to protect them from the environment. 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.

Technical challenges, business challenges, environmental challenges, and regulatory challenges are considerable in the California refining industry. These challenges are accepted with competence and the industry is powerfully efficient in production. The California refining industry is a behemoth, a veritable juggernaut, and it is has all the strength, commitment, experience, and ability necessary to implement advanced control and power technologies for further energy savings, increased productivity, and improved reliability. These technologies can enable this industry, that is already functioning well, 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 changes to complex infrastructure can be a formidable task.

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. People work better 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.

Financial considerations can be as straightforward as having capital available for use and using it wisely. It 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.

6
CONCLUSIONS

Output from the refinery is of paramount importance. Therefore refineries are very conservative in their acceptance and implementation of new control and power technologies.

1. There is a lack of comfort in the process arena where speed control is introduced. No adequate training has been provided in this concept of hydraulic energy control.

2. The adoption of speed control instead of throttle control is not on the horizon for most process engineers.

3. Power technologies will only be adopted when they provide the same system reliability as fixed speed equipment.

4. A combination of advanced control and power technologies will enhance the refineries' ability to expand capacity even under the intense scrutiny of the local government in California.

5. Poor experiences with early power equipments have affected and still affect adoption of speed control.

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

7. Overall refinery control optimization has not been tackled.

8. Implementation of any advanced control and power must be done well or the consequences will be substantial.

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

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

11. Subcontracting work by the refinery is harming efficiency and operating costs.

12. Conditions in reactors are not fully known.

13. Exothermic energy is not extracted optimally in the majority of refineries.

14. Attention should be focused on developing methods to recover wasted heat in the refinery process. 30% of the energy used in the refinery process is wasted as low-grade heat energy.

15. 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.

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

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

18. The potential for energy savings due to advanced control and power technologies in California refineries is 644MW. This is a conservative projection calculated from the limited process data available for this report.

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

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

21. Minimal sophisticated electrical control has been adopted to some degree in California refineries.

22. Local physical, environmental and legislative constraints significantly impact the operation of the refinery.

23. Recent amalgamation of refineries into large corporate groups has brought increased pressure on individual units.

7 RECOMMENDATIONS

1. In order to achieve energy savings, increased productivity and increased reliability in California Refineries, prudent implementation of advanced control and power technologies is recommended.

2. However, in order to prepare to introduce changes it is strongly recommended that control inventory be obtained from process engineers and that a survey of at least one California 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 Californian site in cooperation with process engineering.

4. Also, it is recommended that this report be considered in conjunction with a similar study, presently underway, of refineries and petrochemical plants in the U.S. outside California.

5. 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.

8
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A
REFINERY 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 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 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 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

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

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.

Distributed Control System

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

Program:
Process Industries

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