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Energy Efficiency Improvement and Cost Saving Opportunities for the Petrochemical Industry

An ENERGY STAR® Guide for Energy and Plant Managers

Maarten Neelis, Ernst Worrell, and Eric Masanet

Environmental Energy Technologies Division

Sponsored by the U.S. Environmental Protection Agency

June 2008

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ABSTRACT

Energy is the most important cost factor in the U.S petrochemical industry, defined in this guide as the chemical industry sectors producing large volume basic and intermediate organic chemicals as well as large volume plastics. The sector spent about $10 billion on fuels and electricity in 2004. Energy efficiency improvement is an important way to reduce these costs and to increase predictable earnings, especially in times of high energy price volatility. There are a variety of opportunities available at individual plants in the U.S. petrochemical industry to reduce energy consumption in a cost-effective manner. This Energy Guide discusses energy efficiency practices and energy efficient technologies that can be implemented at the component, process, facility, and organizational levels. A discussion of the trends, structure, and energy consumption characteristics of the petrochemical industry is provided along with a description of the major process technologies used within the industry. Next, a wide variety of energy efficiency measures are described. Many measure descriptions include expected savings in energy and energy-related costs, based on case study data from real-world applications in the petrochemical and related industries worldwide. Typical measure payback periods and references to further information in the technical literature are also provided, when available. The information in this Energy Guide is intended to help energy and plant managers in the U.S. petrochemical industry reduce energy consumption in a cost-effective manner while maintaining the quality of products manufactured. Further research on the economics of all measures—and on their applicability to different production practices—is needed to assess their cost effectiveness at individual plants.

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1. Introduction

As U.S. manufacturers face an increasingly competitive global business environment, they seek out opportunities to reduce production costs without negatively affecting product yield or quality. Uncertain energy prices in today's marketplace negatively affect predictable earnings, which are a concern, particularly for the publicly traded companies in the petrochemical industry. Improving energy efficiency reduces the bottom line of any petrochemical plant. For public and private companies alike, increasing energy prices are driving up costs and decreasing their value added. Successful, cost-effective investment into energy efficient technologies and practices meets the challenge of maintaining the output of a high quality product despite reduced production costs. This is especially important, as energy-efficient technologies often include "additional" benefits, such as increasing the productivity of the company and reducing the emission of greenhouse gases.

Energy use is also a major source of emissions in the petrochemical industry making energy-efficiency improvement an attractive opportunity to reduce emissions *and* operating costs. Energy efficiency should be an important component of a company's environmental strategy. End-of-pipe solutions can be expensive and inefficient while energy efficiency can be an inexpensive opportunity to reduce criteria and other pollutant emissions. Energy efficiency can be an efficient and effective strategy to work towards the so-called "triple bottom line" that focuses on the social, economic, and environmental aspects of a business[1]. In short, energy efficiency investment is sound business strategy in today's manufacturing environment.

Voluntary government programs aim to assist industry to improve competitiveness through increased energy efficiency and reduced environmental impact. ENERGY STAR®, a voluntary program managed by the U.S. Environmental Protection Agency (EPA), highlights the importance of strong and strategic corporate energy management programs. ENERGY STAR provides energy management tools and strategies for successful corporate energy management programs. The current report describes research conducted to support ENERGY STAR and its work with the petrochemical industry. This research provides information on potential energy efficiency opportunities for companies within the petrochemical sector. ENERGY STAR can be contacted through www.energystar.gov for additional energy management tools that facilitate stronger energy management practices in U.S. industry.

This Energy Guide assesses the energy efficiency opportunities for the petrochemical industry. The U.S. chemical industry is the largest chemical industry in the world. The sector employs nearly 800,000 people and generates product shipments and value added of $416 billion and $295 billion respectively. The petrochemical industry - defined in this Energy guide as facilities involved in the production of basic petrochemicals, other organic chemicals and plastic materials and resins – has a share of about 20% in the number of employees and value added and a share of 30% in the product shipments of the total chemical industry.

[1] The concept of the "triple bottom line" was introduced by the World Business Council on Sustainable Development (WBCSD). The three aspects of the "triple bottom line" are interconnected as society depends on the economy and the economy depends on the global ecosystem, whose health represents the ultimate bottom line.

Energy is a very important cost factor in the chemical industry in general and the petrochemical industry is even more energy intensive than other sub-sectors within the chemical industry. The petrochemical industry is responsible for 70% of the chemical industry's expenditures on fuels and 40% of the expenditures on electricity. The costs of energy and raw materials (which are to a very large extent derived from fossil fuels) are roughly 2/3rd of the total value of shipments of the petrochemical industry. Because energy is such an important cost factor, energy efficiency is a very important opportunity for cost reductions.

The Guide first describes the trends, structure and production of the industry in the United States It then describes the main production processes. Following, it summarizes energy use in the petrochemical industry and its main end uses. Finally, it discusses energy efficiency opportunities for U.S. petrochemical production facilities. The Guide focuses on measures and technologies that have successfully been demonstrated in individual plants in the United States or abroad, but that can still be implemented in other plants. Because the petrochemical industry is an extremely complex industry, this Guide, by definition, cannot include all opportunities for all petrochemical plants. Although new technologies are developed continuously (see e.g. Martin et al., 2000), the Guide focuses on practices that are proven and currently commercially available.

This report aims to serve as a guide for energy managers and decision-makers to help them develop efficient and effective corporate and plant energy management programs through information on new or improved energy-efficient technologies.

2. The U.S. Petrochemical Industry

The United States has the world's largest chemical industry. Within the chemical industry, more than 70,000 diverse compounds are produced with production volumes ranging from a few grams to billions of pounds. Given the diversity of the industry, it can be useful to subdivide the chemical industry into various subcategories. One possible division is the division between the organic and inorganic chemicals industry. In the inorganic chemical industry, chemical products are produced from non-carbon elements taken from the earth such as phosphor (phosphoric acid, phosphates), nitrogen (nitrogenous fertilizers) and chlorine. In the organic chemical industry, hydrocarbon raw materials for the chemical industry are used to produce about 10 base products (that are used as the basis for a multitude of products). Approximately 95% of organic products today are produced from oil and natural gas derived raw materials, with a declining share being produced from coal and an increasing but still very small share from biomass raw materials. The base materials are further processed to various intermediates and final products (e.g. polymers, solvents) by introducing functional groups to the base materials. A figure with the various pathways from basic hydrocarbons to end use polymers is provided in Chapter 3.

The North American Industry Classification (NAICS) distinguishes seven 4-digit sub-sectors of the chemical industry:

3251 Basic chemical manufacturing
3252 Resin, synthetic rubber, and artificial synthetic fibers and filaments manufacturing
3253 Pesticide, fertilizer and other agricultural chemical manufacturing
3254 Pharmaceutical and medicine manufacturing
3255 Paint, coating, and adhesive manufacturing
3256 Soap, cleaning compound, and toilet preparation manufacturing
3259 Other chemical product and preparation manufacturing

Within this 4-digit industry classification, seventeen 5-digit and 34 6-digit industrial sub-sectors are distinguished (Appendix A). This Guide focuses on the production of large volume, energy-intensive basic and intermediate *organic* chemicals including the manufacturing of the large volume plastic materials and resins. The Guide excludes the production of fertilizers and pesticides, industrial gases, inorganic chemicals, pharmaceuticals, paints, soaps and other small volume fine chemicals. The industries on which this guide focuses are classified into the following three 6-digit industries in the NAICS classification:

325110 Petrochemical manufacturing

This industry comprises establishments primarily engaged in (1) manufacturing acyclic (i.e., aliphatic) hydrocarbons such as ethylene, propylene, and butylene made from refined petroleum or liquid hydrocarbon and/or (2) manufacturing cyclic aromatic hydrocarbons such as benzene, toluene, styrene, xylene, ethyl benzene, and cumene made from refined petroleum or liquid hydrocarbons.

325199 All other basic organic chemical manufacturing

This industry comprises establishments primarily engaged in basic organic chemical products (except aromatic petrochemicals, industrial gases, synthetic organic dyes *and pigments, gum and wood chemicals, cyclic crudes and intermediates, and ethyl alcohol).*

325211 Plastic material and resin manufacturing

This industry comprises establishments primarily engaged in 1) manufacturing resins, plastics materials, and non-vulcanizable thermoplastic elastomers and mixing and blending resins on a custom basis, and/or 2) manufacturing non-customized synthetic resins.

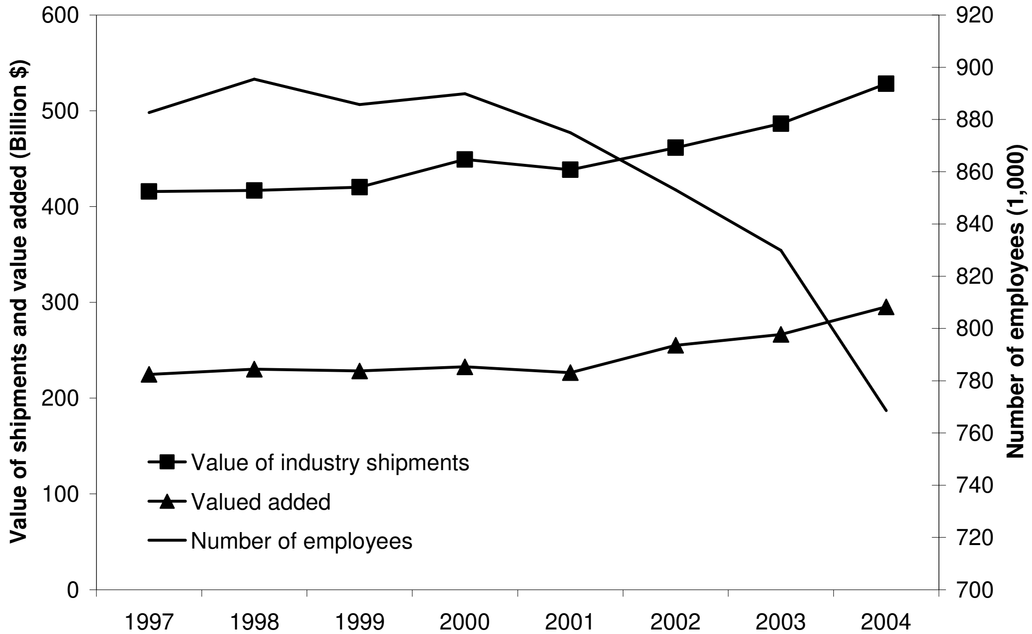
The classification of companies into one of these three NAICS categories is by no means straightforward as a result of the vertical integration of activities on the same site. A company only operating a steam cracker and selling the steam cracker products (ethylene, propylene) will be classified within the petrochemical industry. Another company, operating a steam cracker and converting the main products into basic polymers (polyethylene and polypropylene) will be classified with the resin and synthetic rubber manufacturing industry. In the statistical overviews, this Energy Guide will focus mainly on the sum of the three sectors.

It should further be noted that, although the focus of this guide is on the sectors mentioned above, many of the energy efficiency improvement opportunities mentioned also apply to other parts of the organic (and inorganic) chemical industry. In fact, process integration is an important characteristic of the worldwide chemical industry and some of the companies classified in the sectors cited above are also active in the production of many other organic and inorganic chemicals. As a result, measures such as improvement of energy management systems do apply not only to the petrochemical industry. Several industry examples included in the report are taken from other sub-sectors of the chemical industry.

2.1 Economic Trends for the Total Chemical Industry

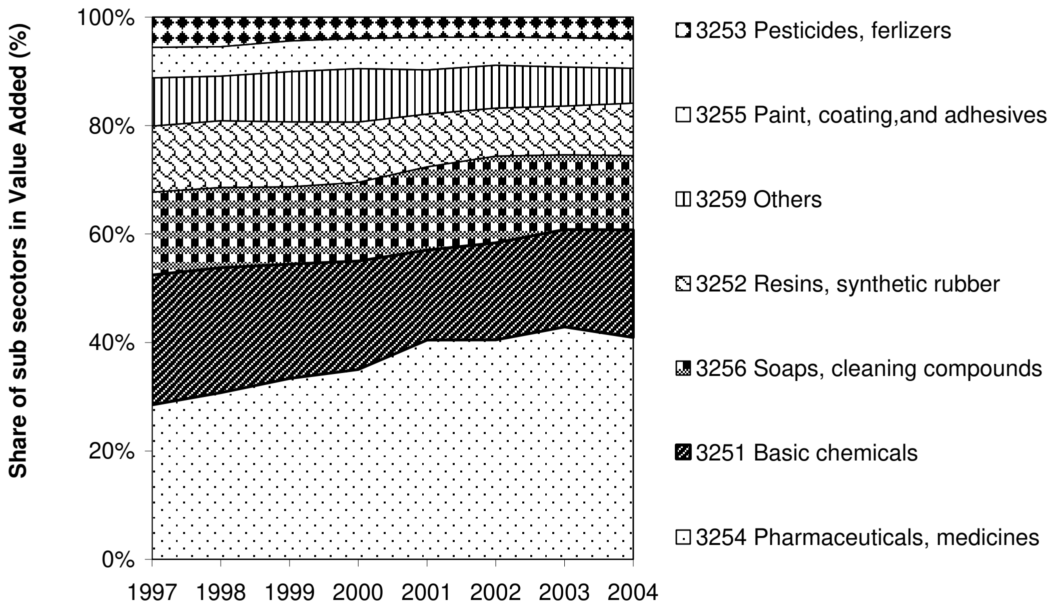
In 2004, the U.S. chemical industry generated $528 billion in product shipments and created a value added of $295 billion (see Figure 2.1). These numbers increased from $416 billion (shipments) and $225 billion (value added) in 1997, an increase of 27 and 31% respectively. The industry creates this value added with a declining number of employees (down from 883,000 in 1997 to 769,000 in 2004). The total number of establishments in 2004 was 13,247 (U.S. Census Bureau, 2006). This number has been quite stable in recent years (13,595 in 1998). Of the 7 four-digit sub-sectors distinguished in the NAICS, the largest and increasing share of value added is created by the pharmaceuticals and medicines sector (30% in 2004), followed by the basic chemical sector (26%) (see Figure 2.2). The share of the sub-sectors in the total energy consumption of the chemical industry is very different compared to the share in total value added and industry shipments as a result of significantly differing energy intensities (see Chapter 4).

Figure 2.1 Value of shipments, value added and number of employees in the U.S. chemical industry.



Source: U.S. Census Bureau (2003 and 2005)

Figure 2.2 Value added by sub-sector of the U.S. chemical industry.



Source: U.S. Census Bureau (2003 and 2005)

2.2 Overview of Relevant Sub-Sectors

The three 6-digit sectors on which this guide focuses employ 19% of the total number of employees in the chemical industry, create 21% of the value added and generate 30% of the total chemical industry shipments (Table 2.1).

Table 2.1 Some key characteristics of the U.S. chemical industry by sub-sector in 2004.

	Number of employees	Value added (billion $)	Total value of shipments (billion $)
325 Total chemical industry	769	295	528
Percentage of total chemical industry	100%	100%	100%
325110 Petrochemicals	8	13	35
Percentage of total chemical industry	1%	5%	7%
325199 All other basic organic chemicals[1]	67	22	60
Percentage of total chemical industry	9%	8%	11%
325211 Plastic materials and resins	58	23	60
Percentage of total chemical industry	8%	8%	11%
Sum of large volume organic chemicals	133	59	155
Percentage of total chemical industry	17%	20%	29%

Source: U.S. Census Bureau (2005). Data on the four 6-digit sectors with the other organic industry (NAICS 32519) were not available for 2004. In 2002, the all other basic organic chemicals manufacturing industry (NAICS 325199) employed about 85% of the total other organic chemical industry (NAICS 32519) and created about 85% of value added and product shipments (U.S. Census bureau, 2004b-e). An 85% share of NAICS sector 325199 is assumed also for 2004.

At the beginning of the chain of organic chemical conversions, basic olefins (ethylene and propylene) and aromatics (benzene) are produced from hydrocarbon feedstocks. The production of these three chemicals from 1975 onwards is shown in Figure 2.3. The production of all three products has more than doubled in this period. On average, annual growth rates in the past 30 years have been 3.1% (ethylene), 4.5% (propylene) and 2.4% (benzene).

Ethylene is produced via steam cracking of hydrocarbon feedstocks such as ethane, propane, butane, naphtha or gasoline. An overview of the steam cracker complexes in the United States is provided in Appendix B. The total capacity for ethylene in the United States is 63.2 billion lbs in 2006. In total, 41 cracker complexes exist in the United States, operated by 16 different companies. The five largest (Chevron Phillips Chemicals, Dow Chemical, Lyondell, ExxonMobil Chemical and Shell Chemicals) together have a share of 67% in total ethylene capacity. Steam crackers can only be found in 6 U.S. states and 95% of the capacity is located in either Texas (71%) or Louisiana (24%). The remaining 5% capacity can be found in single plants in Iowa, Pennsylvania, Kentucky and Illinois. The dominance of Texas and Louisiana is also apparent from the industry statistics for the petrochemical industry (NAICS 32511)[2]. Of the total petrochemical industry shipments of 20$ billion, 90% was generated in Texas and

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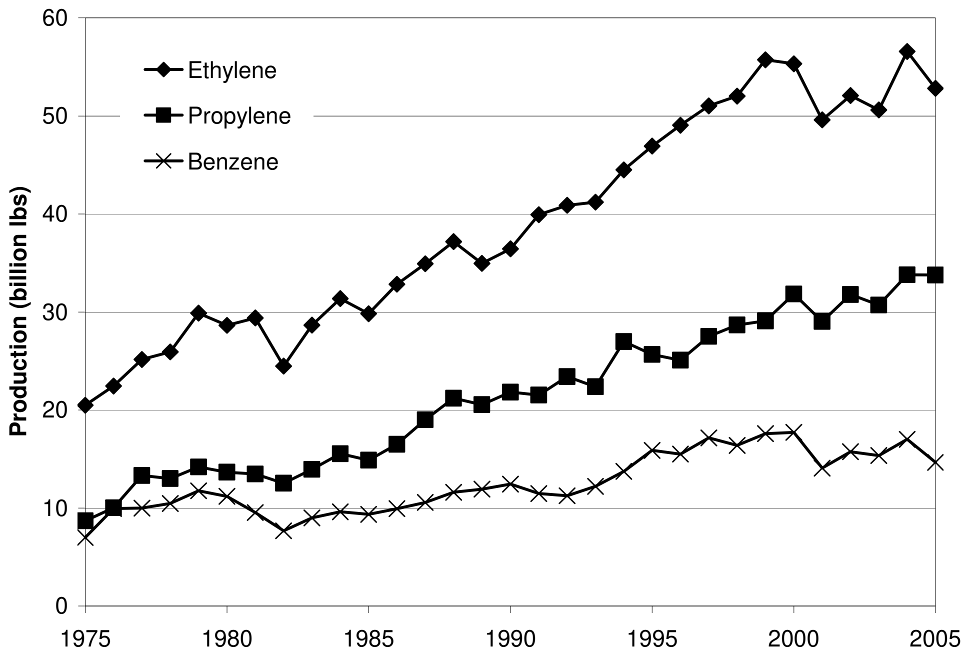
[2] It should be noted that, due to the difficulties with industry classifications in the chemical industry (see section 2.1), most probably not all steam cracker complexes are classified in the petrochemical industry. Some are classified in the other organic chemical industry or the resins and synthetic rubber industry.

Louisiana and establishments in these two states employed more than 80% of the total employees in the petrochemical industry (U.S. Census Bureau, 2004a).

Contrary to Europe, where naphtha is the main feedstock for steam cracking, U.S. cracking complexes use mainly ethane and propane for steam cracking, available as by-products of oil and gas production. Close to 60% of the ethylene capacity is based on cracking of ethane and propane (Oil and Gas Journal, 2006a). Although the Hurricanes Katrina and Rita caused little direct damage to ethylene plants in Louisiana, they caused substantial damage to offshore oil and gas production facilities and to gas processing plants, resulting in feedstock supply difficulties for the olefin industry in 2005 (Oil and Gas Journal, 2006b). In the first quarter of 2006, the sector recovered from this storm damage (Oil and Gas Journal, 2006c), see Figure 2.3.

Figure 2.3 Production of the main basic organic chemicals in the United States, 1975-2005.



Source: Chemical and Engineering News (1985, 1995, 1997, 2006)

Propylene, the other main olefin, is produced in two different ways; as co-product in ethylene production and by petroleum refineries from the fluid catalytic cracking (FCC) off-stream. The amount of propylene produced as co-product in ethylene production depends on the type of feedstock applied. In ethane cracking, the propylene to ethylene production ratio is only 2%. For propane, naphtha and gasoline cracking, this ratio is 27%, 52% and 58% respectively (Neelis et al., 2005a). Given the light feedstock mix in the United States, a relatively small amount of propylene is co-produced in steam crackers compared to e.g. Europe. In the first quarter of 2006, co-product propylene production was 2.9 billion lbs, which is 22% of the total ethylene production of 12.8 billion lbs (Oil and Gas Journal, 2006c). Over the years, demand for propylene has grown faster than the demand for ethylene as shown in Figure 2.3. The propylene to ethylene ratio has gone up from 44% to 64% in the period 1975-2005. The propylene demand not met by steam cracker co-production is met by production of propylene at refineries. In the first quarter of 2006, 3.7 billion lbs of propylene was produced at refineries and 2.9 billion lbs as co-product in steam cracking. Of the refinery propylene, approximately 70% is produced in Texas and Louisiana, 30% in other states (Oil and Gas Journal, 2006c).

1,3 Butadiene is another co-product from steam cracking of heavier feedstocks such as naphtha and is the main basic chemical for the production of synthetic rubber. In 2005, 4.4 billion lbs of butadiene were produced in the U.S (Chemical and Engineering News, 2006).

Aromatics (e.g. benzene, toluene, and xylene) are produced from two main feedstocks: reformates from catalytic reforming in refineries and steam cracker pyrolysis gasoline. Pyrolysis gasoline is only produced in steam crackers when cracking heavier feedstocks such as naphtha and gas oil. As a result of the dominance of ethane and propane as feedstock for steam cracking, the main source for aromatics in the United States is refinery reformate. In the United States, less than 20% of benzene, toluene and xylenes are produced from pyrolysis gasoline from steam crackers (EC-IPPC, 2003) and the remainder from reformate. Of the refinery aromatics, the largest share is produced in Louisiana and Texas, contributing 50% and 14% to the total, respectively (Oil and Gas Journal, 2005). Total production of benzene in the United States in 2005 was approximately 14.8 billion lbs in 2005 (Chemical and Engineering News, 2006). Production of toluene in 2005 was 12.6 billion lbs in 2005, but the majority (76%) of this production is converted to benzene and xylenes (ICIS Chemical Business America, 03/04/2006). Production of p-xylene in 2002 was 8.4 billion lbs (U.S. DOE-OIT, 2004a).

Downstream, the other basic organic chemical industry (NAICS 325199) is more diversified from a product, a company and a geographic point of view. In 2002, Over 450 companies operated 688 establishments, employing 77,000 people, creating a value added of $ 17.8 billion and product shipments of $48.2 billion (U.S. Census Bureau 2004e). Texas and Louisiana are still the largest two states with respect to product shipments, contributing 36% and 14% to the total, but establishments are found in as many as 43 U.S. states (U.S. Census Bureau, 2006). Therefore, the Gulf Coast states are less dominant when compared to the steam cracker industry. The industry produces a wide variety of chemical products including key organic intermediate products such as ethylene dichloride and vinyl chloride (used for polyvinylchloride production) and ethyl benzene and styrene (used for polystyrene production)[3]. The production volumes for some key intermediate organic chemicals in 2005 are given in Table 2.2.

[3] Depending on the main business activity, some companies producing these intermediates can also be classified elsewhere (e.g. when they also produce primary plastics).

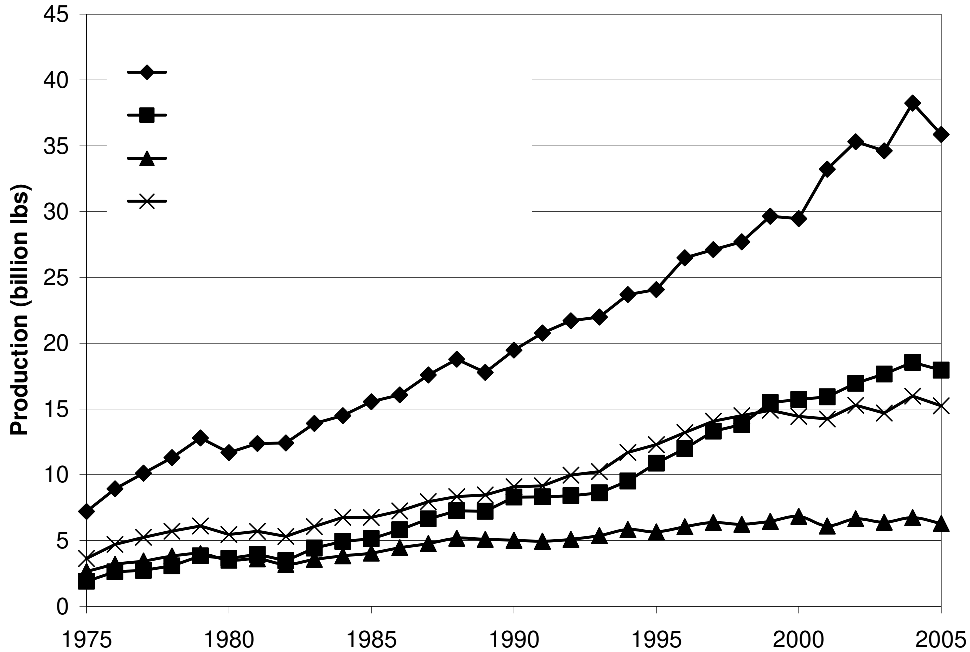
Table 2.2 Production of some key organic intermediate products in 2005.

Chemical	Production volume 2005 (billion lbs)
Ethylene dichloride[1]	24.9
MTBE[2]	19.8
Vinylchloride[3]	17.8
Ethylbenzene[1]	11,6
Styrene[1]	11.1
Formaldehyde[2]	9.3
Terepthalic acid[4]	8.0
Cumene[1]	7.7
Acetic acid[5]	7.6
Methanol[2]	7.3
Ethylene oxide[1]	7.0
Propylene oxide[6]	5.4
Acetone[7]	3.5
Vinylacetate[1]	2.9
Acrylonitrile[1]	2.9

[1] Source: Chemical and Engineering News (2006)
[2] Source: U.S. DOE-OIT (2004a), data for 2002
[3] Source: ICIS Chemical Business America (02/10/2006)
[4] Source: ICIS Chemical Business (16/10/2006), capacity data
[5] Source: ICIS Chemical Business America (06/03/2006)
[6] Source: Chemical Business (18/09/2006), capacity data
[7] ICIS Chemical Business America (27/03/2006)

Polymers are a major end-product of the chemical industry. In 2002, 442 companies in the plastic materials and resin industry (NAICS 325211) operated 688 establishments, employed 68,000 employees, and generated product shipments and value added of $47.9 billion and $17.1 billion respectively (U.S. Census Bureau, 2004f). Establishments exist in almost all U.S. states (U.S. Census Bureau, 2006a) with Texas and Louisiana contributing 38% and 9% to the total shipments of the industry. The industry produces a wide variety of polymeric products. An overview of the production volumes of the four largest volume polymers (polyethylene, polypropylene, polystyrene and polyvinylchloride) from 1975-2005 is shown in Figure 2.4. The production of polymers is still growing rapidly. Between 1975 and 2005, average annual growth rates have been as high as 5.3% (polyethylene), 7.5% (polypropylene) and 4.7% (polyvinylchloride). Growth in polystyrene has been slightly lower (2.8%). The four products together represent 57% of the total plastic material and resin shipments (Table 2.3), the remaining shipments consisting of various other thermoplastic and thermosetting polymers.

Figure 2.4 Production of the main large volume polymers in the United States.



Source: Chemical and Engineering News (1985, 1995, 1997, 2006)

Table 2.3 Product shipments of the plastic materials and resin industry in 2002.

Product	Shipments ($ billion)	Percentage of total
Thermoplastic resins	**37.7**	**83%**
- Polyethylene	11.6	25%
- Polypropylene	5.8	13%
- Polystyrene	2.7	6%
- Polyvinylchloride	6.1	13%
- Polyester	2.3	5%
- Other thermoplastic resins	8.9	20%
- Thermoplastics resins, not specified	0.3	1%
Thermosetting resins	**7.3**	**16%**
- Phenolic	2.0	4%
- Urea	0.4	1%
- Polyester	1.6	4%
- Epoxy	1.1	2%
- Others	2.1	5%
- Thermosetting resins, not specified	0.1	0%
Plastic materials, not specified	**0.6**	**1%**
Total	**45.6**	**100%**

Source: U.S. Census Bureau (2004f)
Note: Included are shipments of these products produced by industries classified elsewhere.

2.3 Imports and Exports

The U.S. chemical industry has a small net importing position. Exports for the total chemical industry amounted to $108 billion in 2004 (U.S. Census Bureau, 2006b), about 25% of the industry shipments and imported $118 billion. Major export partners for U.S. chemicals are Canada (18%) and Mexico (10%), followed by the Netherlands and Belgium (the main European ports for chemicals) and Japan (6%). Main countries from which the U.S. chemical industry imports products are Ireland (16%), Canada (13%), Germany (9%), the UK (8%) and Japan (7%).

Table 2.4 provides an overview of imports and exports of the organic chemical industry. The petrochemical industry (NAICS 325110) exports about 5% of its shipments and is overall a net importer of products. Main source countries for imports of this industry are Algeria, Saudi Arabia, Canada and Iraq, supplying feedstock to the U.S. petrochemical industry. These countries are together responsible for about 60% of the total imports of the petrochemical industry. The more downstream organic chemical sectors have a net exporting position and export a much larger part of their product shipments (approximately 40%).

Table 2.4 Imports and exports of the organic chemical industry in 2004.

Industry	Shipments ($ billion)	Export ($ billion)	Import	Net export
325 Total chemical industry	416	108	118	-10
325110 Petrochemicals	19	1	7	-6
325199 All other basic organic chemicals	52[1]	22	16	6
325211 Plastic materials and resins	45	17	8	9

Source: U.S. Census Bureau (2005 and 2006b).
[1] Estimated as 85% of the shipment of the other organic chemical industry (NAICS 32519), see Table 2.1.

2.4 Outlook and Key Drivers and Challenges for the Petrochemical Industry

Globally, the outlook for the petrochemical industry is very good. Ethylene production capacity has grown by as much as 4% in 2005 and, in general global demand growth for the key petrochemical products is high. In fact, '*chemical companies generally continued to enjoy increases in output last year. Production of most chemical rose … and so did the fortunes of major chemical-producing countries*' according to Chemical Engineering News in its facts and figures for 2005. In the United States, the petrochemical industry suffered from the hurricanes in 2005 with output of ethylene, ethylene dichloride, ethyl benzene and ethylene oxide dropping by 6.7%, 7.0%, 9.1% and 16.1% in 2005 compared to 2004 (Chemical Engineering News, 2006). However, the industry has turned back to normal operation in 2006.

Basic petrochemical products are sold on chemical specification rather than on brand name. Like other commodities, the basic petrochemical business is therefore characterized by a very strong competition on price and profit margins are generally small. Controlling production costs is key in maintaining its competitive position. Raw material and energy costs represent a large share of production costs and product price are therefore largely influenced by oil and gas prices. Traditionally, the profitability of the large volume organic chemical industry is very cyclical, driven by normal commercial demand cycles, but also accentuated by the high capital investment costs of installing new technology. Companies tend to invest only when their cash flow is good and the long lead times before new plants come online results in over-capacity that temporarily depresses cash margins (EC-IPPC, 2003).

In the United States, demand growth is more moderate compared to the global average. Still, demand is expected to grow substantially with annual projected growth rates typically ranging between 0.5 and 3% until 2009 (ICIS Chemical Business America, various issues). Domestic production has, however, to compete with low-cost production abroad. Global ethylene demand growth is for example mainly met by increased capacity in the Middle East, where companies have access to cheap feedstock. It is expected that he Middle East will be the sole net ethylene exporter by 2010 and the North American region will become a net importer of ethylene by 2009. No new ethylene capacity is scheduled in the United States until 2010 (Oil and Gas Journal, 2006). Concern for long-term affordable feedstock limits new investments in the United States and it is expected that the ethylene and ethylene derivatives business will change, because new investments based on cheap natural gas will mainly be made in the Middle East, Asia and the Caribbean region (ICIS Chemical Business America, 31/07/06).

3. Process Description

Despite the complexity and diversity of the petrochemical industry it is possible to divide most production processes into five subsequent process steps (EC-IPPC, 2003):

1. Supply and preparation of the raw materials.
2. Synthesis of the crude product from the raw materials via one or more chemical reactions and
3. Separation and refinement of the desired product from the crude product stream
4. Storage, packaging and shipment of the product
5. Abatement of emissions and waste streams

The core step in each process is the synthesis step where the raw material is transformed to the crude product stream by means of one or more chemical reactions. The raw materials are supplied from other on-site processes or delivered to the site by train, truck or pipeline. Using a variety of unit operations (e.g. distillation, filtration and evaporation), the product is separated from the crude product. Unconverted raw materials are returned to the reactor and waste streams are abated (e.g. by using them as fuel to produce steam and/or power).

3.1 Chemical Reactions

According to U.S.-EPA (1993), between 30 and 35 types of chemical reactions are used to produce 176 high-volume chemicals. Some reactions (e.g. oxidations and halogenations) are used to produce multiple products, whereas some are only used to produce one or two chemicals. An overview of key products is presented in Table 3.1.

Table 3.1 Chemical reaction types.

Reaction type	Number of chemicals [1]	Reaction type	Number of chemicals[1]
1 Pyrolysis	7	16 Oxidation	4
2 Alkylation	13	17 Hydrodealkylation	2
3 Hydrogenation	13	18 Isomerization	3
4 Dehydration	5	19 Oxyacetylation	1
5 Hydroformylation	6	20 Oligormerization	7
6 Halogenation	23	21 Nitration	3
7 Hydrolysis/Hydration	8	22 Hydrohalogenation	2
8 Dehydrogenation	4	23 Reduction	1
9 Esterification	12	24 Sulfonation	4
10 Dehydrohalogenation	1	25 Hydrocyanation	2
11 Ammonolysis	7	26 Neutralization	2
12 Reforming	4	27 Hydrodimerization	1
13 Oxyhalogenation	1	28 Miscellaneous	6
14 Condensation	12	29 Nonreactor processes[2]	26
15 Cleavage	2		

Source: U.S. EPA (1993), based on a source from the early 1980s.
[1] Ranking by amount of production for each chemical reaction type.
[2] Produced by air oxidation, distillation, or other non-reactor processes not covered in the U.S. EPA study.

While section 3.4 provides a detailed description of these reactions and the main processes in which they are applied, more detailed process descriptions can be found in U.S EPA (1993) and EC-IPPC (2003). Chemical reactions are the core of every process and there is a wide array of different reactor types. This is no surprise given the diversity of chemical reactions carried out. In EC-IPPC (2003), reactors are broadly classified by:

- Mode of operation (continuous or batch). Most processes in the large volume organic chemical industry are continuously operated reactors.
- Reaction phase. Reactions can be carried in different phases (gas, liquid, solid). In many cases, catalysts are applied to improve selectivity and/or conversion efficiency. These catalysts can either be homogenous, i.e. in the same phase as the reactants and products, but are mostly heterogeneous (e.g. liquid-solid or gaseous-solid).
- Reactor geometry – the flow pattern and manner of contacting the phases.

The actual design of a reactor will take into account various factors such as process safety, process chemistry including kinetics and heat transfer. Some reactions are exothermic and release energy, whereas others are endothermic requiring energy. Temperature control is important to avoid the formation of undesired by-products and for safety reasons. Hence, reaction sections are often equipped with heat exchangers.

3.2 Unit Operations

Unit operations deal with the physical transfer of energy and materials between process flows in their various states: gas-gas, gas-liquid, gas-solid, liquid-liquid, liquid-solid, and solid-solid. The various unit operations differ in the frequency they are used. Some (like distillation) are used in almost every process in the petrochemical industry, whereas others (like the separation of solids from gaseous streams) are only applied in a few selected processes.

An important category of unit processes are separation processes. The reactions carried out in the core step of the production process are never 100% selective towards the desired products. Also, they are often not carried out to 100% conversion, because of reaction kinetics or to avoid the formation of undesired by-products. Therefore, there is a substantial need for separation processes to separate the main product from by-products and to separate products from unconverted raw materials. Separation techniques can be split into the following categories (EC-IPPC, 2003):

- Liquid-vapor separation (distillation, evaporation, stripping)
- Liquid-liquid separation (extraction, decanting)
- Solid-liquid separation (centrifugal, filtration)
- Solid-gas separation (filtration)
- Solid-solid separation (screening, gravity)

In separation techniques, the different products are separated based on different physical properties such as boiling and melting point, solubility or molecule diameter (in molecular sieve separations).

Important unit operations from an environmentally point of view that are widespread in the large volume organic chemical industry include distillation, extraction, absorption, solids separation, adsorption and condensation (EC-IPPC, 2003). *Distillation* is the most widespread separation technique in the organic chemical industry. Products are separated based on their difference in boiling points. The starting mixture is separated into two fractions: a condensed vapor that is enriched in the more volatile components and a remaining liquid phase that is depleted of these components. Distillations can be divided into subcategories according to the operating mode (batch or continuous), operating pressure (vacuum, atmospheric or pressurized), number of stages, the use of inert gases, and the use of additional compounds to aid separation (U.S. EPA, 1993). At the bottom of the distillation tower, energy is required for evaporation and at the top of the column, condensation energy is available. This offers opportunities for optimization the energy flows of the process (see Chapter 14). Sometimes, distillation is not a suitable separation method, because the boiling points are too similar or because the starting mixture contains an azeotrope. In these cases, *extraction* can be a suitable separation technique. It is the most important liquid-liquid separation process and involves dissolving components in an extraction solvent. In many cases, extraction is used in combination with distillation, for example in the production of aromatics (EC-IPPC, 2003). *Absorption* is the uptake of a substance into another, e.g. gaseous emissions into a solvent. *Solids separations* are important in product finishing and in avoiding emission of solid particles. Typical technologies include cyclones, fabric filters, and dust separation equipment (EC-IPPC, 2003). *Adsorption* is the accumulation of material onto the surface of a solid adsorbent, such as zeolites or other molecular sieves. *Condensation* can be used to separate liquid or solids by fractional condensation from a gas stream.

3.3 Supporting Equipment and Infrastructure

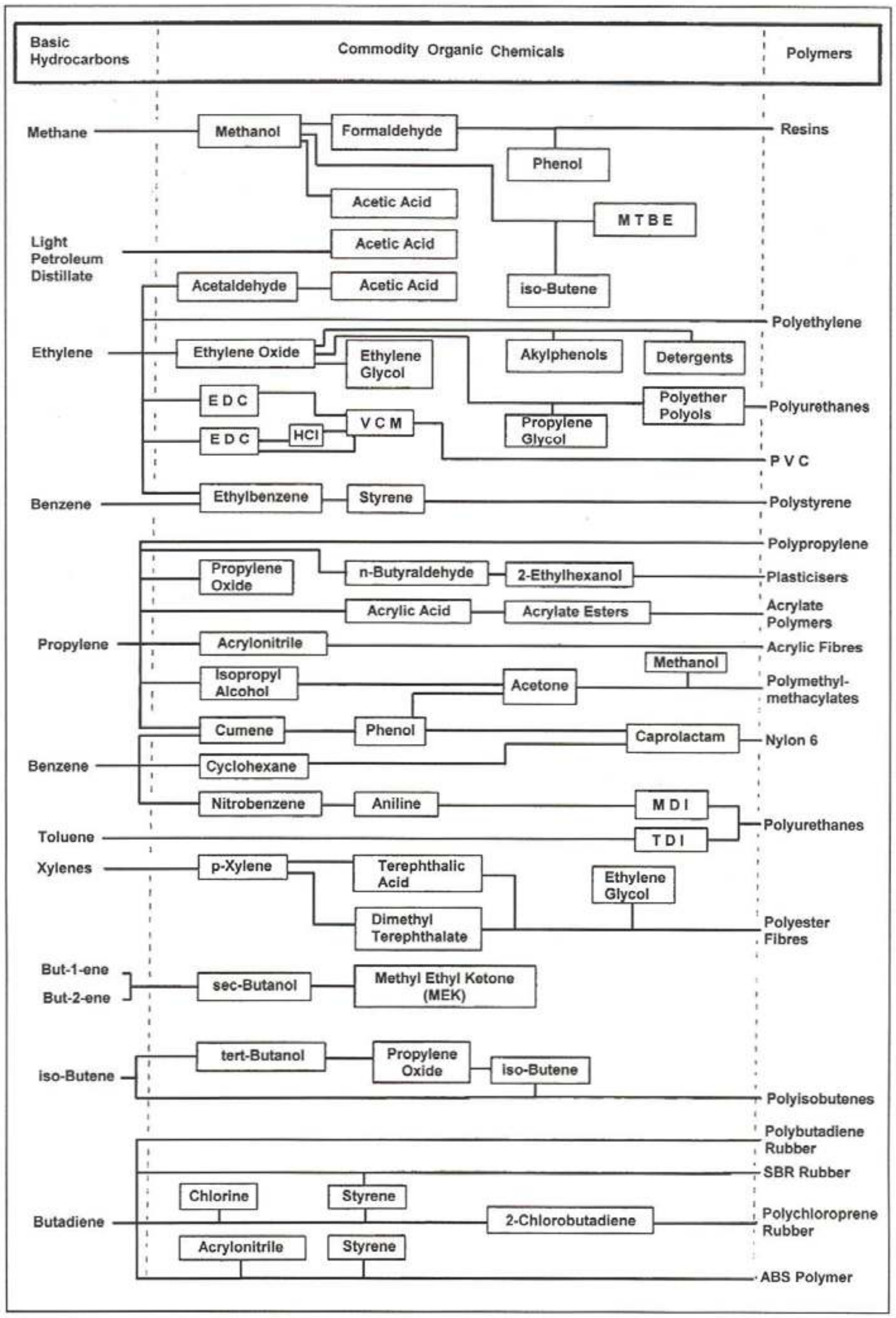
The various process units of an organic chemical process are interconnected by a complex infrastructure dealing with the transfer of materials and heat from one unit to another and with bringing materials to the temperature and pressure levels required for the various operations. Typical equipment used in the supporting infrastructure include:

- Emission abatement equipment.
- Product storage and handling equipment
- Boilers, Combined Heat and Power (CHP) plants and other parts of the steam infrastructure including pipes and valves (Chapter 7).
- Furnaces and process heaters (Chapter 8).
- Pumps, compressors, vacuum, pressure relief equipment and fans (Chapter 10 -13).
- Heat exchangers, cooling and refrigeration (Chapter 9).

3.4 Short Description of the Most Important Processes

Figure 3.1 gives an overview of the processing pathways from the basic hydrocarbon products to intermediates and polymer end-products. In addition, also other end-products (e.g. solvents) are produced from the basic petrochemical products.

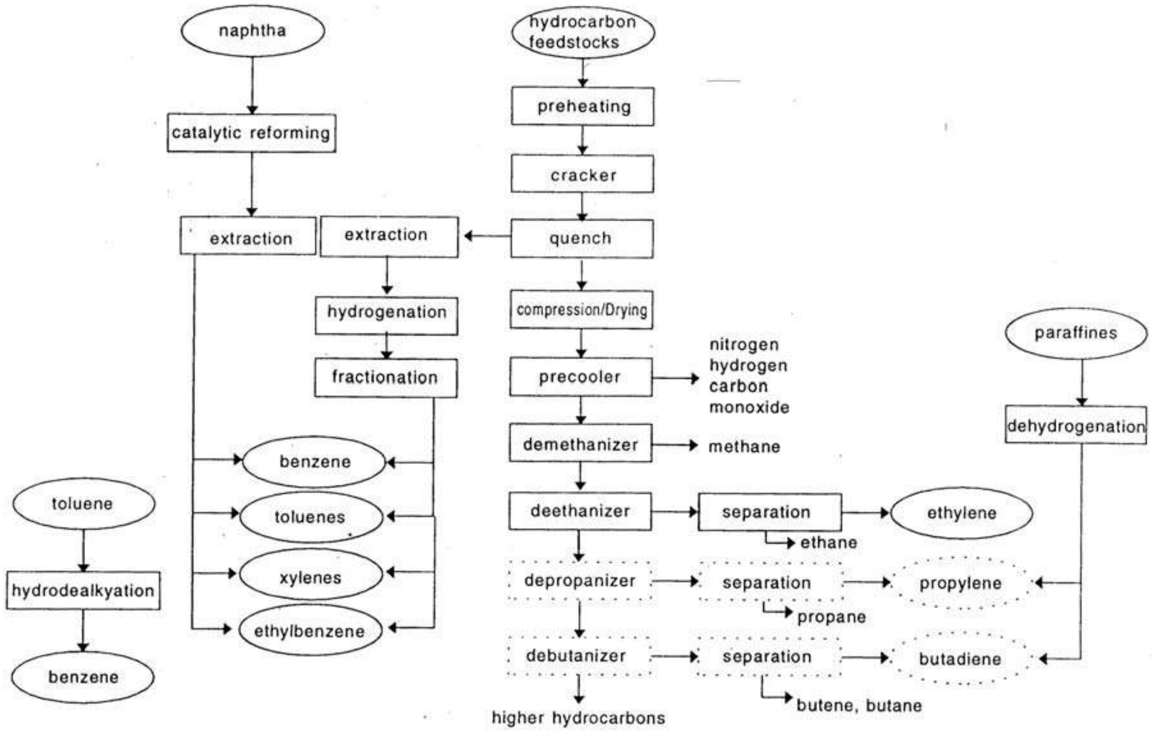
Figure 3.1 Pathways from basic hydrocarbons to polymers.



Source: EC-IPPC (2003)

Production of basic chemicals from hydrocarbon feedstock. The most important building blocks of the petrochemical industry are olefins (ethylene, propylene, butylenes and butadiene) and aromatics (benzene, toluene, xylenes) produced from hydrocarbon feedstocks such as ethane, naphtha, gas oil or aromatic mixtures from catalytic reforming in refineries. The main production routes for these building blocks are provided in Figure 3.2.

Figure 3.2 Process blocks for the production of petrochemical building blocks.



Source: Phylipsen et al. (1998)

Ethylene, propylene, butylenes and butadiene. Worldwide, practically all ethylene and, depending on the country, also a large fraction of propylene, butylenes and butadiene is produced by steam cracking of hydrocarbon feedstocks (e.g. ethane, naphtha, gas oil). A small number of international technology contractors license the main equipment used in steam cracking such as Technip-Coflexip, ABB Lummus, Linde AG, Stone and Webster and Kellog Brown & Root (Hydrocarbon Processing, 2005a). The choice for a particular feedstock, together with the processing conditions (e.g. the steam dilution rate), determine the yield of ethylene, propylene and other co-products in steam cracking. Table 3.3 shows the variation in product yields with the feedstock used. A typical steam cracker is comprised of three sections: Pyrolysis, Primary fractionation / compression and product recovery / separation (EC-IPPC, 2003). In the pyrolysis section the hydrocarbon feedstock is cracked in tubes arranged in cracking furnace. The tubes are externally heated to 750-875ºC (1380-1610°F) by gas or oil-fired burners. After rapid quenching via transfer line heat exchangers (TLE) to avoid further reaction (a process in which high pressure steam is generated), the condensable fuel oil fraction is separated in the primary fractionation. Primary fractionation is only applied in naphtha and gas-oil crackers. In the product fractionation section ethylene, propylene and other products are separated in a fractionation sequence that differs from plant to plant and is different for various feedstock types. A typical configuration is shown in Figure 3.2. The product fractionation takes place at very low temperature (down to -150ºC, or -240°F) and elevated pressures (Ren et al., 2006) and involves de-methanization (removal of methane), de-ethanization (removal of ethane, ethylene) and de-propanization and de-butanization. The lighter the feedstock, the less need for the latter separation systems.

Table 3.3 Influence of feedstock on steam cracker yield (in lb for 1000 lb of feedstock).

	Ethane	Propane	Butane	Naphtha	Gas oil
High value chemicals	842	638	635	645	569
Ethylene	803	465	441	324	250
Propylene	16	125	151	168	144
Butadiene	23	48	44	50	50
Aromatics	0	0	0	104	124
Fuel grade products	157	362	365	355	431
Hydrogen	60	15	14	11	8
Methane	61	267	204	139	114
Others	32	75	151	200	304
Losses	5	5	5	5	5

Source: Neelis et al. (2005a)

In contrast to many other parts of world (e.g. Europe and Japan), ethane and propane are the most important feedstocks for steam cracking in the United States (approximately 60% of ethylene capacity). Because relatively little propylene, butylene and butadiene is produced in ethane and propane cracking, these products are in the United States produced via other processes. More than half of U.S. propylene is produced from propylene rich streams from refineries such as Fluidized Catalytic Cracker off-gas. Another process used in the United States to produce propylene is the methathesis of ethylene and n-butenes, e.g. using Lummus' Olefin Conversion Technology (Hydrocarbon Processing, 2005a). The source for the n-butenes can be the steam cracker C_4 stream and methathesis can it that case be regarded as a process to improve propylene yield in steam cracking. Propylene and Butylene are also be produced by dehydrogenation of propane and butane respectively. The latter process, starting with iso-butane as raw material, is used, for the production of isobutylene for Methyl-Tertiary-Butyl-Ether (MTBE) or Ethyl-Tertiary-Butyl-Ether (ETBE) production.

Benzene, toluene and xylenes production. The key aromatic building blocks benzene, toluene and xylenes are produced from three different sources. The two main sources are pyrolysis gasoline from the steam cracking process and reformates from catalytic reforming in refineries. An additional minor source is coke oven light oil from coke production (Krekel et al., 2000). In the United States, 15% of benzene is separated from pyrolysis gasoline, 50% from reformate and the remainder from hydro-dealkylation and toluene disproportionation (see below). Toluene is for 85% produced from reformate, as are xylenes (EC-IPPC, 2003). The amount and composition of pyrolysis gasoline (pygas) differ extensively with the type of feedstock applied and with the operating conditions in the cracker. With light feedstocks (e.g. light condensates and ethane), small amounts of pygas are produced with high benzene content, but almost no C_8 aromatics. With heavier feedstock, larger amounts of pygas are produced containing also substantial amounts of C_8 aromatics. In benzene extraction from pyrolysis gasoline, the feedstock is first hydrogenated to remove the unsaturated olefins and di-olefins and compounds containing sulfur, nitrogen and oxygen, resulting (after separation of lights and heavies) in a product stream containing 40% benzene and 20% toluene (EC-IPPC, 2003). In a second step, benzene is extracted, leaving a benzene free octane blend stock for the gasoline pool (Krekel et al., 2000). Since the aromatic content of gasoline is bound to certain limits and since there is a need for pure aromatic products as petrochemical building blocks, it is often beneficial to further reduce the aromatic content by extracting toluene and xylenes in additional extractive distillation units using solvents such as sulfolane.

In aromatics production from reformate, the reformate is split into three aromatic cuts (C_6/C_7, C_8 and C_9). The C_6/C_7 cut is used for benzene and toluene production. The C_8 cut is used as the source for p-xylene, which is separated by means of adsorption or crystallization. In some cases also other xylenes are extracted. These standard process configurations can be modified in order to meet market needs by converting some of the products into more beneficial ones using chemical conversion steps. The majority of toluene is for example converted to benzene using hydro-dealkylation and xylene isomerisation is used to convert o- and m-xylene into p-xylene (EC-IPPC, 2003). Extraction technologies for the separation of the various aromatics from non-aromatics have a long history. Liquid-liquid extraction and especially extractive distillation are very flexible technologies that can be adapted to challenges imposed by legislation (e.g. aromatics and gasoline) and varying market demand (Krekel et al., 2000).

Main products in the ethylene chain. The majority of ethylene (over 50%) is used for the production of *polyethylene* (U.S. DOE-OIT, 2000a). Several types of polyethylene can be distinguished such as low density polyethylene (LDPE), linear low density polyethylene (LLDPE) and high density polyethylene (HDPE). LDPE is either produced in tubular or autoclave reactors at very high pressures (up to 3500 bar for a tubular reactor) at moderate temperatures up to 340ºC (550°F). LLDPE is used either in gas-phase or in a solution reactor at temperatures around 100ºC (120°F) and pressures up to 20 bar and HDPE is produced in gas-phase reactor or slurry reactors at about the same operating conditions (EC-IPPC, 2006).

Another main product produced from ethylene is *polyvinylchloride (PVC)* produced via *ethylene dichloride (EDC)* and *vinylchloride monomer (VCM).* EDC is synthesized from ethylene by chlorination of ethylene with chlorine (operating temperatures 50-120ºC (120-250°F), pressure up to 5 bar) or oxychlorination with oxygen and hydrochloric acid (220–250ºC (430-480°F), 2 – 6 bar). After purification, the ethylene dichloride is thermally cracked at 500ºC (930°F) to produce vinyl chloride monomer. VCM is converted to PVC at 4 -12 bar and 35-70ºC (95-160°F) in a suspension process with a small fraction produced via an emulsion process for specialty applications (EC-IPPC, 2003).

Other important products produced from ethylene are *ethyl benzene* (discussed below as part of the aromatics chain) and *ethylene oxide (EO) / ethylene glycol (EG).* EO/EG have an extensive number of applications in the polyester and surfactants industry and is produced via oxidation of ethylene with pure oxygen (air in older units). In most EO process lay-outs, EG (produced by reacting ethylene oxide with water) is produced as part of the same production unit. Other less important derivatives from ethylene with respect to production volume include *vinyl acetate* produced from ethylene and acetic acid.

Main products in the propylene chain. Approximately 50% of all propylene is used to produce *polypropylene* (U.S. DOE-OIT, 2000a). Polypropylene is produced in either suspension or gas phase processes at moderate temperatures (below 100ºC or 212°F) and at pressures up to 50 bar (EC-IPPC, 2006).

Propylene oxide is another important propylene derivative and can be produced in two ways. Before 1969, almost all propylene oxide was produced via the chlorohydrin route. In this process, propylene, water and chlorine react to propylene chlorohydrin. This product is steam-heated and contacted with a lime slurry to produce propylene oxide The second process is based on the peroxidation of propylene. In this process oxygen is used to oxidize isobutene or ethyl benzene to a hydroperoxide. This hydroperoxide reacts with propylene to form propylene oxide and an alcohol by-product, which in the case of ethyl benzene as raw material can be converted to styrene. The division between the two processes in the United States is about 50/50 (U.S. DOE-OIT, 2000f).

Another main product in the propylene chain is *acrylonitrile*, produced by reaction propylene with ammonia in the BP/Sohio process at 400-500ºC (750-930°F) at slightly elevated pressures of 1.5 – 2.5 bar. The reaction is highly exothermic and the selectivity of the catalyst applied has improved steadily to over 75% currently (EC-IPPC, 2003).

Main products in the aromatics chain. The main use of benzene is for the production of *ethyl benzene*, which is almost exclusively used to produce *styrene*. Styrene is used to produce *polystyrene* and other styrene co-polymers. Ethyl benzene is produced from ethylene and benzene in liquid and vapor phase alkylation reactors and as co-product in propylene oxide production (see above). Styrene is produced via dehydrogenation of the ethyl benzene at temperatures of 650ºC (1200°F) and higher. In many units, ethyl benzene and styrene production are combined to allow making use of the energy exported during ethyl benzene manufacture in styrene production. Polystyrene is produced in either continuous stirred tank reactors or batch-operated suspension reactors in the case of expandable polystyrene. Polymerization temperatures are between 65 and 180ºC (150-360°F) and pressures up to 20 bars (EC-IPPC, 2006).

Cumene is another important derivative of benzene (approximately 20% of benzene consumption) and is produced via alkylation of benzene with benzene using zeolitic catalysts (U.S DOE-OIT, 2004a, Hydrocarbon processing, 2005a). Most cumene is converted to *phenol* and *acetone*. In the first stage of this process, cumene is oxidized with air to form a hydroperoxide. This peroxide is in a second stage catalytically decomposed into phenol and acetone (U.S. DOE-OIT, 2000a). A third important derivative of benzene is *cyclohexane* produced via hydrogenation of benzene over a nickel or platinum catalyst and is used for the production of adipic acid and caprolactam.

Toluene, which is not converted to one of the other aromatics, is mainly used for the production of solvents and *toluene diisocyanate (TDI).* Minor uses include benzoic acid, benzyl chloride and benzoic acid. TDI is produced using a complex process configuration including the production of phosgene. The process involves three steps: nitration of toluene, hydrogenation of the resulting dinitrotoluene to toluene diamine and phosgenation of toluene diamine to TDI.

The main derivative of p-xylene is *terephthalic acid*, produced through oxidation of p-xylene over heavy metal catalysts. Terephthalic acid is used for the production of polyesters. Other important derivatives from xylenes are *dimethylterephthalate* (from p-xylene) and phthalic anhydride (from o-xylene) used in the production of plasticizers.

Other large volume products. Next to the large volume organic chemical derived from olefins and aromatics, there are also some key chemical derived from *methanol*. Methanol is mainly produced by steam reforming of natural gas followed by methanol synthesis over a copper catalyst. A large fraction of methanol is used for the production of *formaldehyde*. Formaldehyde is produced by catalytic oxidation under air deficiency (silver process) or air excess (oxide process). In Europe, the production is roughly split equally between the two routes, the division for the United States is not known.

4. Energy Consumption in the U.S. Petrochemical Industry

The chemical industry is one the largest energy consuming industries in the United States, spending more than $ 17 billion on fuels and electricity in 2004. Including feedstock, the chemical industry consumed 6,465 TBtu or 28% of all energy consumed by the manufacturing industry in the United States in 2002 (U.S. DOE, 2005c). The large volume organic chemical industry on which this study focuses consumed approximately 70% of the total energy used in the chemical industry.

At the beginning of the chain of chemical conversions in the petrochemical industry, petrochemical feedstocks (e.g. ethane, naphtha, refinery streams) are converted to basic chemical products. These and more downstream chemical conversions are often accomplished at high temperatures and fuels are used to reach and maintain these temperature levels. A lot of the chemical conversions are exothermic and in many cases, the reaction heat is recovered to be used elsewhere in the plant or on the site. The crude product streams have to be purified to get chemical-grade products. These separation steps consume quite some electricity and heat. Heat is either supplied by direct heating or by steam produced in stand-alone boilers or via cogeneration of electricity and heat.

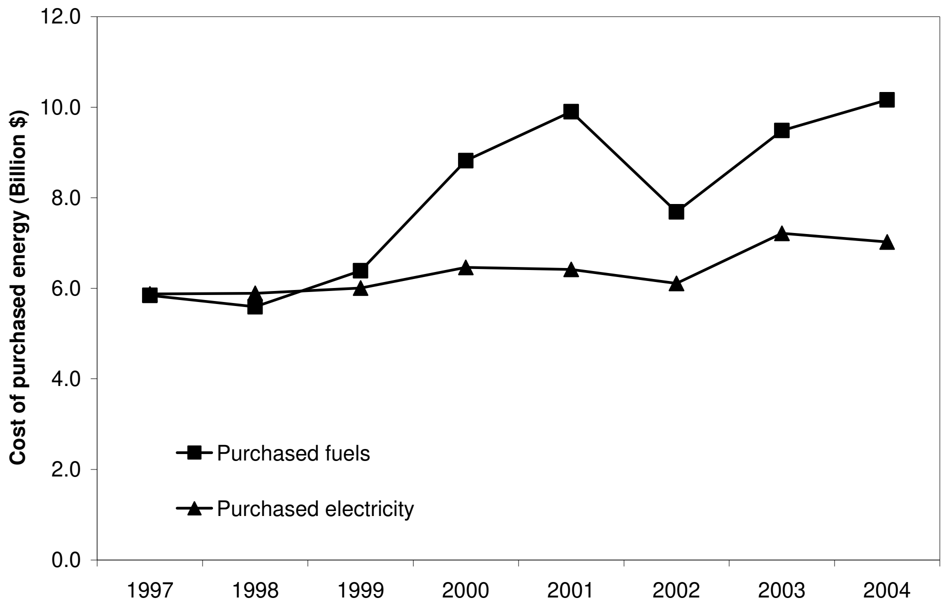
Electricity is used throughout the industry for pumps, compressors as well as for buildings lighting and heating, ventilation and air conditioning. Electricity is also used for refrigeration systems and process heating.

4.1 Energy Expenditures

Figure 4.1 gives the cost of purchased fuels and electricity in the total U.S. chemical industry between 1997 and 2004 (U.S. Census bureau, 2003 and 2005). Fuel costs grew more rapidly than power costs in recent years. The peak in 2001 for purchased fuel costs is mainly due to the spike in natural gas prices across the United States (CEC, 2003). Due in part to a combination of strong winter demand for natural gas and constrained natural supply, the price for natural gas more than doubled in many parts of the United States for the first half of 2001 (CEC, 2002). As a result, the cost of purchased fuels in 2001 was more than 55% higher than in 1999. Note that the purchased fuel costs exclude the self-generated fuels from feedstock conversion. Hence, the actual value of energy use may be higher than indicated in Chapter 4, depending on the value assigned to the self-generated fuels.

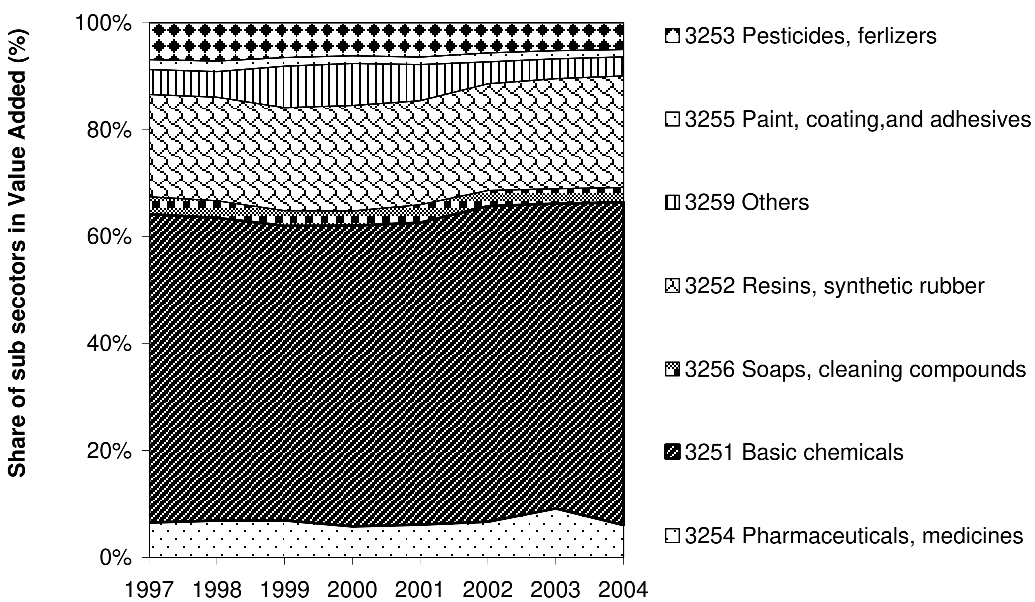
These data demonstrate the significant impact that energy prices can have on the U.S. chemical industry. It underscores the importance of energy efficiency as a means of reducing the industry's susceptibility to volatile and rising energy prices. Figure 4.2 provides an overview of energy expenditures in the chemical industry by 4-digit sub-sector. Comparison of this figure with Figure 2.2, which provides the share of the sub-sectors in value added, makes clear that the significance of energy costs differs widely between the main sub-sectors of the chemical industry. The pharmaceutical industry created 41% of the value added and produced 30% of the shipments of the total chemical industry, but is responsible for only 6% of the expenditures on fuel and electricity in 2004. The basic chemical industry, on the other hand, had a share of 60% in the electricity and fuel costs, but a much smaller share in the total value added and product shipments (20% and 26% respectively. Figure 4.3, which gives the share of energy expenditures in the product shipments of the 4-digit sub-sector, further clarifies this. In the period 1997-2004, this share ranges from 6-9% for the basic chemical industry to less than 1% for the pharmaceuticals, paints and soaps industry.

Figure 4.1 Cost of purchased fuels and electricity in the U.S. chemical industry 1997-2004.



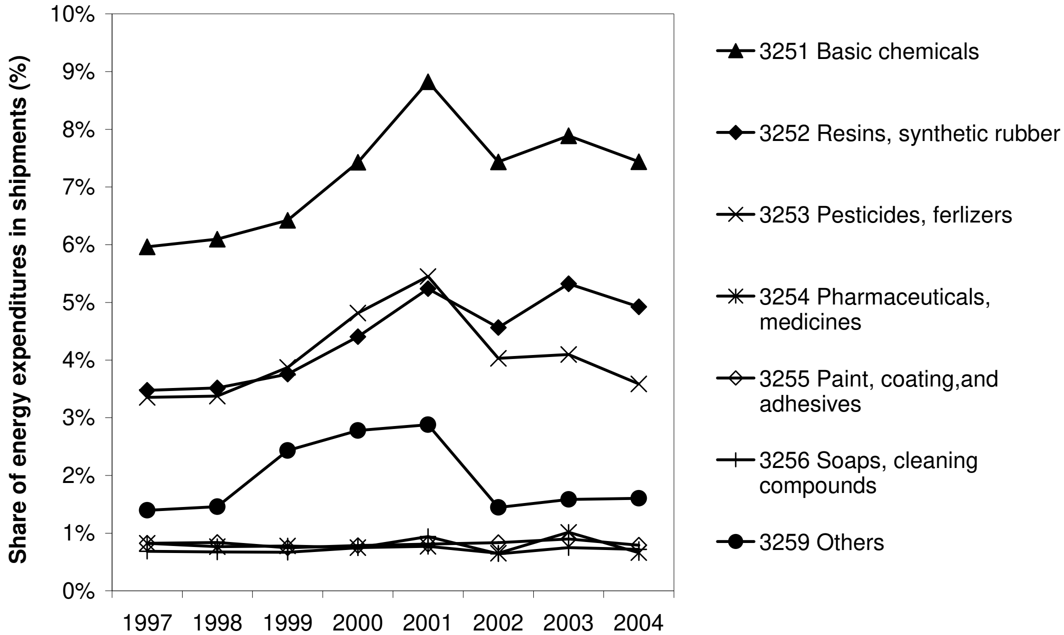
Source: U.S. Census Bureau (2003, 2005)

Figure 4.2 Share of 4-digit sub-sectors in energy expenditures of the chemical industry 1997-2004.



Source: U.S. Census Bureau (2003, 2005)

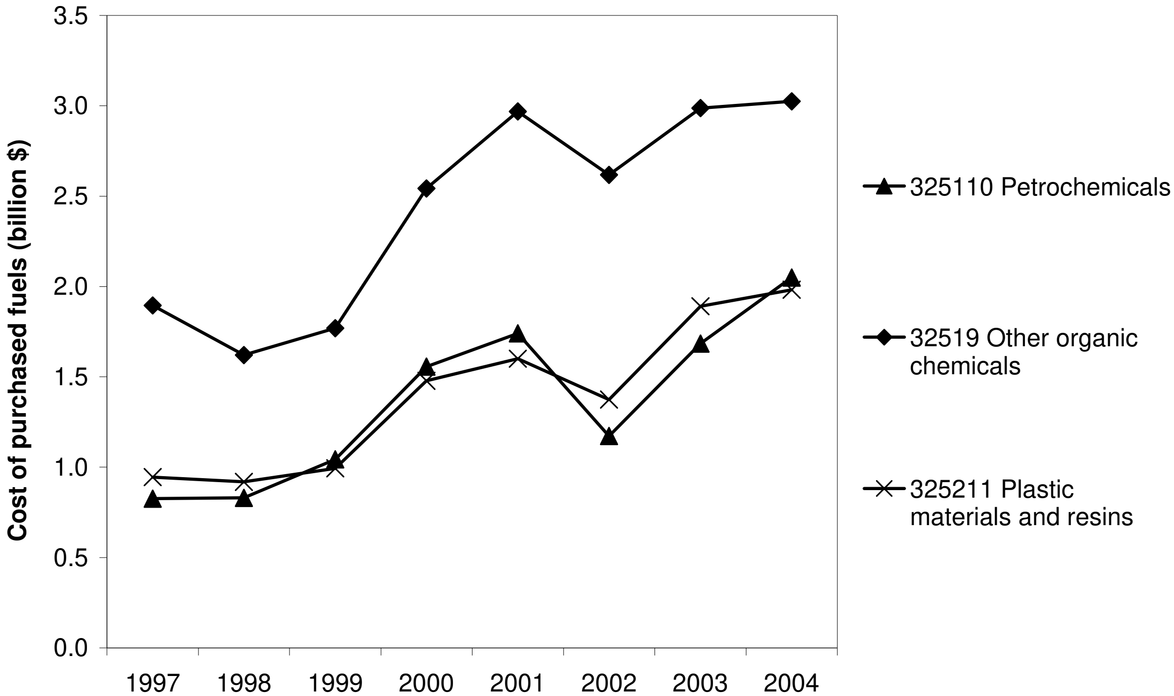
Figure 4.3 Energy expenditures as share of industry shipments in the U.S. chemical industry.



Source: U.S. Census Bureau (2003, 2005)

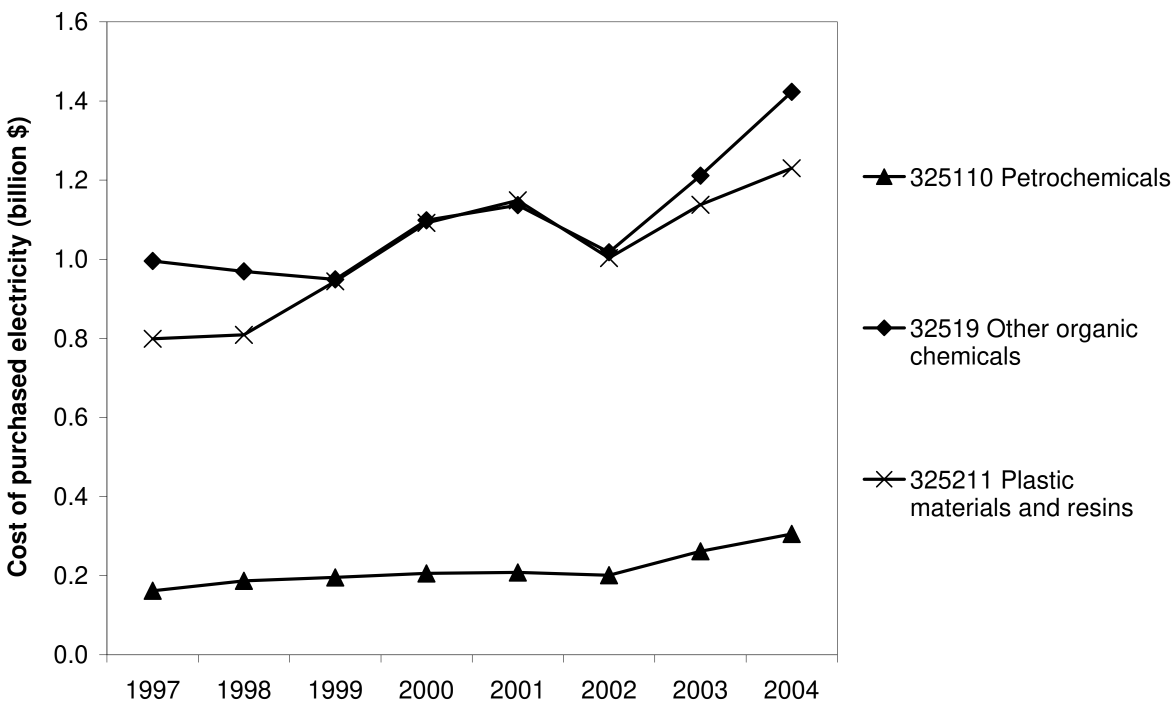
Figure 4.4 and 4.5 give the expenditures for electricity and fuels of the three large volume organic chemical industry sectors. In the last couple of years, the costs of purchased fuels in the three sectors increased dramatically. Between 1997 and 2004, fuel costs have approximately doubled and expenditures for electricity have grown by about 50% (Plastic materials and resins and other organic chemicals) and 90% (petrochemical industry). Although many of the fuel and electricity supplied to the industries are based on long-term contracts, rising energy prices as discussed above result in substantially higher costs for energy for the large volume organic chemical industry. Nationwide, the average industrial price for natural gas rose from around $4 per thousand cubic feet in 2002 to nearly $8,50 per thousand cubic feet in 2005 (U.S. DOE 2006). Similarly, the average industrial price for electricity rose from 4.9 cents per kWh in 2002 to 5.6 cents per kWh in 2005. Since for the organic chemical industry the main raw materials are also derived from energy resources, the increase in energy prices is even more important. In total, raw material and energy cost make up about 70% of the value of shipments in the large volume organic chemical industry (see Table 4.1). The industry often uses long-term contracts and it is not always possible to pass on production costs increases (e.g. as a result of higher energy prices) directly to purchasers of products. Therefore, there has always been a strong incentive for improved energy management and energy efficiency in the chemical industry. With the current high energy prices, this incentive is now perhaps stronger than ever.

Figure 4.4 Cost of purchased fuels in the relevant petrochemical sub-sectors.



Source: U.S. Census Bureau (2003, 2005)

Figure 4.5 Cost of purchased electricity in the relevant petrochemical sub-sectors.



Source: U.S. Census Bureau (2003, 2005)

Table 4.1 Share of electricity, fuel and raw material expenditures in industry shipments.

Values in $ billion	325 Total chemical industry	325110 Petrochemical industry	32519 Other organic chemicals	325211 Plastics Resins
Value of shipments	528	35	70	60
Fuel expenditures	10	2	3	2
Percentage of shipments	1.9%	5.8%	4.3%	2.9%
Electricity expenditures	7	0	1	1
Percentage of shipments	1.3%	0.9%	2.0%	1.9%
Total costs of materials	237	22	45	37
Percentage of shipments	44.9%	63.5%	63.6%	62.6%

Source: U.S. Census Bureau (2003, 2005)

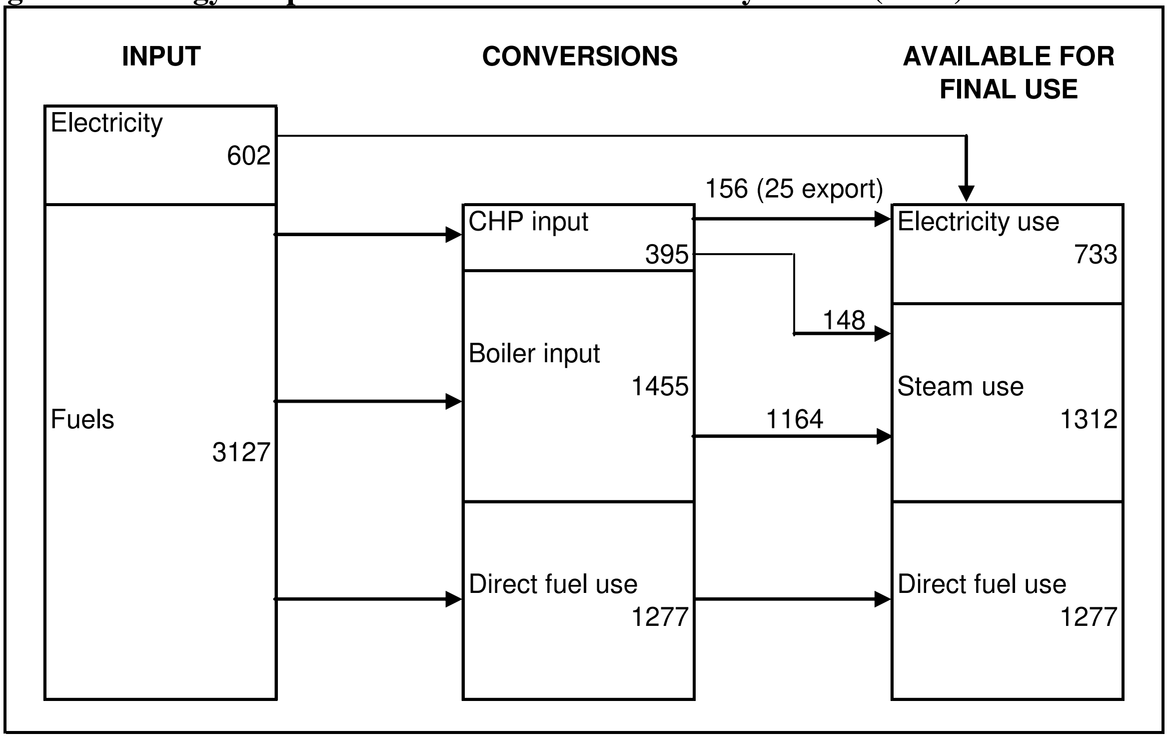
4.2 Energy Consumption by Sub-Sector

Based on the U.S. DOE's Manufacturing Energy Consumption Survey for 1998 (MECS) (U.S. DOE, 2001), the U.S. Department of Energy prepared an energy footprint for the chemical industry. An overview is provided in Figure 4.6, based on U.S. DOE-OIT (2006a). The figures shown exclude the use of energy as feedstock material[4]. The amount of electricity available for final use in 1998 was 733 TBtu. Of this total, 131 TBtu was produced on-site in combined heat and power (CHP) plants. Steam production in boilers and CHP plants was 1,312 TBtu and 1,277 TBtu of fuels were used directly in e.g. fired heaters. According to the energy footprint, a significant fraction of the energy available for final use is lost in distribution (322 TBtu, e.g. in pipes, valves, traps and electrical transmission lines) and another 656 TBtu is lost due to equipment inefficiencies (motors, mechanical drives etc.). As a result, the total process energy end use amounted to only 2,221 TBtu, which is only 2/3rd of the energy available for final use (3,347 TBtu). Overall losses therefore account for 1/3rd of the total final energy use, which demonstrates that, at least theoretically, a large potential exist for energy efficiency improvements in the chemical industry.

Table 4.2 provides an overview of the energy by type of fuel for 2002, based on the MECS 2002 survey (U.S. DOE, 2005c). Compiling good energy statistics for the chemical industry is complex, because fuels are used both as fuel and as feedstock. In some processes, part of the feedstock is not converted to chemical grade products, but to fuel by-products which are used as fuel in the same process or elsewhere. To make it even more complex, some chemical grade products such as ethylene and propylene are in the MECS classified under product group LPG and NGL and therefore regarded as energy products. The total first use of fuels as feedstock in the U.S. Chemical industry was 3,750 TBtu in 2002, but 503 TBtu of this feedstock is converted to waste fuels, which are used on-site. Another 504 TBtu is converted to other energy carriers which are shipped to other establishments. The net feedstock use is therefore only 2,743 TBtu. The main feedstock used is LPG and NGL (70%, mainly steam cracker feedstocks such as ethane and propane) and natural gas (23% mainly input for ammonia production).

[4] While feedstock energy use is not explicitly considered in this Energy Guide, it should be noted that feedstock savings are also possible, depending on the definition of feedstock used. Improvements in process selectivity for example lower the feedstock requirements.

Figure 4.6 Energy footprint of the U.S. chemical industry in 1998 (TBtu).



Source: Based on U.S. DOE-OIT (2006a)
Note: Feedstock use is excluded.

The energy use for heat and power in 2002 amounted to 3,721 TBtu. Natural gas is the main fuel of choice in the chemical industry, accounting for nearly half of the energy used for heat and power production in 2002. Fuel by-products derived from feedstock and used on-site are a second important source of fuels used for heat and power amounting to 14% of the fuels used for heat and power. Other energy sources including steam and fuel by-products bought from other establishments account for 16% of the fuels used for heat and power.

The large volume organic chemical industry consumes 83% of the feedstock use of all feedstock use in the chemical industry (see Table 4.3). This can be explained by the fact this sector includes the production of basic chemicals from petrochemical feedstock. The remainder of the feedstock is consumed mainly for ammonia production by the fertilizer industry (9%). Not only the petrochemical industry (NAICS 325110), but also the other organic chemicals industry (NAICS 325199) and the plastic materials and resins industry (NAICS 325211) consume some fuels as feedstock. Partly, this can be explained by the classification of some chemical products (e.g. ethylene and propylene) as energy carrier in the MECS survey. The use of these products in downstream industries is therefore seen as feedstock use. Another explanation is the classification of some companies operating steam crackers in the other organic chemicals and plastic materials industries. They operate integrated sites where the basic chemicals are further converted onsite to downstream chemicals.

Table 4.2 Energy use in the chemical industry by fuels and feedstock category, 2002.

Energy use for heat and power	TBtu	% of total
Net electricity	522	14%
Fuel oils	58	2%
Natural gas	1,678	45%
LPG and NGL	37	1%
Coal, coke and breeze	315	8%
Others[1]	608	16%
By-products[2]	503	14%
Total	**3,721**	**100%**
Energy use as feedstock		
Fuels oils	43	2%
Natural gas	629	23%
LPG and NGL[3]	1,957	71%
Coal, coke and breeze	35	1%
Others	79	3%
Total	**2,743**	**100%**

Source: U.S. DOE (2005c) and own calculations

[1] 'Other' includes net steam (the sum of purchases, generation from renewables, and net transfers), and other energy.

[2] Derived from feedstock and consumed on-site.

[3] Excluding 503 TBtu of by-products which are derived from the feedstock.

Table 4.3 Energy use by sub-sector, 2002.

	Net electricity (TBtu)	Fuel use (TBtu)	Feedstock use (TBtu)	Total
325 Total chemical industry	522	3199	2743	6464
Percentage of total chemical industry	100%	100%	100%	100%
325110 Petrochemicals	18	467	404	889
Percentage of total chemical industry	3%	15%	15%	14%
325199 All other organics	78	1069	686	1833
Percentage of total chemical industry	15%	33%	25%	28%
325211 Plastic materials and resins	73	571	1177	1821
Percentage of total chemical industry	14%	18%	43%	28%
Sum of large volume chemical industry	169	2107	2267	4543
Percentage of total chemical industry	32%	66%	83%	70%

Source: U.S. DOE (2005c) and own calculations

The share of the large volume organic chemical industry in the total fuel use of the chemical industry is also substantial (66%). This is significantly larger share than the share of these sectors in the total value added and product shipments of the chemical industry (see Table 2.1), showing again the high energy intensity of the industry sector. A significant fraction of the fuels is used for on-site generation of electricity and heat. In the three sectors combined, 106 TBtu of electricity was co-generated (see Table 4.3). If the same steam to electricity ratio as for the total chemical industry in 1998 is assumed (see Figure 4.6), the corresponding steam production was 101 TBtu. Assuming the same conversion efficiency as for the total chemical industry, the corresponding fuel input was 272 TBtu or 13% of the total fuel use of the sector. The remainder of the fuels (1,835 TBtu) is consumed in either stand alone boilers or is directly used for process heating or other purposes. Co-generated electricity accounted for 38% of the electricity used in the large volume organic chemical industry. This is high compared to the chemical industry average of 20%.

Table 4.4 Components of electricity demand by sub-sector, 2002 (TBtu).

Values in TBtu	Purchase	CHP	Sales	Total demand	CHP share
325 Total chemical industry	551	168	28	690	20%
Percentage of total chemical industry	100%	100%	100%	100%	
325110 Petrochemicals	18	13	0	31	40%
Percentage of total chemical industry	3%	8%	1%	4%	
325199 All other organics	86	38	8	116	33%
Percentage of total chemical industry	16%	23%	27%	17%	
325211 Plastic materials and resins	75	55	2	129	43%
Percentage of total chemical industry	14%	33%	6%	19%	
Sum of sectors studied	179	106	10	276	38%
Percentage of total chemical industry	33%	63%	34%	40%	

Source: U.S. DOE (2005c) and own calculations

Table 4.5 End use of electricity in the total chemical industry and the sub-sectors studied, 2002.

NAICS sector	325 Total chemical industry		325110 / 325199 / 325211 Petrochemicals, all other organic chemicals , plastic materials and resins	
	TBtu	Percentage of total	TBtu	Percentage of total
Total electricity demand[1]	696	100%	281	100%
Use for boilers and CHP	4	1%	2	1%
Process use				
Process Heating	23	3%	15	5%
Process Cooling and Refrigeration	59	8%	27	10%
Machine Drive	399	57%	161	57%
Electro-Chemical Processes	121	17%	48	17%
Other Process Use	1	0%	0	0%
Non-process use				
Facility HVAC (g)	40	6%	11	4%
Facility Lighting	30	4%	11	4%
Other non-process use	8	1%	2	1%
Not reported	12	2%	4	1%

Source: U.S. DOE (2005c) and own calculations

[1] Figures differ slightly from Table 4.3, because of different data sources (MECS Table 5.4 in this table, MECS table 11.1 in Table 4.3).

The share of the three sectors in the total electricity use of the chemical industry is less dominant compared to fuel and feedstock use. Of all electricity consumed by the chemical industry, about 1/3rd is consumed by the large volume organic chemical industry (see Table 4.3). As is the case for most manufacturing industries, the majority of all electricity in the chemical industry is consumed by machine drives (57%). For the large volume organic chemical industry, facility lighting and heating, ventilation and air-conditioning (HVAC) consume 10% of the electricity use and process heating, cooling and refrigeration consumes 15%. A substantial part of electricity (17%) is consumed by electro-chemical processes, but this mainly relates to inorganic chemicals such as chlorine. Some chlorine facilities are operated by companies that may be classified as petrochemical industry (e.g. Dow Chemical's Freeport, Texas, site), explaining the large electro-chemical electricity consumption in the organic chemical industry.

4.3 Energy Use by Process

Energy is used in the petrochemical industry in a diverse way for a wide variety of unit operations. Still, a few processes dominate the energy use of the sector. Table 4.6 provides an overview of specific energy consumption (SEC), production volumes and resulting total estimated final energy use. In general, bottom-up estimates are difficult to make, because wide ranges of specific energy consumption figures can be found in the literature. The overview presented in Table 4.6 should therefore only be regarded as a first estimate to give a rough indication of final energy consumption.

Table 4.6 Estimated final energy consumption for selected key chemicals.

	2002 production billion lbs	SEC, process Btu / lb	SEC, feedstock Btu / lb	Total process energy TBtu	Total feedstock energy TBtu
Ethylene and co-products	52.1	11,588	27,158	604	1,414
Polyethylene	35.3	1,184		42	
Styrene	10.8	3,777		41	
Vinylchloride	17.8	2,103		38	
MTBE	19.8	1,871		37	
Benzene, Toluene, Xylene	26.1	1,255	18,933	33	494
Acetone	3.5	7,717		27	
Polyvinylchloride	15.3	1,463		22	
Acetic acid	7.6	2,552		19	
Terephtalic acid	8.0	2,217		18	
Polystyrene	6.6	2,264		15	
Polypropylene	16.9	877		15	
Ethylene oxide	7.6	1,916		15	
Ethyl benzene	11.9	1,174		14	
Propylene oxide	5.4	2,567		14	
Cumene	7.7	878		7	
Polyamine	1.3	4,329		6	
Acrylonitrille	2.7	626		2	
Methanol	7.3		13,339	0	97
Total				**966**	**2,006**

Various sources. Production data based on Chemical Engineering News (2006), ICIS Chemical Business and ICIS Chemical Business America, SEC values based on Neelis et al. (2005b) and U.S. DOE-OIT (2000).

The comparison with Table 4.3 demonstrates a relatively good match between the bottom-up estimated feedstock use (2,006 TBtu) and the feedstock energy use reported in the energy statistics (2,267 TBtu). This is not surprising, because the most important processes converting feedstocks to basic chemicals are included in the bottom-up overview. The bottom-up process energy use of 966 TBtu is 42% of the total estimated process energy in the sectors studied (2,276 TBtu). A first explanation for the low coverage for process energy use is the inclusion of only about 20 products in Table 4.6 out of the hundreds of products produced in the sector. Also, the specific process energy use estimates have been taken from open literature sources. In these sources, the data refers to the end use of fuels and steam, thereby neglecting losses in for example steam transportation. Also, energy use for supporting equipment such as cooling water pumps; facility lighting etc is generally not included, partly explaining the low coverage.

5. Energy Efficiency Opportunities

A large variety of opportunities exist within the petrochemical industries to reduce energy consumption while maintaining or enhancing the productivity of the plant. Studies by several companies in the petrochemical industries have demonstrated the existence of a substantial potential for energy efficiency improvement in almost all facilities. Improved energy efficiency may result in co-benefits that far outweigh the energy cost savings, and may lead to an absolute reduction in carbon dioxide and other fuel-related emissions.

Major areas for energy-efficiency improvement are utilities[5] (30%), fired heaters (20%), process optimization (15%), heat exchangers (15%), motor and motor applications (10%), and other areas (10%). Of these areas, optimization of utilities, heat exchangers and fired heaters offer the most low investment opportunities, whereas in other areas low-cost opportunities will exist, other opportunities may need investments. Experiences of various oil and chemical companies have shown that most investments are relatively modest. However, all projects require operating costs as well as engineering resources to develop and implement the project. Every petrochemical plant will be different. Based on your unique situation the most favorable selection of energy-efficiency opportunities should be made.

In the following chapters energy efficiency opportunities are classified based on technology area. In each of the technology area or uses technology opportunities and specific applications by process are discussed. In a final chapter, some key individual processes are discussed selected based on their importance in view of the energy use of the sector.

This Guide is far from exhaustive. For example, the Global Energy Management System (GEMS) of ExxonMobil has developed 12 manuals - containing some 1200 pages, which describe in detail over 200 best practices and performance measures for key process units, major equipment, and utility systems in the petrochemicals and petroleum refining operations. In addition to the strong focus on operation and maintenance of existing equipment, these practices also address energy efficiency in the design of new facilities. GEMS identified opportunities to improve energy efficiency by 15-20% at ExxonMobil refineries and chemical plants worldwide. ExxonMobil has realized half of potential savings since, reducing emissions by 8 $MtCO_2$ annually. The ENERGY STAR guide provides a general overview in a relatively easy accessible format to help energy managers to select areas for energy-efficiency improvement based on experiences around the world.

The Energy Guide includes case studies for the U.S. petrochemical industry with specific energy and cost savings data when available. For other measures, the Guide includes case study data from chemical plants around the world. For individual plants, actual payback period and energy savings for the measures will vary, depending on plant configuration and size, plant location and plant operating characteristics. Hence, the values presented in this Guide are offered as guidelines. Wherever possible, the Guide provides a range of savings and payback periods found under varying conditions.

[5] Utilities include steam generation and distribution (including condensate), power generation (including cogeneration), compressors, as well as various smaller applications.

Although technological changes in equipment conserve energy, changes in staff behavior and attitude can have a great impact; staff should be trained in both skills and the company's general approach to energy efficiency in their day-to-day practices. Personnel at all levels should be aware of energy use and objectives for energy efficiency improvement. Often this information is acquired by lower level managers but not passed to upper management or down to staff (Caffal, 1995). Though changes in staff behavior, such as switching off lights or improving operating guidelines often save only very small amounts of energy at one time, taken continuously over longer periods they can have a great effect. Further details for these programs can be found in Chapter 6.

Participation in voluntary programs like the EPA ENERGY STAR program, or implementing an environmental management system such as ISO 14001 or Six Sigma can help companies to track energy and implement energy efficiency measures. One ENERGY STAR partner noted that combining the energy management programs with the ISO 14001 program has had the largest effect on saving energy at their plants. Companies like BP have successfully implemented aggressive greenhouse gas (GHG) emission reduction programs at all their facilities worldwide (including exploration, refining and chemicals). BP has reduced its global GHG emissions to 10% below 1990 levels within 5 years of the inception of its program; years ahead of its goal, while decreasing operation costs. These efforts demonstrate the potential success of a corporate strategy to reduce energy use and associated emissions.

Yet, other companies used participation in voluntary programs to boost energy management programs. In Canada, a number of chemical firms including Bayer, Dow, DuPont and Shell joined the Climate Change Voluntary Challenge and Registry. As part of this voluntary program, they develop action plans for managing greenhouse gas emissions and report regularly on the results. In Europe, various countries have voluntary agreements between industry sectors and governments to reduce energy or greenhouse gas emission intensity. The chemical industry in The Netherlands participated in the Long-Term Agreements between 1989 and 2000, including companies such as ExxonMobil, Dow and Shell. Within the Long-Term Agreements, energy efficiency plans were developed for each of the plants participating and the development of the energy efficiency was monitored from year to year. The basis of the monitoring was the energy intensity measured as energy use per pound of product. The total chemical industry achieved a 25% improvement of energy efficiency between 1989 and 2000. Improved energy management and good housekeeping, discussed in Chapter 6 contributed 2% to the total efficiency improvement. Debottlenecking and improvement of the various process installations (options discussed in Chapter 7 through 16) contributed 31% to the total. In many cases, better process integration and waste heat recovery has been applied. New production facilities with improved efficiency contributed 9% to the total energy savings and 4% of the realized savings can be attributed to improvements in the utilities systems (e.g. steam, Chapter 7 and compressed air, Chapter 13). Examples of the latter are reduced condensate and steam losses and the use of reduced steam pressure. Combined heat and power generation (discussed in Chapter 7) contributed 29% to the overall energy efficiency improvement and better capacity utilization resulting from increased production contributed the remaining 25% (Novem, 2001).

Since 2000, energy intensive chemical companies in the Netherlands participate in a new benchmarking agreement in which the companies strive towards operating the world's most energy-efficient plants for their type of product by 2010.

To enable easy access to information, this Energy Guide is organized into chapters that focus on specific areas of opportunity for energy and water efficiency.

Chapters 6 through 11 of this Energy Guide focus on cross-cutting energy efficiency measures, which are defined as energy efficiency measures that are in principle applicable across all manufacturing industries. After a brief overview of corporate energy management programs in Chapter 6, this Energy Guide focuses on the following cross-cutting industrial systems, which are of particular importance to the U.S. petrochemical industry: steam systems, furnaces/process heater, heating/cooling and process integration, electric motors, pumps, fans and blowers, compressors and compressed air systems, distillation, and building systems (HVAC and lighting). Chapter 16 of this Energy Guide presents a variety of energy efficiency measures that are applicable to specific processes employed in the petrochemical industry. An overview of the cross-cutting measures discussed in this Guide is given in Table 5.1, while Table 5.2 gives an overview of process-specific measures. Table 5.3 provides an access key to the guide showing the key chapters for key processes.

Table 5.1 Summary of cross-cutting energy efficiency measures discussed in this Energy Guide.

Energy Management Programs and Systems (Chapter 6)	
Energy management programs	Energy teams
Energy monitoring and control systems	
Steam Systems: (Chapter 7)	
Steam Supply	
Boiler feed water preparation	Flue gas heat recovery
Boiler process control	Blow down steam recovery
Reduction of flue gas quantities	Reduce standby losses
Reduction of excess air	Combined Heat and Power (CHP)
Improved boiler insulation	High temperature CHP
Boiler maintenance	Steam expansion turbines
Steam Distribution Systems and Steam End Use	
Improved distribution system insulation	Leak repair
Insulation maintenance	Flash steam recovery
Steam trap improvement	Return condensate
Steam trap maintenance	Improve efficiency at steam end use
Steam trap monitoring	
Furnaces / Process Heaters (Chapter 8)	
Control air-to-fuel ratio	Improve control
Improve heat transfer	Maintenance
Improve heat containment	Switch electric heaters to fuelled heaters
Heating, Cooling and Process Integration (Chapter 9)	
Reduce fouling in heat transfer equipment	Process integration
Regular checks of cooling water systems	Pinch analysis
Heat recovery	Total site pinch analysis

Electric Motors Systems (Chapters 10-13)	
Motor Systems	
Properly sized motors	Reduce voltage unbalance
High efficiency motors	Adjustable-speed drives
Improve power factor	Variable voltage controls
Pumps	
Pump system maintenance	Avoiding throttling valves
Pump system monitoring	Replacement of belt drives
Pump demand reduction	Proper pipe sizing
Controls	Adjustable-speed drives
High-efficiency pumps	Precision castings, surface coatings or polishing
Properly sized pumps	Improve sealings
Multiple pumps for variable loads	Curtailing leakage through clearance reduction
Impeller trimming	Use dry vacuum pumps
Fans and blowers	
Properly sized fans	Improved controls
Adjustable speed drives	High efficiency belts
Compressors and compressed air systems	
System improvements (pressure reduction)	Controls
Maintenance	Properly sized regulators
Monitoring	Properly size piping
Leak reduction	Heat recovery
Reducing the inlet air temperature	Adjustable speed drives
Maximize allowable pressure dew point	High efficiency motors
Improved load management	
Distillation (Chapter 14)	
Optimization of reflux ratio	Feed conditioning
Check required product purity	Upgrading column internals
Seasonal operating pressure adjustments	Stripper optimization
Reducing reboiler duty	Insulation
Enhanced distillation control	
Building Energy Efficiency Measures (Chapter 15)	
HVAC Systems	
Energy efficient system design	Fan modification
Recomissioning	Efficient exhaust fans
Energy monitoring and control systems	Use of ventilation fans
Non-production hours set-back temperatures	Cooling water recovery
Duct leakage repair	Solar air heating
Variable-air-volume systems	Building reflection
Adjustable-speed drives	Low-emittance windows
Heat recovery systems	
Lighting	
Turning off lights in unoccupied areas	Replacement of mercury lights
Lighting controls	High-intensity discharge voltage reduction
Exit signs	High-intensity fluorescent lights
Electronic ballasts	Daylighting
Replacement of T-12 tubes with T-8 tubes	

Table 5.2 Summary of process specific measures included in this Energy Guide.

Process Specific Measures (Chapter 16)	
Process	**Measures**
Ethylene	More selective furnace coils
	Improved transfer line exchangers
	Secondary transfer line exchangers
	Increased efficiency cracking furnaces
	Pre-coupled gas turbine to cracker furnace
	Higher gasoline fractionator bottom temperature
	Improved heat recovery quench water
	Reduced pressure drop in compressor inter-stages
	Additional expander on de-methanizer
	Additional re-boilers (cold recuperation)
	Extended heat exchanger surface
	Optimization steam and power balance
	Improved compressors
Aromatics	Improved product recovery systems
Polymers	Low pressure steam recovery
	Gear pump to replace extruder
	Online compounding extrusion
	Re-use solvents, oils and catalysts
Ethylene Oxide / Ethylene Glycol	Increased selectivity catalyst
	Optimal design EO/EG-sections
	Multi-effect evaporators (Glycol)
	Recovery and sales of by-product CO_2
	Process integration
Ethylene Dichloride / Vinyl Chloride Monomer	Optimize recycle loops
	Gas-phase direct chlorination of ethylene
	Catalytic cracking EDC
Styrene	Condensate recovery and process integration
Toluene diisocyanate	Recover exothermic heat
	Recuperative incinerators

Table 5.3 Access key to the Energy Guide for the Petrochemical Industry.

Chapter	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**
Key Process	Steam	Furnace	Process Heating	Motors	Pumps	Fans	Compressed Air	Distillation	Buildings	Process Specific
Ethylene	X	X	X	X	X	X		X		X
Propylene	X	X	X	X	X	X		X		
Aromatics	X	X	X	X	X	X		X		X
Polymers	X	X	X	X	X	X	X		X	X
Ethylene oxide/Glycol				X	X	X		X		X
EDC/VCM				X	X	X		X		X
Styrene				X	X	X		X		X
TDC				X	X	X		X		X
Utilities	X			X	X	X	X		X	

6. Energy Management and Controls

6.1 Energy Management Systems (EMS) and Programs

Improving energy efficiency in the petrochemical industry should be approached from several directions. Crosscutting equipment and technologies such as boilers, compressors and pumps, common to most plants and manufacturing industries including the petrochemical industry, present well-documented opportunities for improvement. Changing how energy is managed by implementing an organization-wide energy management program is one of the most successful and cost-effective ways to bring about energy efficiency improvements.

Continuous improvements to energy efficiency typically only occur when a strong organizational commitment exits. A sound energy management program is required to create a foundation for positive change and to provide guidance for managing energy throughout an organization. Energy management programs help to ensure that energy efficiency improvements do not just happen on a one-time basis, but rather are continuously identified and implemented in an ongoing process of continuous improvement. Without the backing of a sound energy management program, energy efficiency improvements might not reach their full potential due to lack of a systems perspective and/or proper maintenance and follow-up.

In companies without a clear program in place, opportunities for improvement may be known but may not be promoted or implemented because of organizational barriers. These barriers may include a lack of communication among plants, a poor understanding of how to create support for an energy efficiency project, limited finances, poor accountability for measures, or organizational inertia to changes from the status quo. Even when energy is a significant cost, many companies still lack a strong commitment to improve energy management.

The U.S. EPA, through the ENERGY STAR program, works with leading industrial manufacturers to identify the basic aspects of effective energy management programs.[6] The major elements in a strategic energy management program are depicted in Figure 6.1. In Europe, the chemical branch organization CEFIC developed the Responsible Care initiative that provides a useful framework for the implementation of energy and environmental management techniques.

Other environmental management frameworks, such as ISO 14001 and Six Sigma, can be used to complement energy management programs to ensure optimal organizational management of energy. One ENERGY STAR partner noted that using energy management programs in combination with the ISO 14001 program has had a greater impact on conserving energy at its plants than any other strategy.

A successful program in energy management begins with a strong organizational commitment to continuous improvement of energy efficiency. This involves assigning oversight and management duties to an energy director, establishing an energy policy, and creating a cross-functional energy team (see the section on energy teams below). Steps and procedures are then put in place to assess performance through regular reviews of energy data, technical

[6] Read more about strategic energy management at http://www.energystar.gov/.

assessments, and benchmarking. From this assessment, an organization is able to develop a baseline of energy use and set goals for improvement. Performance goals help to shape the development and implementation of an action plan.

An important aspect for ensuring the success of the action plan is involving personnel throughout the organization. Personnel at all levels should be aware of energy use and goals for efficiency. Staff should be trained in both skills and general approaches to energy efficiency in day-to-day practices. Some examples of simple tasks employees can do are outlined in Appendix C.

Figure 6.1 Main elements of a strategic energy management program.

Evaluating performance involves the regular review of both energy use data and the activities carried out as part of the action plan. Information gathered during the formal review process helps in setting new performance goals and action plans and in revealing best practices. Establishing a strong communications program and seeking recognition for accomplishments are also critical steps. Strong communication and recognition help to build support and momentum for future activities. A quick assessment of an organization's efforts to manage energy can be made by comparing the current program against the ENERGY STAR Energy Program Assessment Matrix provided in Appendix D.

The successes of plant-wide energy-efficiency assessments and the implementation of energy management programs in reducing energy use and CO_2 emissions have been proven in a large number of cases like the examples discussed below.

Dow Chemical Co. is an example of a company with a long-term active energy management system, demonstrating the benefits of a well-structured energy management approach. In 1994 Dow established a goal to reduce the company's global energy intensity by 20% by 2005. Utilizing a structured, focused approach, Dow exceeded that goal, reaching an energy intensity improvement of 22% versus the 1994 baseline and saving over 900 TBtu globally with over 370 TBtu from U.S. Operations alone. Leveraging the lessons learned and successes achieved, in 2006 Dow announced another aggressive energy intensity reduction goal of an additional 25 % by the year 2015 and reduction of its greenhouse gas (GHG) emissions intensity by 2.5 percent annually. Dow's energy efficiency and conservation initiative relies strongly on its structured approach to resources conservation and energy intensity reduction. This structured approach consists of a clear leadership objective, an effectively aligned organization, a proven methodology, and tenacity for implementation. The overall Energy Efficiency and Conservation effort within Dow is driven by a Global Energy Efficiency Leader, who has full responsibility and accountability for implementing and managing an aggressive global energy conservation plan. The energy conservation leader sponsors business and site energy efficiency teams and networks throughout the company to identify energy saving opportunities, develop long-term energy improvement plans and to implement projects. In addition, each business unit at Dow is responsible for aligning its goals and plans to the corporate goal on energy efficiency. Focal points within each business unit are responsible for driving energy efficiency within their respective technologies. Energy efficiency is further driven by the energy conservation teams at our 13 largest energy-consuming sites, which account for over 90% of Dow's energy usage. These local teams actively engage employees in energy efficiency improvement projects at their sites and drive an energy efficiency mindset and culture at the local level and through site integration.

A review of the cost structure of the Deer Park, Texas production facility of Rohm and Haas identified energy use as an important opportunity to reduce costs. This recognition resulted in the creation of a formal Energy Management Program, structured along the lines of Figure 6.1. The program resulted in a decrease in energy intensity (consumption of energy per pound of product) of 23.3% between 1996 and 2002. From 1997-1999 (the two years following the introduction of the Energy Management Program) energy intensity dropped by 15%. Total annual energy savings in 2002 compared to 1996 levels were 4.3 TBtu, resulting in annual CO_2 emission reductions of 67 kT CO_2. Up to 2003, the Energy Management Program in Deer Park has saved Rohm and Haas over $18.5 million in avoided energy costs. The key elements of the program's success included an effective collaborative framework that involved personnel at all levels and active support from senior management. Plant-wide efficiency assessments at other plants of Rohm and Haas in Knoxville, Tennessee, La Mirada, California and Louisville, Kentucky resulted in several projects with a total energy saving potential of 16,502 MWh electricity, 48,400 MMBtu of steam and 21,600 MMBtu of fuels (U.S. DOE-OIT, 2003b). Several of the measures identified such as optimization of the compressed air, steam and cleaning systems did not require any capital investment and still result in substantial energy savings.

In a pilot project for its North American plants, the Netherlands-based company AKZO Nobel implemented a Site-Wide Energy Efficiency Plan (EEP) at its Morris, Illinois site (U.S. DOE-OIT, 2003c). The EEP was designed to help plant personnel monitor energy consumption during production and to identify potential energy-saving opportunities. This resulted in 5 energy savings projects with payback times between 2 and 7 years that save roughly 15% of the energy intake. Introduction of an energy management system is estimated to result in additional savings of 3%.

A similar exercise at a Bayer Polymers plant in New Martinsville, West Virginia resulted in several projects saving 236,000 MMBTU ($1.16 million) annually and 6.3 million kWh of electricity (U.S. DOE-OIT, 2003d). Payback times for the projects ranged 0.5 and 32 months. Four of the identified projects (better insulation, repairing steam leaks, adjustment of the fuel/air ratio in one boiler and repairing of compressed air leaks) had estimated capital costs below $10,000 and pay back periods below 0.5 year. Energy savings due to these measures were estimated at 95,000 MMBtu annually (equivalent to 40% of the total identified savings), resulting in CO_2 emission reductions of 11 million lbs.

Regular reviews of the opportunities to improve energy efficiency are essential within a structured approach to energy management. Companies use different names for these reviews, such as Treasure Hunts (Toyota), Energy Deep Drill (Dow). A plant-wide energy-efficiency assessment at the Anaheim, California site of Neville Chemical company resulted in 5 potential projects that could save 436 MWh of electricity ($31,840) and 7,473 MMBtu ($43,600) annually with payback periods below 2.1 year (U.S. DOE-OIT, 2003e). An additional benefit of the assessment in Anaheim, California was that several of the projects were also applicable to the much larger Pittsburg, Pennsylvania, site of the company. A similar assessment there resulted in 15 projects with projected annual savings of $715,000.

In an energy-efficiency assessment of the 3M Hutchinson, Minnesota, production facility (U.S. DOE-OIT, 2003f), 6 projects were identified with electricity savings of 5,722 MWh / year and natural gas and oil savings of 38,788 and 175,702 MMBtu, resulting in avoid energy expenses over $1 Million.

An assessment of the Curtis Bay Works in Baltimore, Maryland, based on Six Sigma methodologies identified four projects (technically and economically viable) with combined savings of $840,000 per year. Fuel savings were estimated at 96,000 MMBtu per year and electricity savings at 4,800 MWh per year (U.S. DOE-OIT, 2003g). In addition, a project was identified that would link the company up with the city of Baltimore by using landfill gas (methane) to co-generate steam and electricity for use in the plant facilities.

An assessment of the Formosa Plastics Corporation polyethylene plant in Point Comfort, Texas, yielded six projects that could save energy, increase productivity, and reduce waste and environmental emissions. Energy savings of the projects were estimated at 115,000 MMBtu of fuels and 14 million kWh annually with payback times ranging from 0.1 – 2.3 years and annual cost savings of $1,495,880 (U.S. DOE-OIT, 2005a).

6.2 Energy Teams

The establishment of an energy team is an important step toward solidifying a commitment to continuous energy efficiency improvement.[7] The energy team should primarily be responsible for planning, implementing, benchmarking, monitoring, and evaluating the organizational energy management program, but its duties can also include delivering training, communicating results, and providing employee recognition (U.S. EPA 2006).

In forming an energy team, it is necessary to establish the organizational structure, designate team members, and specify roles and responsibilities (see also the example of Dow Chemical above). Senior management needs to perceive energy management as part of the organization's core business activities, so ideally the energy team leader will be someone at the corporate level who is empowered by support from senior-level management. The energy team should also include members from each key operational area within an organization and be as multi-disciplinary as possible to ensure a diversity of perspectives. It is crucial to ensure adequate organizational funding for the energy team's activities, preferably as a line item in the normal budget cycle as opposed to a special project.

Prior to the launch of an energy team, a series of team strategy meetings should be held to consider the key initiatives to pursue as well as potential pilot projects that could be showcased at the program's kickoff. The energy team should then perform facility audits with key plant personnel at each facility to identify opportunities for energy efficiency improvements. As part of the facility audits, the energy team should also look for best practices in action to help highlight success stories and identify areas for inter-plant knowledge transfer.

A key function of the energy team is to develop mechanisms and tools for tracking and communicating progress and for transferring the knowledge gained through facility audits across an organization. Examples of such mechanisms and data tools include best practice databases, facility benchmarking tools, intranet sites, performance tracking scorecards, and case studies of successful projects. Corporate energy summits and employee energy fairs are also effective means of information exchange and technology transfer.

To sustain the energy team and build momentum for continuous improvement, it is important that progress results and lessons learned are communicated regularly to managers and employees and that a recognition and rewards program is put in place.

A checklist of key steps for forming, operating, and sustaining an effective energy management team is offered in Appendix E.

6.3 Monitoring and Process Control Systems

The use of energy monitoring and process control systems can play an important role in energy management and in reducing energy use. These may include sub-metering, monitoring

[7] For a comprehensive overview of establishing, operating, and sustaining an effective energy management team, please consult the U.S. EPA's *Teaming Up to Save Energy* guide available at http://www.energystar.gov/ (U.S. EPA 2006).

and control systems. They can reduce the time required to perform complex tasks, often improve product and data quality and consistency and optimize process operations.

Typically, energy and cost savings are around 5% or more for many industrial applications of process control systems. These savings apply to plants without updated process control systems; many chemical plants may already have modern process control systems in place to improve energy efficiency.

Although, energy management systems are already widely disseminated in various industrial sectors, the performance of the systems can still be improved, reducing costs and increasing energy savings further. For example, total site energy monitoring and management systems can increase the exchange of energy streams between plants on one site. Traditionally, only one process or a limited number of energy streams were monitored and managed. Various suppliers provide site-utility control systems (Hydrocarbon Processing, 2005b).

Specific energy savings and payback periods for overall adoption of an energy monitoring system vary greatly from plant to plant and company to company. A variety of process control systems are available for virtually any industrial process. A wide body of literature is available assessing control systems in most industrial sectors such as chemicals and petroleum refining. Table 6.1 provides an overview of classes of process control systems.

Table 6.1 Classification of control systems and typical energy efficiency improvement potentials.

System	Characteristics	Typical energy savings (%)
Monitoring and Targeting	Dedicated systems for various industries, well established in various countries and sectors	Typical savings 4-17%, average 8% , based on experiences in the UK
Computer Integrated Manufacturing (CIM)	Improvement of overall economics of process, e.g. stocks, productivity and energy	> 2%
Process control	Moisture, oxygen and temperature control, air flow control "Knowledge based, fuzzy logic"	Typically 2-18% savings

Note: The estimated savings are valid for specific applications (e.g. lighting energy use). The energy savings cannot be added, due to overlap of the systems. Sources: (Caffal, 1995, Martin et al., 2000).

Modern control systems are often not solely designed for energy efficiency, but rather at improving productivity, product quality and efficiency of a production line. Applications of advanced control and energy management systems are in varying development stages and can be found in all industrial sectors. Control systems result in reduced downtime, reduced maintenance costs, reduced processing time, and increased resource and energy efficiency, as well as improved emissions control. Many modern energy-efficient technologies depend heavily on precise control of process variables, and applications of process control systems are growing rapidly. Modern process control systems exist for virtually any industrial process.

Still, large potentials exist to implement control systems and more modern systems enter the market continuously. Hydrocarbon Processing produces a semi-annual overview of new advanced process control technologies for the refinery and petrochemical industry (see e.g. Hydrocarbon Processing, 2005b).

Process control systems depend on information of many stages of the processes. A separate but related and important area is the development of sensors that are inexpensive to install, reliable, and analyze in real-time. Development aims at the use of optical, ultrasonic, acoustic, and microwave systems, that should be resistant to aggressive environments (e.g. oxidizing environments in furnace or chemicals in chemical processes) and withstand high temperatures. The information of the sensors is used in control systems to adapt the process conditions, based on mathematical ("rule"-based) or neural networks and "fuzzy logic" models of the industrial process.

Neural network-based control systems have successfully been used in the cement (kilns), food (baking), non-ferrous metals (alumina, zinc), pulp and paper (paper stock, lime kiln), petroleum refineries (process, site), and steel industries (electric arc furnaces, rolling mills). New energy management systems that use artificial intelligence, fuzzy logic (neural network), or rule-based systems mimic the "best" controller, using monitoring data and learning from previous experiences.

Process knowledge based systems (KBS) have been used in design and diagnostics, but are hardly used in industrial processes. KBS incorporates scientific and process information applying a reasoning process and rules in the management strategy. A recent demonstration project in a sugar beet mill in the UK using model based predictive control system demonstrated a 1.2 percent reduction in energy costs, while increasing product yield by almost one percent and reducing off-spec product from 11 percent to 4 percent. This system had a simple payback period of 1.4 years (CADDET, 2000a).

Although, energy management systems are already widely disseminated in various industrial sectors, the performance of the systems can still be improved, reducing costs and increasing energy savings further. Research for advanced sensors and controls is ongoing in all sectors, both funded with public funds and private research. Several projects within U.S. DOE's Industrial Technologies Program (ITP) try to develop more advanced control technologies. Sensors and control techniques are identified as key technologies in various development areas including energy efficiency, mild processing technology, environmental performance and inspection and containment boundary integrity. Sensors and controls are also represented in a crosscutting ITP-program. Outside the United States, Japan and Europe also give much attention to advanced controls. Future steps include further development of new sensors and control systems, demonstration in commercial scale, and dissemination of the benefits of control systems in a wide variety of industrial applications.

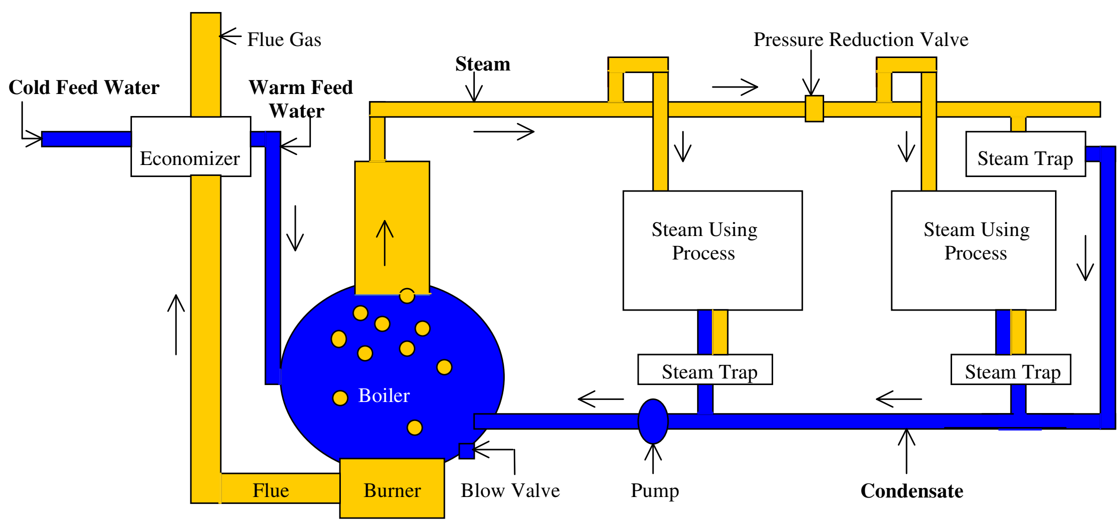
At the ExxonMobil chemical plant in Baton Rouge, Louisiana, replacement of old pneumatic control systems by an advanced digital distribution control system in the isoprene unit reduced steam demand by 43,000 MMBtu. Energy savings accounted for only 20% of the annual savings from the project, with other savings coming from improved product yield, reduced maintenance and lower staffing requirements (U.S. DOE-OIT, 2000b).

7. Steam Systems

Steam is used throughout the chemical industry. An estimated 37% of all onsite energy use in the U.S. chemical industry in 1998 is in the form of steam (U.S. DOE-OIT, 2006a). Steam can be generated by boilers, waste heat recovery from processes and cogeneration with electricity. In the U.S. chemical industry, 11% of the steam (148 TBtu) is produced in cogeneration systems and the remainder in central boiler systems (U.S. DOE-OIT, 2006)[8].

While the size and use of modern systems vary greatly, there is an overall pattern that steam systems follow, as shown in Figure 7.1. This figure depicts a schematic presentation of a steam system. Treated cold feed water is fed to the boiler, where it is heated to form steam. Chemical treatment of the feed water is required to remove impurities. The impurities would otherwise collect on the boiler walls. Even though the feed water has been treated, some impurities still remain and can build up in the boiler water. As a result, water is periodically purged from the boiler in a process known as blowdown. The generated steam travels along the pipes of the distribution system to get to the process where the heat will be used. Sometimes the steam is passed through a pressure reduction valve if the process requires lower pressure steam. As the steam is used to heat processes, and even as it travels through the distribution system to get there, the steam cools and some is condensed. This condensate is removed by a steam trap, which allows condensate to pass through, but blocks the passage of steam. The condensate can be recirculated to the boiler, thus recovering some heat and reducing the need for fresh treated feed water. The recovery of condensate and blowdown will also reduce the costs of boiler feed water treatment.

Figure 7.1 Simplified schematic of a steam production and distribution system. [9]



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[8] According to Onsite (2000), 450 TBtu of steam is produced in cogeneration units, corresponding to 33% of the total steam demand.

[9] Back-pressure steam turbines which may be used to recover power from super-heated steam are not depicted.

Industry uses steam for a wide variety of purposes, the most important being process heating, drying, concentrating, steam cracking, distillation and to drive e.g. compressors. Whatever the use or the source of the steam, efficiency improvements in steam generation, distribution and end use are possible. A recent study by the U.S. Department of Energy estimates the overall potential for energy savings in the U.S. chemical industry at 12.4% of the fuels used to generate steam (U.S. DOE, 2002a). The payback time of the 19 measures included in the analysis ranged from 2-34 months with eleven measures having a payback time of less than 1 year.

It is important to take a system approach in evaluating steam systems. As a first step, it is important to identify where and how steam is used. As one of the results of a site-wide Energy Efficiency Plan, Netherlands-based company Akzo Nobel identified potential savings in the steam system (U.S. DOE-OIT, 2003c). In many areas, steam was not measured. Substantial savings were predicted if steam measurement instrumentation was installed and the use of steam was attributed to specific process areas, so that the plant could employ specific steam waste reduction options. Still, actual steam savings may be hard to quantify. Optimization of the steam system at the Texas Petrochemicals Corporation yielded annual savings of over $2.3 million with a payback time of just over three months. The project included the replacement of an oil contaminating compressor turbine, allowing steam to be re-directed to the main steam line. As a result, also the cooling water system could be revised resulting in savings both in terms of energy and cooling water (U.S. DOE-OIT, 2000c). The use of checklists to conserve energy in steam systems such as the one given by Huchler (2006) can help to systematically pinpoint improvement potentials.

This section focuses on the steam generation in boilers (including waste heat boilers) and distribution. Table 7.1 summarizes the boiler efficiency measures, while Table 7.2 summarizes the steam distribution system measures. Steam, like any other secondary energy carrier, is expensive to produce and supply. The use of steam should be carefully considered and evaluated. Often steam is generated at higher pressures than needed or in larger volumes than needed at a particular time. These inefficiencies may lead steam systems to let down steam to a lower pressure or to vent steam to the atmosphere. Hence, it is strongly recommended to evaluate the steam system on the use of appropriate pressure levels and production schedules. At Nalco Chemical Company in Bedford Park, Illinois, steam pressure could be reduced from 125 to 100 psig without affecting the performance of the plant. The project did not require any capital investment and the specific energy use per pound of product was reduced by 8%. Annual savings are 56,900 MMBtu, cutting costs by $142,000 (U.S. DOE-OIT, 2000d). In a chloromethane unit at the Geismar, Louisiana plant of Vulcan Chemicals, system pressure in two distillation units could be lowered from 35 to 26 psig and from 15 to 11 psig respectively, reducing steam demand in the two units by 5.8%, resulting in energy savings of 22,000 million Btu per year (U.S. DOE-OIT, 2000e).

If it is not possible to reduce the steam generation pressure, it may still be possible to recover the energy through a turbo expander or steam turbine (see section 7.2). In many systems steam may be produced at higher pressures to allow for the efficient cogeneration of power and heat through the use of back-pressure turbines. Excess steam generation can be reduced through improved process integration (see Chapter 9) and improved management of steam flows in the industry (see Chapter 6 on total site management systems).

The normal replacement investments cycle might offer opportunities to change to more energy-efficient steam systems. The implementation of a project that replaces the existing steam generation facility with new boilers in the Rohm and Haas Knoxville, Tennessee, plant is primarily motivated by the age of the existing boilers. It results in higher efficiency and more appropriately sized boilers with steam generation controls tailored to the varying demand of the plant (U.S. DOE-OIT, 2003b). At the same production facility, improved steam system maintenance had an estimated potential to reduce steam demand by approximately 2%.

7.1 Steam Supply – Boilers

Boiler feed water preparation. Depending on the quality of incoming water the boiler feed water (BFW) needs to be pre-treated to a varying degree. Various technologies may be used to clean the water, and the choice of the appropriate technology depends on the water quality and minerals to be removed. A new technology is based on the use of membranes. In reverse osmosis (RO) the pre-filtered water is passed at increased pressure through a semi-permeable membrane. Reverse osmosis and other membrane technologies are used more and more in water treatment (Martin et al., 2000). Membrane processes are very reliable, but need semi-annual cleaning and periodic replacement to maintain performance. In the largest site of Dow Chemicals outside the United States in Terneuzen, the Netherlands, sea-water used to be cleaned by means of reverse osmosis. In collaboration with a water utility company nearby, sea-water is being replaced with effluent water from a nearby sewage treatment plant, reducing energy costs of water treatment by approximately 60% (van Gool, 2006).

Improved process control. Flue gas monitor and control units are used to maintain optimum oxygen concentration in the combustion zone of the boiler. Combustion control also impacts flame temperature, combustible products in the exhaust gases, and smoke. The oxygen content of the exhaust gas is a combination of excess air (which is deliberately introduced to improve efficiency, manage safety, and reduce emissions) and air infiltration (air leaking into the boiler). Using a combination of CO and oxygen readings, it is possible to optimize the fuel/air mixture for an optimal flame temperature that optimizes energy efficiency and NOx emissions. The payback of installing flue gas analyzers to determine proper air/fuel ratios is on average 0.6 years (IAC, 2006). This measure may be too expensive for small boilers. Changes in the existing control system of two boilers at ExxonMobil's Mary Ann Plant in Mobile, Alabama, reduced annual energy consumption by 170 TBtu. The original control system was based on past operating conditions where excess high pressure steam was provided by waste heat boilers. Changes in the plant now require production of high pressure steam via boilers. After the modifications, the plant operates in a more efficient thermal following mode, whereas before the modification, the boilers were operated base load (U.S. DOE-OIT, 2002b). An upgrade of the Burner Management System (more specifically the flame detection system) of two large coal-fired boilers at the soda ash mine of FMC chemicals in Green River, Wyoming resulted in annual energy savings of 250 TBtu with a payback time of only 6 weeks (U.S. DOE-OIT, 2004b) due to elimination of the co-firing of natural gas as the flame detection system was inadequate.

Reduce flue gas quantities. Often, excessive flue gas results from leaks in the boiler and the flue, reducing the heat transferred to the steam, and increasing pumping requirements. These leaks are often easily repaired. Savings amount to 2-5% (OIT, 1998). This measure consists of a periodic repair based on visual inspection. The savings from this measure and from flue gas monitoring are not cumulative, as they both address the same losses.

Reduce excess air. The more air is used to burn the fuel, the more heat is wasted in heating the air. Air slightly in excess of the ideal stoichiometric fuel/air ratio is required for safety, and to ensure all the fuel reacts. NO_x emissions are also impacted by the amount of excess air in the combustion zone, which is dependent on the type of fuel. For gas and oil-fired boilers approximately 15% excess air is adequate (OIT, 1998; Ganapathy, 1994). Poorly maintained boilers can have up to 140% excess air. Reducing this back down to 15% (using continuous automatic monitoring and controls) would save 8% in fuel use. On well-designed natural gas-fired systems, an excess air level of 10% is attainable. An often stated rule of thumb is that boiler efficiency can be increased by 1% for each 15% reduction in excess air (U.S. DOE-OIT, 2006b), however actual savings will depend strongly on flue gas temperature.

Improve insulation. New materials insulate better, and have a lower heat capacity. Savings of 6-26% can be achieved if this improved insulation is combined with improved heater circuit controls. This improved control is required to maintain the output temperature range of the old firebrick system. As a result of the ceramic fiber's lower heat capacity the output temperature is more vulnerable to temperature fluctuations in the heating elements (Caffal, 1995). The shell losses of a well-maintained boiler should be less than 1%.

Maintenance. A simple maintenance program to ensure that all components of the boiler are operating at peak performance can result in substantial savings. In the absence of a good maintenance system, the burners and condensate return systems can wear or get out of adjustment. These factors can end up costing a steam system up to 20-30% of the initial efficiency over 2-3 years (DOE, 2001a). On average the possible energy savings are estimated at 10% (DOE, 2001a). Improved maintenance may also reduce the emission of criteria air pollutants.

Fouling of the fireside of the boiler tubes or scaling on the waterside of the boiler should also be controlled. Fouling and scaling are more of a problem with coal-fed boilers than natural gas or oil-fed ones (i.e. boilers that burn solid fuels like coal should be checked more often as they have a higher fouling tendency than liquid fuel boilers do). Tests show that a soot layer of 0.03 inches (0.8 mm) reduces heat transfer by 9.5%, while a 0.18 inch (4.5 mm) layer reduces heat transfer by 69% (CIPEC, 2001). For scaling, 0.04 inches (1 mm) of buildup can increase fuel consumption by 2% (CIPEC, 2001). Moreover, scaling may result in tube failures.

Recover heat from flue gas. Heat from flue gasses can be used to preheat boiler feed water in an economizer. While this measure is fairly common in large boilers, there is often still potential for additional heat recovery. The limiting factor for flue gas heat recovery is the economizer wall temperature that should not drop below the dew point of acids in the flue gas.

Traditionally this is done by keeping the flue gases at a temperature significantly above the acid dew point. However, the economizer wall temperature is more dependent on the feed water temperature than flue gas temperature because of the high heat transfer coefficient of water. As a result, it makes more sense to preheat the feed water to close to the acid dew point before it enters the economizer. This allows the economizer to be designed so that the flue gas exiting the economizer is just barely above the acid dew point. 1% of fuel use is saved for every 25°C reduction in exhaust gas temperature. (Ganapathy, 1994). Since exhaust gas temperatures are already quite low, limiting savings to 1% across all boilers, with a payback of 2 years (IAC, 2006). For individual boilers, savings can be up to 5-10% (U.S. DOE-OIT, 2006c).

Recover heat from boiler blowdown. When the water is blown from the high-pressure boiler tank, the pressure reduction often produces substantial amounts of steam. This steam is low grade, but can be used for space heating and feed water preheating. For larger high-pressure boilers the losses may be less than 0.5%. It is estimated that this measure can save 1.3% of boiler fuel use for all boilers below 100 MMBtu/hr. According to U.S. DOE-OIT (2002a), installation of continuous blowdown heat recovery is a feasible option at 12% of the boilers in the pulp and paper, chemical and refinery industries. The payback time is estimated at 20 months with typical fuels savings of 0.8%.

Table 7.1 Summary of energy efficiency measures in boilers.

Measure	Fuel Saved	Payback Period (years)	Other Benefits
Improved Process Control	3%	0.6	Reduced Emissions
Reduced Flue Gas Quantity	2-5%	-	Cheaper emission controls
Reduced Excess Air	1% improvement for each 15% less excess air	-	
Improved Insulation	6-26%	?	Faster warm-up
Boiler Maintenance	10%	0	Reduced emissions
Flue Gas Heat Recovery	1%	2	
Blowdown Steam Heat Recovery	1.3%	1 - 2.7	Reduced damage to structures (less moist air is less corrosive).
Alternative Fuels	Variable	-	Reduces solid waste stream at the cost of increased air emissions

Reduce standby losses. In the chemical industry, often one or more boilers are kept on standby in case of failure of the operating boiler. The steam production at standby can be reduced to virtually zero by modifying the burner, combustion air supply and boiler feedwater supply. By installing an automatic control system the boiler can reach full capacity within 12 minutes. Installing the control system and modifying the boiler can result in energy savings up to 85% of the standby boiler, depending on the use pattern of the boiler. The Kemira Oy ammonia plant at Rozenburg (The Netherlands) applied this system to a 40 t/hr steam boiler, reducing the standby steam consumption from the boiler from 6 t/hr to 1 t/hr. This resulted in energy savings of 54 TBtu/year. Investments were approximately $270,000 (1991$), resulting in a payback period of 1.5 years at this particular plant (CADDET, 1997a).

7.2 Steam Supply - Combined Heat and Power

The chemical industry offers an excellent opportunity for energy-efficient power generation in the form of combined heat and power production (CHP). CHP provides the opportunity to use internally generated fuels for power production, allowing greater independence of grid operation and even export to the grid. This increases reliability of supply as well as the cost-effectiveness. The cost benefits of power export to the grid will depend on the regulation in the state where the industry is located. Not all states allow wheeling of power (i.e. sales of power directly to another customer using the grid for transport) while the regulation may also differ with respect to the tariff structure for power sales to the grid operator. The chemical industry is the largest user of cogeneration or CHP in the country. Installed capacity in 1999 was estimated to be over 17,000 MWe (Onsite, 2000), making the chemical industry by far the largest CHP user. Still only 450 TBtu of steam on a total steam load of 1332 TBtu steam load (33%) in the chemical industry is generated in cogeneration units (Onsite, 2000)[10]. The chemical industry is therefore also identified as one of the industries with the largest potential for increased application of CHP. The potential for conventional cogeneration (CHP) is estimated at an additional 9,440 MWe and 495 TBtu of steam (Onsite, 2000), of which most in medium to large-scale gas installations (> 1 MW).

As a result of the introduction of a site-wide Energy Efficiency Plan Akzo Nobel identified cogeneration of steam and electricity as an important means of saving energy at its Morris, Illinois plant (U.S. DOE-OIT, 2003c). Project costs were estimated at $4.5 – $5 million with a pay-back period of 4-5 year.

Where process heat, steam or cooling and electricity are used, cogeneration plants are significantly more efficient than standard power plants because they take advantage of what are losses in conventional power plants by utilizing waste heat. In addition, transportation losses are minimized when CHP systems are located at or near the end user. Third parties have developed CHP for use by the chemical industry. In this scenario, the third party company owns and operates the system for the chemical industry, which avoids the capital expenditures associated with CHP projects, but gains (part of) the benefits of a more energy efficient system of heat and electricity supply. In fact, about 60% of the cogeneration facilities operated within the manufacturing industry has some third party involvement (Onsite, 2000). In some cases, the plant neighborhood offers opportunities for innovative collaborations. In a plant-wide energy efficiency assessment of the W.R. Grace Curtis Bay Works in Baltimore, Maryland, a project was identified that would link the plant with the city of Baltimore. It involves using landfill gas (methane) currently being flared for cogeneration of electricity and steam. The cogeneration facility could provide 40% of the Curtis Bay Works' electricity requirements and 65% of its steam requirements. Implementation would require working together with the city of Baltimore and the third-party owner of the landfill (U.S. DOE-OIT, 2003g).

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[10] According to energy footprint (U.S. DOE-OIT, 2006a), only 148 TBtu of steam is produced in cogeneration units, corresponding to only 11% of the total steam demand.

For systems requiring cooling, absorption cooling can be combined with CHP, using waste heat to produce cooling power. In the chemical industry, refrigeration and cooling consumes about 5-6% of all electricity. Cogeneration in combination with absorption cooling has been demonstrated for building sites and sites with refrigeration leads. The authors do not know of applications in the petrochemical industry.

Innovative gas turbine technologies can make CHP more attractive for sites with large variations in heat demand.

Steam injected gas turbines (STIG or Cheng cycle) can absorb excess steam, e.g. due to seasonal reduced heating needs, to boost power production by injecting the steam in the turbine. The size of typical STIGs starts around 5 MW_e, and is currently scaled up to sizes of 125 MW. STIGs have been installed at over 50 sites worldwide, and are found in various industries and applications, especially in Japan and Europe, as well as in the U.S. Energy savings and payback period will depend on the local circumstances (e.g. energy patterns, power sales conditions). In the United States, the Cheng Cycle is marketed by International Power Systems (San Jose, California). The Austrian oil company OMV has considered the use of a STIG to upgrade an existing cogeneration system. The authors do not know of any current commercial applications of STIG in the petrochemical industry.

Steam turbines are often used as part of the CHP system in the chemical industry or as stand-alone systems for power generation. The efficiency of the steam turbine is determined by the inlet steam pressure and temperature as well as the outlet pressure. Each turbine is designed for a certain steam inlet pressure and temperature, and operators should make sure that the steam inlet temperature and pressure are optimal. An 18°F decrease in steam inlet temperature will reduce the efficiency of the steam turbine by 1.1% (Patel and Nath, 2000). Similarly, maintaining exhaust vacuum of a condensing turbine or the outlet pressure of a backpressure turbine too high will result in efficiency losses.

Combined cycle CHP plants include heat-recovery boilers. The design of these units differs considerably from the design of conventional oil or gas fired boilers and requires good understanding of the temperature profile in the unit. Options to improve efficiency include proper pinch analysis and auxiliary firing as discussed by Ganapathy (2001).

High-temperature CHP. Turbines can be pre-coupled to a crude distillation unit (or other continuously operated processes with an applicable temperature range). The off gases of the gas turbine can be used to supply the heat for the distillation furnace, if the outlet temperature of the turbine is high enough. One option is the so-called `repowering' option. In this option, the furnace is not modified, but the combustion air fans in the furnace are replaced by a gas turbine. The exhaust gases still contain a considerable amount of oxygen, and can thus be used as combustion air for the furnaces. Gas turbine coupling in ethylene crackers is discussed in Chapter 16.

Another option, with a larger CHP potential and associated energy savings, is "high-temperature CHP". In this case, the flue gases of a CHP plant are used to heat the input of a furnace or to preheat the combustion air. This option requires replacing the existing furnaces.

This is due to the fact that the radiative heat transfer from gas turbine exhaust gases is much smaller than from combustion gases, due to their lower temperature (Worrell et al., 1997). A distinction is made between two different types. In the first type, the exhaust heat of a gas turbine is led to a waste heat recovery furnace, in which the process feed is heated. In the second type the exhaust heat is led to a "waste heat oil heater" in which thermal oil is heated. By means of a heat exchanger, the heat content is transferred to the process feed. In both systems, the remaining heat in the exhaust gases after heating the process feed should be used for lower temperature purposes to achieve a high overall efficiency. The second type is more reliable, due to the fact that a thermal oil buffer can be included. The main difference is that in the first type the process feed is directly heated by exhaust gases, where the second uses thermal oil as an intermediate, leading to larger flexibility. An installation of the first type is installed in Fredericia, Denmark at a Shell refinery. The low temperature remaining heat is used for district heating. Detailed design studies for the chemical industry and the optimization of furnace design, and more demonstration projects have to be carried out.

Steam expansion turbines. Steam is generated at high pressures, but often the pressure is reduced to allow the steam to be used by different processes. For example, steam is generated at 120 to 150 psig. This steam then flows through the distribution system within the plant. The pressure is reduced to as low as 10-15 psig for use in different process. Once the heat has been extracted, the condensate is often returned to the steam generating plant. Typically, the pressure reduction is accomplished through a pressure reduction valve (PRV). These valves do not recover the energy embodied in the pressure drop. This energy could be recovered by using a micro scale backpressure steam turbine. Several manufactures produce these turbine sets, such as Turbosteam (previously owned by Trigen) and Dresser-Rand.

The potential for application will depend on the particular steam system used. Applications of this technology have been commercially demonstrated for various installations. The investments of a typical expansion turbine are estimated at 600 $/kWe, and operation and maintenance costs at 0.011 $/kWh.

In an energy-efficiency assessment of the 3M Hutchinson, Minnesota facility, the installation of a steam turbine replacing a pressure-reduction valve was identifies as a project that could save 3,166 MWh of electricity per year (U.S. DOE-OIT, 2003f). Capital costs for the project were estimated at $604,034 and avoided first year energy expenses at $163,999.

7.3 Steam Distribution

When designing new steam distribution systems it is very important to take into account the velocity and pressure drop (Van de Ruit, 2000). This reduces the risk of oversizing a steam pipe, which is not only a cost issue but would also lead to higher heat losses. A pipe too small may lead to erosion and increased pressure drop. Installations and steam demands change over time, which may lead to under-utilization of the steam distribution capacity, and extra heat losses. However, it may be too expensive to optimize the system for changed steam demands. Still, checking for excess distribution lines and shutting off those lines is a cost-effective way to reduce steam distribution losses. Other maintenance measures for steam distribution systems are described below.

Improve insulation. This measure can include the use of more insulating material, or to make a careful analysis of the proper insulation material. Crucial factors in choosing insulating material include: low thermal conductivity, dimensional stability under temperature change, resistance to water absorption, and resistance to combustion. Other characteristics of insulating material may also be important depending on the application, e.g. tolerance of large temperature variations and system vibration, and compressive strength where insulation is load bearing (Baen and Barth, 1994). Improving the insulation on the existing stock of heat distribution systems would save an average of 3-13% in all systems (OIT, 1998) with an average payback period of 1.1 years (IAC, 2006). The U.S. Department of Energy has developed the software tool 3E-Plus to evaluate the optimal insulation for steam systems (see Appendix F).

Maintain insulation. It is often found that after repairs, the insulation is not replaced. In addition, some types of insulation can become brittle, or can rot. As a result, energy can be saved by a regular inspection and maintenance system (CIBO, 1998). Energy savings and payback periods will vary with the specific situation in each plant.

Improve steam traps. Using modern thermostatic element steam traps can reduce energy use while improving reliability. The main advantages offered by these traps are that they open when the temperature is very close to that of the saturated steam (within 2°C), purge non-condensable gases after each opening, and are open on startup to allow a fast steam system warm-up. These traps are also very reliable, and useable for a wide variety of steam pressures (Alesson, 1995). Energy savings will vary depending on the number of steam traps installed and the state of maintenance. Examples of thermostatic traps are pinch traps. In these traps, a modulator automatically closes off flow as a chemically resistant elastomer around the modulator expands with the passage of hot condensate. As the condensate builds up and cools, the elastomer around the modulator contracts allowing the orifice to open and create flow. It automatically responds to condensate temperature, has no live steam losses and uses energy in the steam line at maximum efficiency (Kane et al., 1998).

Maintain steam traps. A simple program of checking steam traps to ensure they operate properly can save significant amounts of energy. If the steam traps are not regularly monitored, 15-20% of the traps can be malfunctioning. In some plants as many as 40% of the steam traps were malfunctioning. Energy savings for a regular system of steam trap checks and follow-up maintenance is estimated at 10% (OIT, 1998; Jones 1997; Bloss, 1997) with a payback period of 0.4 years (IAC, 2006). This measure offers a quick payback but is often not implemented because maintenance and energy costs are separately budgeted. Some systems already use this practice. Improvement of steam trap maintenance system at the Chestertown facility of Velsicol Chemical Corporation resulted in energy savings of 27,308 million Btu annually ($80,000). In addition, because of the reduced need for boiler feed water, consumption of water treatment chemicals was also reduced by 1,000 pounds, saving $20,000 annually (U.S. DOE-OIT, 2000f).

Monitor steam traps automatically. Attaching automated monitors to steam traps in conjunction with a maintenance program can save even more energy, without significant added cost. This system is an improvement over steam trap maintenance alone, because it gives quicker notice of steam trap malfunctioning or failure. Using automatic monitoring is estimated to save an additional 5% over steam trap maintenance, with a payback of 1 year[11] (Johnston, 1995; Jones, 1997). Systems that are able to implement steam trap maintenance are also likely to be able to implement automatic monitoring. On average 50% of systems can still implement automatic monitoring of steam traps.

Repair leaks. As with steam traps, the distribution pipes themselves often have leaks that go unnoticed without a program of regular inspection and maintenance. In addition to saving up to 3% of energy costs for steam production, having such a program can reduce the likelihood of having to repair major leaks. (OIT, 1998). On average leak repair has a payback period of 0.3 years (IAC, 2006).

Recover flash steam. When a steam trap purges condensate from a pressurized steam distribution system to ambient pressure, flash steam is produced. This steam can be used for space heating or feed water preheating (Johnston, 1995). The potential for this measure is extremely site dependent, as it is unlikely that a producer will want to build an entirely new system of pipes to transport this low-grade steam to places where it can be used, unless it can be used close to the steam traps. Many sites will use multi-pressure steam systems. In this case flash steam formed from high-pressure condensate can be routed to reduced pressure systems.

Vulcan Chemicals in Geismar (Louisiana) implemented a flash steam recovery project at one of the processes at their chemical plant. The project recovers 100% of the flash steam and resulted in net energy savings of 2.8% (Bronhold, 2000).

Table 7.2 Summary of energy efficiency measures in steam distribution systems.

Measure	Fuel Saved	Payback Period (years)	Other Benefits
Improved Insulation	3-13%	1.1	
Improved Steam Traps	Unknown	Unknown	Greater reliability
Steam Trap Maintenance	10-15%	0.5	
Automatic Steam Trap Monitoring[12]	5%	1	
Leak Repair	3-5%	0.4	Reduced requirement for major repairs
Flash Steam Recovery/ Condensate Return	83%[13]	Unknown	Reduced water treatment costs
Condensate Return Alone	10%	1.1	Reduced water treatment costs

[11] Calculated based on a UK payback of 0.75 years. The U.S. payback is longer because energy prices in the U.S. are lower, while capital costs are similar.
[12] In addition to a regular maintenance program
[13] Includes flash steam recovery from the boiler. Although this represents actual savings achieved in a case study, it seems much too high to be a generally applicable savings number. As a result, it is not included in our total savings estimate.

Return condensate. Reusing the hot condensate in the boiler saves energy and reduces the need for treated boiler feed water. The substantial savings in energy costs and purchased chemicals costs makes building a return piping system attractive. This measure has already been implemented in most places where it is easy to accomplish. Care has to be taken to design the recovery system to reduce efficiency losses (van de Ruit, 2000). Maximum energy savings are estimated at 10% (OIT, 1998) with a payback of 1 year (IAC, 2006) for those sites without or with insufficient condensate return. An additional benefit of condensate recovery is the reduction of the blowdown flow rate because boiler feedwater quality has been increased.

In a plant-wide assessment of a Bayer Polymers plant in New Martinsville, West Virginia (U.S. DOE-OIT, 2003d), increasing steam boiler return condensates rates from the present 30% to 75% was identified as a project that would result in energy savings of 66,600 MMBtu per year and a 7.53 million pound reduction in CO_2 emissions. Estimated pay-back time for the project was 3 months at total project costs of $ 100,000. In an assessment of the Formosa Plastics Corporation polyethylene plant (U.S. DOE-OIT, 2005a), the recovery of steam condensate was identified as a project that could result in fuel savings of 5,600 MMBtu per year, saving $56,000 in fuel costs and reduced water make-up costs. The payback time for the project was 1.4 year.

7.4 Steam End Uses

Additional opportunities exist to improve the steam system at the end use level. Two examples are the more efficient use of steam in heating and vacuum production applications. In a study by U.S. DOE-OIT (2002a), the potential fuel savings at the facility level were estimated at 2.0% (heating application) and 2.1% (vacuum production). It was estimated that these measures could be applied at 18% (heating applications) and 7% (vacuum production) of all chemical facilities operating.

8. Furnaces / Process Heaters

Approximately 30% of the fuel used in the chemical industry is used in fired heaters. The average thermal efficiency of furnaces is estimated at 75-90% (Petrick and Pellegrino, 1999). Accounting for unavoidable heat losses and dewpoint considerations the theoretical maximum efficiency is around 92% (HHV) (Petrick and Pellegrino, 1999). This suggests that typical savings of 10% can be achieved in furnace and burner design, and operations. In the following section, various improvement opportunities are discussed, including improving heat transfer characteristics, enhancing flame luminosity, installing recuperators or air-preheaters and improved controls. New burner designs aim at improved mixing of fuel and air and more efficient heat transfer. Many different concepts are developed to achieve these goals, including lean-premix burners (Seebold et al., 2001), swirl burners (Cheng, 1999), pulsating burners (Petrick and Pellegrino, 1999) and rotary burners (U.S. DOE-OIT, 2002c). At the same time, furnace and burner design has to address safety and environmental concerns. The most notable is the reduction of NOx emissions. Improved NOx control will be necessary in many chemical industries to meet air quality standards.

Heat generation. In heat generation, chemical or electrical energy is converted into thermal energy. A first opportunity to improve the efficiency of heat generation is to control the air-to-fuel ratio in furnaces. Badly maintained process heaters may use excess air. This reduces the efficiency of the burners. Excess air should be limited to 2-3% oxygen to ensure complete combustion. Typical energy savings of better controlled air to fuel ratios vary between 5 and 25% (U.S. DOE-OIT, 2004c). The use of up-to-date exhaust gas oxygen analyzer can help to maintain optimal air-to-fuel ratios. At the Deer Park facility of Rohm and Haas, old exhaust oxygen analyzers resulted in delayed reading and made it more difficult to accurately monitor combustion conditions. Installation of three new analyzers in the furnace ducts resulted in real-time readings of oxygen levels and better process control (U.S. DOE-OIT, 2006d). Typical payback times of projects aiming to reduce combustion air flows by better control are around 6 months or less (IAC, 2006).

In many areas new air quality regulation will demand industries to reduce NOx and VOC emissions from furnaces and boilers. Instead of installing expensive selective catalytic reduction (SCR) flue-gas treatment unit's new burner technology allows to reduce emissions dramatically. This will result in cost savings as well as help to decrease electricity costs for the SCR. In a plant-wide assessment of a Bayer Polymers plant in New Martinsville, West Virginia (U.S. DOE-OIT, 2003d), the replacement of natural gas and hydrogen fuelled burners with efficient low NO_x design burners was identified as a project that could result in 2% efficiency improvements saving 74,800 MMBtu per year and annual CO_2 emission reductions of 8.46 million pounds. Estimated pay-back time for the project was 13 months at total project costs of $ 390,000. Efficient use of existing burners can also help to save energy and reduce NO_x emissions. In an energy-efficiency assessment of the Anaheim, California site of Neville Chemical Company (U.S. DOE-OIT, 2003e), a potential project was identified in which only a single natural gas fuelled incinerator (instead of the two operated) can be used to incinerate Volatile Organic Compounds (VOCs). This would result in energy savings of 8 TBtu per year. Project costs were estimated at $57,500 with a payback period of 1.3 years.

Heat transfer and heat containment in heaters. Improved heat transfer within a furnace, oven or boiler can result in both energy savings and productivity gains. There can be several ways to improve heat transfer such as the use of soot blowers, burning off carbon and other deposits from radiant tubes and cleaning the heat exchange surfaces. Typical savings are 5-10% (U.S. DOE-OIT, 2004c). Ceramic coated furnace tubes can improve heat transfer of metal process tubing, while stabilizing the process tube's surface. They can improve energy efficiency, increase throughput or both. Increased heat transfer is accomplished by eliminating the insulating layers on the fire-side of process tubing that form during operation. Applications in boilers and petrochemical process units have shown efficiency improvements between 4% and 12% (Hellander, 1997). Heat containment can be improved by numerous measures, including reducing wall heat losses (typical savings 2-5%), furnace pressure control (5-10%), maintenance of door and tube seals (up to 5%), reducing cooling of internal parts (up to 5%) and reducing radiation heat losses (up to 5%). Typical payback times of project aiming to reduce heat losses and improved heat transfer are between 3 months and 1 year (IAC, 2006).

Flue gas heat recovery. Reducing exhaust losses (e.g. by the measures described above) should always be the first concern in any energy conservation program. Once this goal has been met, the second level should be considered – recovery of exhaust gas waste heat. Use of waste heat to preheat combustion air is commonly used in medium to high temperature furnace. It is an efficient way of improving the efficiency and increasing the capacity of a process heater. The flue gases of the furnace are used to preheat the combustion air. Every 35°F drop in the exit flue gas temperature increases the thermal efficiency of the furnace by 1% (Garg, 1998). Typical fuel savings range between 8 and 18%, and is typically economically attractive if the flue gas temperature is higher than 650°F and the heater size is 50 MMBtu/hr or more (Garg, 1998). The optimum flue gas temperature is also determined by the sulfur content of the flue gases to reduce corrosion. When adding a preheater the burner needs to be re-rated for optimum efficiency. Energy recovery can also be applied in catalytic oxidizers used to reduce volatile organic compound (VOC) emissions, e.g. via a regenerative heat exchanger in the form of a ceramic packing (Hydrocarbon Processing, 2003).

Heat from furnace exhaust gases or from other sources (discussed in Chapter 9) can also be used in waste heat or quench boilers to produce steam (discussed in Chapter 7) or to cascade heat to other applications requiring lower temperature heat as part of the total plant heat demand and supply optimization (see also Chapter 9 on process integration). Recovering thermal energy in the form of steam from incineration of waste products should be considered carefully. Because a waste stream is used, the stream will have variations in contaminant and component concentrations which influence to load on the boiler. Also, the contaminants might create acid gases causing corrosion problems for the boiler. These aspects should be taken into account in designing waste heat boilers (Ganapathy, 1995).

The benefits from heat recovery projects have been shown in various case studies. In an energy-efficiency assessment of the 3M Hutchinson, Minnesota, facilities, heat recovery from thermal oxidizers in the form of low-pressure steam was identified as a project that could save 210,000 MMBtu of fuels (U.S. DOE-OIT, 2003f). Project capital costs are $913,275 with avoided first year energy expenses of $772,191. In an audit of the W.R. Grace facility in

Curtis Bay, Baltimore, Maryland, a project was identified that uses flue gas heat in an air-to-water heat exchanger for fresh water heating, reducing the original steam demand for heating this water by 31%. Capital costs for this project are estimated at $346,800 with a relatively long payback period of 5.3 years (U.S. DOE-OIT, 2003g). In a project in the UK, heat recovery from an incinerator via a run-around coil system yielded energy savings of 9 TBtu per year with a payback time of 1.5 years (Best Practice Programme, 1991). Heat recovery from the SO_2 containing gases of a sulphur burning process in a sulphonation plant in Norway resulted in energy savings of 4,800 MWh per year (CADDETT, 2000b). Investment costs were $800,000 and the simple payback time of the project 6 years.

Others – controls, maintenance and electric heaters. Energy losses can also be reduced via improved process control. Improved control systems can help to improve aspects such as material handling, heat storage and plant turndown. Typical savings of improved control systems can be in the range of 2-10% (U.S DOE-OIT, 2004c). A relatively small part of the heating requirements in the chemical industry is supplied by electrically heated devices. Still, electric heaters account for approximately 3% of the electricity use of the chemical industry (U.S. DOE-OIT, 2006a). Not in all cases, electric heating is the right choice (Best Practice Programme, 2001) and in a number of cases, improvements are possible. For example, in an energy-efficiency assessment of the Anaheim, California site of Neville Chemical Company (U.S. DOE-OIT, 2003e), a potential project was identified in which electric heaters are to be replaced with a natural-gas fired heat fired system, using 557 MMBtu per year, but replacing 114,318 kWh of electricity. Project costs for the project were estimated at $6,100 with a payback time of 0.9 years. In an assessment of a Formosa Plastics Corporation polyethylene plant (U.S. DOE-OIT, 2005a), improvement of an electrically heated extruder was identified as a project that could result in electricity savings of 1,488,000 kWh annually, resulting in annual cost savings of $59,520. The estimated payback time for the projects was 0.1 year.

9. Heating, Cooling and Process Integration

Heating and cooling are operations found throughout the petrochemical industry. Within processes, multiple streams are heated and cooled multiple times. Optimal design of heat exchangers is a key are for energy efficiency improvement (Section 9.1) as well as proper design of the cooling water system (Section 9.2), optimal heat recovery (Section 9.3) and overall process integration (Section 9.4).

9.1 Heat Transfer – Fouling.

Heat exchangers are used throughout the chemical industry to recover heat from processes and transfer heat to the process flows. Next to efficient integration of heat flows throughout the chemical industry (see process integration below), the efficient operation of heat exchangers is a major area of interest. In many chemical plants, processes occur under high temperature and/or pressure conditions; the management and optimization of heat transfer among processes is therefore key to increasing overall energy efficiency. Fouling, a deposit buildup in units and piping that impede heat transfer, requires the combustion of additional fuel. For example, in the processing of feedstock in the production ethylene and other olefins in the steam cracker process, carbon builds up on the radiant coils. All cracking furnaces therefore require periodic de-coking. Cycle times are typically in the range of 14 – 100 days, depending on the type of feedstock, the coil configuration and the operating conditions (EC-IPPC, 2003).

Fouling is the effect of several process variables and heat exchanger design. Fouling may follow the combination of different mechanisms (Bott, 2001). Several methods of investigation have been underway to attempt to reduce fouling, including the use of sensors to detect early fouling, physical and chemical methods to create high temperature coatings (without equipment modification), the use of ultrasound, as well as the improved long term design and operation of facilities. The U.S. Department of Energy initially funded preliminary research into this area, but funding has been discontinued (Huangfu, 2000; Bott, 2000). Worldwide, research in fouling reduction and mitigation is continuing (Polley and Pugh, 2002; Polley et al. 2002) by focusing on understanding the principles of fouling and redesign of heat exchangers and reactors. Currently, various methods to reduce fouling focus on process control, temperature control and regular maintenance and cleaning of the heat exchangers (either mechanically or chemically) or retrofit the reactor tubes (Barletta, 1998). In steam cracker furnaces, typical options include the use of either sulfuric or non-sulfuric inhibitor chemicals and the use of surface coatings.

Prevention of fouling and clogging is better than the cure and it is therefore recommendable to either select those heat exchangers that are least likely to suffer from fouling or to use filtration equipment more upstream (Best Practice Programme, 1994).

9.2 Cooling Water Equipment

Virtually all industrial companies operate plants or equipment that requires cooling. Depending on the temperature level required, various cooling methods can be applied including ambient air cooling (for temperature down to 45ºC, or 113°F), water cooling (down to around 15ºC or 59°F) and refrigerated systems for lower temperatures (Best Practice Programme, 1999a).

It goes without saying that total cooling (and heating) demands should be optimized using process integration techniques as described in section 9.4. Optimization of the various cooling efforts on a plant site could reduce energy demand. Through consolidation of the chilled water system of two plants at the 3M Hutchinson, Minnesota production facility, the newer and more efficient chiller of one the two plants could be used for larger loads for longer periods, reducing electricity demand by 1.5 million kWh per year (U.S. DOE-OIT, 2003f). Project capital costs were estimated at $292,545 with a payback period of 3.3 years. Optimizing the cooling of the air compressors at the same site could further reduce the electricity demand by approximately 1 million kWh, with capital costs of $236,115 and payback period of 4.2 years.

Cooling water systems are historically the most common means of providing industrial cooling, because of multiple advantages such as the safety of water, the ease of operating large centralized systems that are easy to engineer and operate (Best Practice Programme, 1999a). Regular checks of the cooling water system, e.g. by metering water flows at appropriate spots can help to identify water leaks and opportunities for system optimization. A site survey and a full mass balance of all water flows at AH Marks, an organic chemical producer in the UK, resulted in total reduction of water use by 70%. This was achieved by repairing faulty valves, an underground leak and by reducing losses during the filling and emptying of reactor jackets (Best Practice Programme, 1999a). Although water savings will not be that high in most cases, good regular maintenance checks can contribute to significant water and hence energy savings.

Since pumps are the major energy consumer in cooling water systems, measures to improve pump efficiency can yield significant energy savings (see Chapter 11). Other potential efficiency improvements in cooling water systems included improved flow control to avoid over-cooling of process streams. Cooling towers are often designed for the maximum summer temperature would be over dimensioned most of the year. In mechanical draught towers, fans can often be switched off without adverse effects (Best Practice Programme, 1999a).

9.3 Heat Recovery

Heat recovery is not limited to heat recovery from flue gases (see Section 7.1 and 8.3). Also other, often low-temperature heat sources can be recovered in an economic way, e.g. for space heating or feed (water) preheating. At a plastic factory in Scotland, waste heat from plastic injection molding machines was discarded to the atmosphere, whereas at the same time, additional energy was used to provide space heating. Redesign of the system made it possible to use the waste heat for space heating, thereby reducing energy use by over 3.2 TBtu/year. The payback time for the project was only 6-7 months (CADDET, 1991).

As a result of the introduction of a site-wide Energy Efficiency Plan, Netherlands-based company Akzo Nobel identified heat recovery in one of the main distillation column in a fatty acid production unit at its Morris, Illinois site as a potential energy saving project, resulting in natural gas savings of nearly 7 TBtu with project costs of $250,000. The payback period, however, was quite long with an estimated 6-7 years (U.S. DOE-OIT, 2003c).

In an audit of the W.R. Grace facility in Curtis Bay, Baltimore, Maryland, two projects were identified that recover low temperature heat. In the first project (capital costs, $197,000, payback period 2.4 years), waste water with a temperature of 145 ºF is used to pre-heat fresh water intake of the same plant by installing a heat exchanger, reducing the steam demand to heat the fresh water by 90%. In the second project (capital costs $614,500, payback period 2.2 years), the heat embodied in heated air that is now exhausted directly into the atmosphere is used in an air-to-water heat exchanger to heat incoming fresh water in two other plants, replacing 100% of the fresh water heating steam demand in one of the plants and 23% in the other (U.S. DOE-OIT, 2003g).

9.4 Process Integration

Process integration refers to the exploitation of potential synergies that are inherent in any system that consists of multiple components working together. German chemical producer BASF uses process integration as the key towards energy efficient production (Williams, 2006).

In plants that have multiple heating and cooling demands, the use of pinch analysis techniques may significantly improve efficiencies. Developed in the early 1970's, pinch technology is now a well established methodology for continuous processes (Linnhoff, 1992; CADDET, 1993b). The methodology involves the linking of hot and cold streams in a process in a thermodynamic optimal way (i.e. not over the so-called 'pinch'). Process integration is the art of ensuring that the components are well suited and matched in terms of size, function and capability. Pinch Analysis takes a systematic approach to identifying and correcting the performance limiting constraint (or pinch) in any manufacturing process (Kumana, 2000a). It was developed originally in the late 1970s at the University of Manchester in England and other places (Linnhoff, 1993) in response to the "energy crisis" of the 1970s and the need to reduce steam and fuel consumption in oil refineries and chemical plants by optimizing the design of heat exchanger networks. Since then, the pinch approach has been extended to resource conservation in general, whether the resource is capital, time, labor, electrical power, water or a specific chemical compounds such as hydrogen.

The critical innovation in applying pinch analysis was the development of "composite curves" for heating and cooling, which represent the overall thermal energy demand and availability profiles for the process as a whole. When these two curves are drawn on a temperature-enthalpy graph, they reveal the location of the process pinch (the point of closest temperature approach), and the minimum thermodynamic heating and cooling requirements. These are called the energy targets. The methodology involves first identifying the targets and then following a systematic procedure for designing heat exchanger networks to achieve these targets. The optimum approach temperature at the pinch is determined by balancing the capital-energy tradeoffs to achieve the desired payback. The procedure applies equally well to new designs as well as retrofit of existing plants.

The analytical approach to this analysis has been well documented in the literature (Kumana, 2000b; Smith, 1995; Shenoy, 1994). Energy savings potential using Pinch Analysis far exceeds that from well-known conventional techniques such as heat recovery from boiler flue gas, insulation and steam trap management. Examples in styrene and ethylene oxide/ethylene glycol production are described in Chapter 16. Briones et al. (1999) describe the application of pinch analysis in atmospheric and vacuum distillation in refineries.

Pinch analysis, and competing process integration tools, have been developed further in recent years. The most important developments in the energy area are the inclusion of alternative heat recovery processes such as heat pumps and heat transformers, as well as the development of pinch analysis for batch processes (or in other words bringing in time as a factor in the analysis of heat integration). Furthermore, pinch analysis should be used in the design of new processes and plants, as process integration goes beyond optimization of heat exchanger networks (Hallale, 2001). Even in new designs additional opportunities for energy-efficiency improvement can be identified. Pinch analysis has also been extended to the areas of water recovery and efficiency, and hydrogen recovery. Water used to be seen as a low-cost resource to the chemical industry, and was used inefficiently. However, as the standards and costs for waste water treatment increase and the costs for feedwater makeup increase, the industry has become more aware of water costs. In addition, large amounts of energy are used to process and move water through the plant. Hence, water savings will lead to additional energy savings. Water Pinch can be used to develop targets for minimal water use by reusing water in an efficient manner. Optimization software has been developed to optimize investment and operation costs for water systems in a plant (Hallale, 2001). New tools have been developed to optimize water and energy use in an integrated manner (Wu, 2000). Water Pinch has until now mainly been used in the food industry, reporting reductions in water intake of up to 50% (Polley and Polley, 2000). Dunn and Bush (2001) report the use of Water Pinch for optimization of water use in chemical plants operated by Solutia, resulting in sufficient water use reductions to allow expansion of production and of the site with no net increase in water use.

Total site pinch analysis has been applied by many chemical sites around the world to find optimum site-wide utility levels by integrating heating and cooling demands of various processes, and by allowing the integration of CHP into the analysis. Process integration analysis of existing processes should be performed regularly, as continuous changes in product mix, mass flows and applied processes can provide new or improved opportunities for energy and resource efficiency.

Typical savings identified in these site-wide analyses are around 20-30%. Typically, 10-15% savings are achievable under normal economic investment criteria (Linnhoff-March, 2000). Total site pinch analysis has been applied in over 100 case studies on all continents. The largest energy-consuming site ever analyzed by pinch techniques is the fuels and petrochemicals at the coal complex of Sasol Synthetic Fuels in South Africa. In the analysis, various energy efficiency projects were identified. Typical projects were improvement in condensate handling in the steam system, optimizing distillation column feed conditions and increased used of on-site power and heat generation. A powerful deliverable from Total Site analysis is the investment roadmap. The roadmap brings together all the project ideas identified in the pinch study and develops a strategic investment plan which takes the plant personnel from the current situation at the plant to the longer term of improved operation of the site. Such a roadmap has for example been developed for a UK petrochemical plant which was considering the implementation of a large CHP facility to supply heat and power to the site. The roadmap looks at a five year plan for the company before and after the possible implementation of cogeneration. The scoping study first identified steam savings that prevented oversized design of the CHP or boiler replacements. Having established a realistic future steam demand, further project decisions would depend on the choice between CHP and boiler replacement. These choices were all summarized in the roadmap, providing the company with the up-front information required in decision making (Linnhof-March, 2000). Example projects from the plant-wide pinch analysis of a European oil refiner are described by Ricci and Bealing (2003).

In a site analyses by chemical producer Solutia annual savings of $3.9 Million (of which 70% with a low payback time) were identified at their Decatur plant, 0.9M$/year at the Anniston site and 3.6 M$/year at the Pensacola site (Dunn and Bush, 2001).

10. Electric Motors

Motor-driven systems are used throughout the chemical industry for a variety of applications. Of the total electricity use of the chemical industry, about 57% is used in motor systems (U.S. DOE-OIT, 2006a)[14]. Of all electricity used in motors in the U.S. chemical industry, 26% is used by pumps, 11.9% by fans, 27.7% in compressed air systems, 7.7% in refrigeration systems, 23.6% in material processing, 1.4% in material handling and 1.8% for other purposes (Xenergy, 1998).

This Chapter discusses opportunities for motors in general; Pumps, Fans and Compressed air systems are discussed in the other Chapters of the Guide. In order to provide concise information, this section is not exhaustive. The Best Practices initiative of the U.S. Department of Energy (for more information and resources please visit: http://www1.eere.energy.gov/industry/bestpractices/systems.html) and the Motor Decision Matter campaign provide a multitude of specific resources to help optimize motor systems.

When considering energy efficiency improvements to a facility's motor systems, it is important to take a "systems approach." A systems approach strives to optimize the energy efficiency of entire motor systems (i.e., motors, drives, driven equipment such as pumps, fans, and compressors, and controls), not just the energy efficiency of motors as individual components. A systems approach analyzes both the energy supply and energy demand sides of motor systems as well as how these sides interact to optimize total system performance, which includes not only energy use but also system uptime and productivity.

A systems approach typically involves the following steps. First, all applications of motors in a facility should be located and identified. Second, the conditions and specifications of each motor should be documented to provide a current systems inventory. Third, the needs and the actual use of the motor systems should be assessed to determine whether or not motors are properly sized and also how well each motor meets the needs of its driven equipment. Fourth, information on potential repairs and upgrades to the motor systems should be collected, including the economic costs and benefits of implementing repairs and upgrades to enable the energy efficiency improvement decision-making process. Finally, if upgrades are pursued, the performance of the upgraded motor systems should be monitored to determine the actual costs savings (SCE 2003).

The motor system energy efficiency measures below reflect important aspects of this systems approach, including matching motor speeds and loads, proper motor sizing, and upgrading system components.

Motor management plan. A motor management plan is an essential part of a plant's energy management strategy. Having a motor management plan in place can help companies realize long-term motor system energy savings and will ensure that motor failures are handled in a quick and cost effective manner. The Motor Decisions Matter[SM] Campaign suggests the following key elements for a sound motor management plan (MDM 2007):`

[14] The remaining electricity is used for facilities (10%), electrochemical processes (19%) process cooling (8%) and other applications such as electrically fired heaters (6%)

1. Creation of a motor survey and tracking program.
2. Development of guidelines for proactive repair/replace decisions.
3. Preparation for motor failure by creating a spares inventory.
4. Development of a purchasing specification.
5. Development of a repair specification.
6. Development and implementation of a predictive and preventive maintenance program.

The Motor Decisions Matter^{SM} Campaign's *Motor Planning Kit* contains further details on each of these elements (MDM 2007).

Strategic motor selection. Several factors are important when selecting a motor, including motor speed, horsepower, enclosure type, temperature rating, efficiency level, and quality of power supply. When selecting and purchasing a motor, it is also critical to consider the life-cycle costs of that motor rather than just its initial purchase and installation costs. Up to 95% of a motor's costs can be attributed to the energy it consumes over its lifetime, while only around 5% of a motor's costs are typically attributed to its purchase, installation, and maintenance (MDM 2007). Life cycle costing (LCC) is an accounting framework that allows one to calculate the total costs of ownership for different investment options, which leads to a more sound evaluation of competing options in motor purchasing and repair or replacement decisions. A specific LCC guide has been developed for pump systems (Fenning et al. 2001), which also provides an introduction to LCC for motor systems.

The selection of energy-efficient motors can be an important strategy for reducing motor system life-cycle costs. Energy-efficient motors reduce energy losses through improved design, better materials, tighter tolerances, and improved manufacturing techniques. With proper installation, energy-efficient motors can also run cooler (which may help reduce facility heating loads) and have higher service factors, longer bearing life, longer insulation life, and less vibration.

To be considered energy efficient in the United States, a motor must meet performance criteria published by the National Electrical Manufacturers Association (NEMA). The Consortium for Energy Efficiency (CEE) has described the evolution of standards for energy-efficient motors in the United States, which is helpful for understanding "efficient" motor nomenclature (CEE 2007):

- NEMA Energy Efficient (NEMA EE) was developed in the mid-1980s to define the term "energy efficient" in the marketplace for motors. NEMA Standards Publication No. MG-1 (Revision 3), Table 12-11 defines efficiency levels for a range of different motors (NEMA 2002).
- The Energy Policy Act of 1992 (EPACT) required that many commonly used motors comply with NEMA "energy efficient" ratings if offered for sale in the United States.
- In 1996, the CEE Premium Efficiency Criteria specification was designed to promote motors with higher efficiency levels than EPACT required, for the same classes of motors covered by EPACT. The CEE efficiency levels specified were

generally two NEMA efficiency bands (Table 12-10, NEMA MG-1 Revision 3) above those required by EPACT.

- In 2001, the NEMA Premium Efficiency Electric Motor specification was developed to address confusion with respect to what constituted the most efficient motors available in the market. This specification was developed by NEMA, CEE, and other stakeholders, and was adapted from the CEE 1996 criteria. It currently serves as the benchmark for premium energy efficient motors. NEMA Premium^R also denotes a brand name for motors which meet this specification. Specifically, this specification covers motors with the following attributes:

    - Speed: 2, 4, and 6 pole
    - Size: 1-500 horsepower (hp)
    - Design: NEMA A and B
    - Enclosure type: open and closed
    - Voltage: low and medium voltage
    - Class: general, definite, and special purpose

The choice of installing a premium efficiency motor strongly depends on motor operating conditions and the life cycle costs associated with the investment. In general, premium efficiency motors are most economically attractive when replacing motors with annual operation exceeding 2,000 hours/year. However, software tools such as MotorMaster+ (see Appendix E) can help identify attractive applications of premium efficiency motors based on the specific conditions at a given plant.

Sometimes, even replacing an operating motor with a premium efficiency model may have a low payback period. According to data from the Copper Development Association, the upgrade to high-efficiency motors, as compared to motors that achieve the minimum efficiency as specified by EPACT, can have paybacks of less than 15 months for 50 hp motors (CDA 2001). Payback times will vary based on size, load factor, running time, local energy costs, and available rebates and/or incentives (see Appendix E). Given the quick payback time, it usually makes sense to by the most efficient motor available (U.S. DOE and CAC 2003).

NEMA and other organizations have created the Motor Decisions Matter^{SM} campaign to help industrial and commercial customers evaluate their motor repair and replacement options, promote cost-effective applications of NEMA Premium^R motors and "best practice" repair, and support the development of motor management plans before motors fail.

At the Odwalla Juice Company's facility in Dinuva, California, an IAC energy assessment found that the installation of more energy efficient motors would lead to $6,300 in annual cost savings with a simple payback period of only eight months (U.S. DOE 2002a). Similarly, in energy audits of seven fresh fruit and vegetable processing facilities in California, the installation of premium efficiency motors as motors wear out was expected to yield simple payback periods ranging from 0.7 to 1.6 years (Hackett et al. 2005).

Stahlbush Island Farms, a grower, canner, and freezer of fruits and vegetables in Corvalis, Oregon, also replaced targeted motors with higher efficiency models as motors wore out. The expected average payback period was estimated at 2.7 years (ODEQ 1996). When all targeted motors are replaced over a 12-year period, the company expects to save 50,000 kWh of electricity per year and to cut their electricity bill by around $2,300 per year.

In some cases, it may cost-effective to rewind an existing energy efficient motor, instead of purchasing a new motor. As a rule of thumb, when rewinding costs exceed 60% of the costs of a new motor, purchasing the new motor may be a better choice (MDM 2007). When rewinding a motor, it is important to choose a motor service center that follows best practice motor rewinding standards in order to minimize potential efficiency losses. An ANSI-approved recommended best practice standard has been offered by the Electric Apparatus Service Association (EASA) for the repair and rewinding of motors (EASA 2006). When best rewinding practices are implemented, efficiency losses are typically less than 0.5% to 1% (EASA 2003). However, poor quality rewinds may result in larger efficiency losses. It is therefore important to inquire whether the motor service center follows EASA best practice standards (EASA 2006).

Maintenance. The purposes of motor maintenance are to prolong motor life and to foresee a motor failure. Motor maintenance measures can be categorized as either preventative or predictive. Preventative measures, the purpose of which is to prevent unexpected downtime of motors, include electrical consideration, voltage imbalance minimization, load consideration, and motor ventilation, alignment, and lubrication. The purpose of predictive motor maintenance is to observe ongoing motor temperature, vibration, and other operating data to identify when it becomes necessary to overhaul or replace a motor before failure occurs (Barnish et al. 1997). The savings associated with an ongoing motor maintenance program are significant, and could range from 2% to 30% of total motor system energy use (Efficiency Partnership 2004).

Properly sized motors. Motors that are sized inappropriately result in unnecessary energy losses. Where peak loads on driven equipment can be reduced, motor size can also be reduced. Replacing oversized motors with properly sized motors saves, on average for U.S. industry, 1.2% of total motor system electricity consumption (Xenergy 1998). Higher savings can often be realized for smaller motors and individual motor systems.

To determine the proper motor size, the following data are needed: load on the motor, operating efficiency of the motor at that load point, the full-load speed of the motor to be replaced, and the full-load speed of the replacement motor. The U.S. DOE's BestPractices program provides a fact sheet that can assist in decisions regarding replacement of oversized and under loaded motors (U.S. DOE 1996). Additionally, software packages such as MotorMaster+ (see Appendix E) can aid in proper motor selection.

Adjustable speed drives (ASDs).[15] Adjustable-speed drives better match speed to load requirements for motor operations, and therefore ensure that motor energy use is optimized to a given application. Adjustable-speed drive systems are offered by many suppliers and are

[15] Several terms are used in practice to describe a motor system that permits a mechanical load to be driven at variable speeds, including adjustable speed drives (ASDs), variable speed drives (VSDs), adjustable frequency drives (AFDs), and variable frequency drives (VFDs). The term ASD is used throughout this Energy Guide for consistency.

available worldwide. Worrell et al. (1997) provide an overview of savings achieved with ASDs in a wide array of applications; typical energy savings are shown to vary between 7% and 60% with estimated simple payback periods for ASDs ranging from 0.8 to 2.8 years (Hackett et al. 2005).

Power factor correction. Inductive loads like transformers, electric motors, and HID lighting may cause a low power factor. A low power factor may result in increased power consumption, and hence increased electricity costs. The power factor can be corrected by minimizing idling of electric motors (a motor that is turned off consumes no energy), replacing motors with premium-efficient motors (see above), and installing capacitors in the AC circuit to reduce the magnitude of reactive power in the system.

Minimizing voltage unbalances. A voltage unbalance degrades the performance and shortens the life of three-phase motors. A voltage unbalance causes a current unbalance, which will result in torque pulsations, increased vibration and mechanical stress, increased losses, and motor overheating, which can reduce the life of a motor's winding insulation. Voltage unbalances may be caused by faulty operation of power factor correction equipment, an unbalanced transformer bank, or an open circuit. A rule of thumb is that the voltage unbalance at the motor terminals should not exceed 1%. Even a 1% unbalance will reduce motor efficiency at part load operation, while a 2.5% unbalance will reduce motor efficiency at full load operation.

For a 100 hp motor operating 8,000 hours per year, a correction of the voltage unbalance from 2.5% to 1% will result in electricity savings of 9,500 kWh or almost $500 at an electricity rate of $0.05/kWh (U.S. DOE 2005e).

By regularly monitoring the voltages at the motor terminal and through regular thermographic inspections of motors, voltage unbalances may be identified. It is also recommended to verify that single-phase loads are uniformly distributed and to install ground fault indicators as required. Another indicator that a voltage unbalance may be a problem is 120 Hz vibration, which should prompt an immediate check of voltage balance (U.S. DOE 2005e). The typical payback period for voltage controller installation on lightly loaded motors in the United States is 2.6 years (IAC 2005).

11. Pumps

In the chemical industry, about 26% of all electricity use in motors is for pumps (Xenergy, 1998). This equals 16% of the total electrical energy in the chemical industry (U.S. DOE-OIT, 2006a) making pumps the one of the largest electricity users in the chemical industry together with compress air systems and material processing. Pumps are used throughout the industry to generate a pressure and move liquids. Studies have shown that on average in the manufacturing industry, 20% of the energy consumed by these systems could be saved through equipment or control system changes, roughly equally divided between speed reduction or control measures and other system efficiency measures (Xenergy, 1998). The potential for the chemical industry is with 21% close to the manufacturing industry average (Xenergy, 1998).

It is important to note that initial costs are only a fraction of the life cycle costs of a pump system. Energy costs, and sometimes operations and maintenance costs, are much more important in the lifetime costs of a pump system. In general, for a pump system with a lifetime of 20 years, the initial capital costs of the pump and motor make up merely 2.5% of the total costs (Best Practice Programme, 1998). Depending on the pump application, energy costs may make up about 95% of the lifetime costs of the pump. Hence, the initial choice of a pump system should be highly dependent on energy cost considerations rather than on initial costs. Optimization of the design of a new pumping system should focus on optimizing the lifecycle costs. Hodgson and Walters (2002) discuss software developed for this purpose (OPSOP) and discuss several case studies in which they show large reductions in energy use and lifetime costs of a complete pumping system. Typically, such an approach will lead to energy savings of 10-17%.

Pumping systems consist of a pump, a driver, pipe installation and controls (such as adjustable speed drives or throttles) and are a part of the overall motor system, discussed in Chapter 10. The following section applies to all areas that use pumps. Using a “systems approach” on the entire motor system (pumps, compressors, motors and fans) was also discussed in section 10.1. In this section, the pumping systems are addressed; for optimal savings and performance, it is recommended that the systems approach incorporating pumps, compressors, motors and fans be used.

There are two main ways to increase pump system efficiency, aside from reducing use. These are reducing the friction in dynamic pump systems, (not applicable to static or "lifting" systems) or adjusting the system so that it draws closer to the best efficiency point (BEP) on the pump curve (Hovstadius, 2002). Correct sizing of pipes, surface coating or polishing and adjustable speed drives, for example, may reduce the friction loss, increasing energy efficiency. Correctly sizing the pump and choosing the most efficient pump for the applicable system will push the system closer to the best efficiency point on the pump curve.

In a pump improvement project at Kodak various measures were implemented including trimming impellers, replacing valves and reconfiguring pipes (see below). This systematic approach yielded annual electricity savings of 1,092 MWh and cost savings of $100,000 with a simple pay-back time of only 3 months (U.S. DOE-OIT, 2005b).

Operations and maintenance. Inadequate maintenance at times lowers pump system efficiency, causes pumps to wear out more quickly and increases costs. Better maintenance will reduce these problems and save energy. Proper maintenance includes the following (Hydraulic Institute, 1994; LBNL, RDC, and HI, 1999):

- Replacement of worn impellers, especially in caustic or semi-solid applications.
- Bearing inspection and repair.
- Bearing lubrication replacement, once annually or semiannually.
- Inspection and replacement of packing seals. Allowable leakage from packing seals is usually between two and sixty drops per minute.
- Inspection and replacement of mechanical seals. Allowable leakage is typically one to four drops per minute.
- Wear ring replacement. Pump efficiency degrades from 1 to 6 points increased wear ring clearances (Hydraulic Institute, 1994). While, it is true that the efficiency increases with the diameter of the impeller, it is not true that the largest impeller diameter always has the highest efficiency.
- Pump/motor alignment check.
- The largest opportunity is usually to avoid throttling losses.

Typical energy savings for operations and maintenance are estimated to be between 2 and 7% of pumping electricity use for the U.S. industry. The payback is usually immediate to one year (Xenergy, 1998; U.S. DOE-OIT, 2002e).

Monitoring. Monitoring in conjunction with operations and maintenance can be used to detect problems and determine solutions to create a more efficient system. Monitoring can determine clearances that need be adjusted, indicate blockage, impeller damage, inadequate suction, operation outside preferences, clogged or gas-filled pumps or pipes, or worn out pumps. Monitoring should include:

- Wear monitoring
- Vibration analyses
- Pressure and flow monitoring
- Current or power monitoring
- Differential head and temperature rise across the pump (also known as thermodynamic monitoring)
- Distribution system inspection for scaling or contaminant build-up

One of the best indicators to follow is the specific energy or power consumption as function of the flow rate (Hovstadius, 2007) .

Reduce need. Holding tanks can be used to equalize the flow over the production cycle, enhancing energy efficiency and potentially reducing the need to add pump capacity. In addition, bypass loops and other unnecessary flows should be eliminated. Energy savings may be as high as 5-10% for each of these steps (Easton Consultants, 1995). Total head requirements can also be reduced by lowering process static pressure, minimizing elevation rise from suction tank to discharge tank, reducing static elevation change by use of siphons and lowering spray nozzle velocities.

More efficient pumps. According to inventory data, 16% of pumps are more than 20 years old. Pump efficiency may degrade 10 to 25% in its lifetime (Easton Consultants, 1995). Newer pumps are 2 to 5% more efficient. However, industry experts claim the problem is not necessarily the age of the pump but that the process has changed and the pump does not match the operation. Replacing a pump with a new efficient one saves between 2 to 10% of its energy consumption (Elliott, 1994). Higher efficiency motors have also been shown to increase the efficiency of the pump system 2 to 5% (Tutterow, 1999). When replacing the motor by an energy efficient motor, other changes like impeller trimming may be necessary to optimize the pump system.

A number of pumps are available for specific pressure head and flow rate capacity requirements. Choosing the right pump often saves both in operating costs and in capital costs (of purchasing another pump). For a given duty, selecting a pump that runs at the highest speed suitable for the application will generally result in a more efficient selection as well as the lowest initial cost (Hydraulic Institute and Europump, 2001). Exceptions to this include slurry handling pumps, high specific speed pumps or where the pump would need a very low minimum net positive suction head at the pump inlet.

Correct sizing of pump(s) (matching pump to intended duty). Pumps that are sized inappropriately result in unnecessary losses. Where peak loads can be reduced, pump size can also be reduced. Correcting for pump oversizing can save 15 to 25% of electricity consumption for pumping (on average for the U.S. industry) (Easton Consultants, 1995). In addition, pump load may be reduced with alternative pump configurations and improved O&M practices.

The Welches Point Pump Station, a medium sized waste water treatment plant located in Milford (CT), as a participant in the Department of Energy's Motor Challenge Program, decided to replace one of their system's three identical pumps with one smaller model (Flygt, 2002). They found that the smaller pump could more efficiently handle typical system flows and the remaining two larger pumps could be reserved for peak flows. While the smaller pump needed to run longer to handle the same total volume, its slower pace and reduced pressure resulted in less friction-related losses and less wear and tear. Substituting the smaller pump has a projected savings of 36,096 kW, more than 20% of the pump system's annual electrical energy consumption. Using this system at each of the city's 36 stations would result in energy savings of over $100,000. In addition to the energy savings projected, less wear on the system results in less maintenance, less downtime and longer life of the equipment. The station noise is significantly reduced with the smaller pump.

Use multiple pumps. Often using multiple pumps is the most cost-effective and most energy-efficient solution for varying loads, particularly in a static head-dominated system. Installing parallel systems for highly variable loads saves 10 to 50% of the electricity consumption for pumping (on average for the U.S. industry) (Easton Consultants, 1995). Variable speed controls should also be considered for dynamic systems (see below). Parallel pumps also offer redundancy and increased reliability. One case study of a Finnish pulp and paper plant indicated that installing an additional small pump (a "pony pump"), running in parallel to the existing pump used to circulate water from the paper machine into two tanks, reduced the load in the larger pump in all cases except for startup. The energy savings were estimated at $36,500 (or 486 MWh, 58%) per year giving a payback of 0.5 years (Hydraulic Institute and Europump, 2001).

Trimming impeller (or shaving sheaves). If the pump delivers too much head compared to the demand at the operating rate of flow (indicating excessive flow), the impeller (diameter) can be trimmed so that the pump does not develop as much head. In the food processing, paper and petrochemical industries, trimming impellers or lowering gear ratios is estimated to save as much as 75% of the electricity consumption for specific pump applications (Xenergy, 1998). Care has to be taken when an impeller is trimmed or the speed is changed so that the new operating point does not end up in an area where the pump efficiency is low.

In one case study in the chemical processing industry, the impeller was reduced from 320 mm to 280 mm, which reduced the power demand by more than 25% (Hydraulic Institute and Europump, 2001). Annual energy demand was reduced by 83 MWh (26%). In this particular case, the very low investment costs of $390, resulted in a 23 day payback on energy savings alone. In addition to energy savings, maintenance costs were reduced, system stability was improved, cavitation reduced and excessive vibration and noise were eliminated. However, in most cases it will be more expensive to take a pump out of service to trim the impeller.

In another case study, Salt Union Ltd., the largest salt producer in the UK, trimmed the diameter of a pump impeller at its plant from 320 mm to 280 mm (13 to 11 inches) (Best Practice Programme, 1996). After trimming the impeller, they found significant power reductions of 30%, or 197 MWh per year, totaling 8,900 GBP ($14,000 (1994)). With an investment cost of 260 GBP ($400 (1993)), and maintenance savings of an additional 3,000 GBP ($4,600 (1994)), this resulted in a payback of 8 days (11 days due to energy savings alone). In addition to energy and maintenance savings, like the chemical processing plant, cavitation was reduced and excessive vibration and noise were eliminated. With the large decrease in power consumption, the 110 kW motor could be replaced with a 75kW motor, with additional energy savings of about 16,000 kWh per year. A smaller motor will not always in result in energy savings, as the savings will depend on the load of the motor, and only if the larger motor operates at a low efficiency, motor replacement may result in energy savings.

Controls. The objective of any control strategy is to shut off unneeded pumps or reduce the load of individual pumps until needed. Remote controls enable pumping systems to be started and stopped more quickly and accurately when needed, and reduce the required labor. In 2000, Cisco Systems (CA) upgraded the controls on its fountain pumps that turn off the pumps during peak hours (CEC and OIT, 2002). The wireless control system was able to control all pumps simultaneously from one location. The project saved $32,000 and 400,000 kWh annually, representing a savings of 61.5% of the fountain pumps' total energy consumption. With a total cost of $29,000, the simple payback was 11 months, of which a large part was due to the automatic shutdown of the pumps by the controls. In addition to energy savings, the project reduced maintenance costs and increased the pumping system's equipment life.

Adjustable speed drives (ASDs). ASDs better match speed to load requirements for friction-dominated pump systems where, as for motors, energy use is approximately proportional to the cube of the flow rate[16]. Hence, small reductions in flow that are proportional to pump speed may yield large energy savings. New installations may result in short payback periods. In addition, the installation of ASDs improves overall productivity, control and product quality, and reduces wear on equipment, thereby reducing future maintenance costs. However, in static heard dominated systems, ASDs may result in increased energy use under specific conditions (i.e. if speed is turned down too much).

According to inventory data collected by Xenergy (1998), 82% of pumps in U.S. industry have no load modulation feature (or ASD). Similar to being able to adjust load in motor systems, including modulation features with pumps is estimated to save between 20 and 50% of pump energy consumption, at relatively short payback periods, depending on application, pump size, load and load variation (Xenergy, 1998; Best Practice Programme, 1996a). As a general rule of thumb, unless the pump curves are exceptionally flat, a 10% regulation in flow should produce pump savings of 20% and 20% regulation should produce savings of 40% (Best Practice Programme, 1996).

In a plant-wide assessment of a Bayer Polymers plant in New Martinsville, West Virginia (U.S. DOE-OIT, 2003d), the use of variable speed drives in cooling tower pumps was identified as a project that could reduce electricity use by 4.64 million kWh annually and a 10.2 million pound of CO_2 reductions. Project costs were estimated at $ 264,000 and the pay-back time at 21 months. In an energy-efficiency assessment of the Anaheim, California, site of Neville Chemical Company (U.S. DOE-OIT, 2003e), energy saving projects were identified that make use of variable speed drives on heat transfer oil pumps and cooling water pumps respectively. Yearly electricity savings were estimated at 30,800 and 221,400 kWh at project costs of $5,104 and $13,660 and payback times of 2.1 and 0.8 year. Installation of Variable Speed Drives (VSD) on two cooling water and one stirrer pump at Cray Valley Limited polymer and resin plant in the UK saves 1,300 GJ electricity yearly with pay-back times for the three pumps ranging from 1.4 – 2.4 years (Best Practice Program, 1993).

In a systematic assessment of the motor system at the 3M corporate headquarters (U.S. DOE-OIT, 2002d), it turned out that the reheat water supply system of a building's HVAC system was controlled by diverting the unneeded flow of a full-flow operating pump through a by-pass valve. Replacing the motors with more efficient ones controlled by variable frequency drives (VFD) could save a substantial amount of electricity. The simple payback time for the project was estimated at 2.6 years.

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[16] This equation applies to dynamic systems only. Systems that solely consist of lifting (static head systems) will accrue no benefits from (but will often actually become more inefficient) ASDs because pump efficiency usually drops when speed is reduced in such systems. A careful choice of operating points can to some extent overcome this problem Similarly, systems with more static head will accrue fewer benefits than systems that are largely dynamic (friction) systems. More careful calculations must be performed to determine actual benefits, if any, for these systems.

Hodgson and Walters (2002) discuss the application of a ASD to replace a throttle of a new to build pumping system. Optimization of the design using a dedicated software package led to the recommendation to install an ASD. This would result in 71% lower energy costs over the lifetime of the system, a 54% reduction in total lifetime costs of the system.

Avoid throttling valves. Throttling valves should always be avoided. Extensive use of throttling valves or bypass loops may be an indication of an oversized pump (Tutterow et al., 2000). Variable speed drives or on off regulated systems always save energy compared to throttling valves (Hovstadius, 2002).

Correct sizing of pipes. Similar to pumps, undersized pipes also result in unnecessary losses. The pipe work diameter is selected based on the economy of the whole installation, the required lowest flow velocity, and the minimum internal diameter for the application, the maximum flow velocity to minimize erosion in piping and fittings and plant standard pipe diameters. Increasing the pipe diameter may save energy but must be balanced with costs for pump system components. Friction losses are inversely proportional to the 5^{th} power of the pipe diameter. Easton Consultants (1995) and others in the pulp and paper industry (Xenergy, 1998) estimate retrofitting pipe diameters saves 5 to 20% of their energy consumption, on average for the U.S. industry. Correct sizing of pipes should be done at the design or system retrofit stages where costs may not be restrictive.

Replace belt drives. Most pumps are directly driven. However, **i**nventory data suggests 4% of pumps have V-belt drives (Xenergy, 1998). Standard V-belts tend to stretch, slip, bend and compress, which lead to a loss of efficiency. Replacing standard V-belts with cog belts can save energy and money, even as a retrofit. It is even better to replace the pump by a direct driven system, resulting in increased savings of up to 8% and payback periods as short as 6 months (Studebaker, 2007).

Precision castings, surface coatings or polishing. The use of castings, coatings or polishing reduces surface roughness that in turn, increases energy efficiency. It may also help maintain efficiency over time. This measure is more effective on smaller pumps. One case study in the steel industry analyzed the investment in surface coating on the mill supply pumps (350 kW pumps). They determined that the additional cost of coating, $1200, would be paid back in 5 months by energy savings of $2700 (or 36 MWh, 2%) per year (Hydraulic Institute and Europump, 2001). Energy savings for coating pump surfaces are estimated to be 2 to 3% over uncoated pumps (Best Practice Programme, 1998).

Sealings. Seal failure accounts for up to 70% of pump failures in many applications (Hydraulic Institute and Europump, 2001). The sealing arrangements on pumps will contribute to the power absorbed. Often the use of gas barrier seals, balanced seals, and no-contacting labyrinth seals reduce seal losses and increase pump efficiency.

Curtailing leakage through clearance reduction. Internal leakage losses are a result of differential pressure across the clearance between the impeller suction and pressure sides. The larger the clearance, the greater is the internal leakage causing inefficiencies. The normal clearance in new pumps ranges from 0.35 to 1.0 mm (0.014 to 0.04 in.) (Hydraulic Institute and Europump, 2001). With wider clearances, the leakage increases almost linearly with the clearance. For example, a clearance of 5 mm (0.2 in.) decreases the efficiency by 7 to 15% in closed impellers and by 10 to 22% in semi-open impellers. Abrasive liquids and slurries, even rainwater, can affect the pump efficiency. Using very hard construction materials (such as high chromium steel) can reduce the wear rate.

Dry vacuum pumps. Dry vacuum pumps were introduced in the semi-conductor industry in Japan in the mid-1980s, and were introduced in the U.S. chemical industry in the late 1980s. The advantages of a dry vacuum pump are high energy-efficiency, increased reliability, and reduce air and water pollution. It is expected that dry vacuum pumps will displace oil-sealed pumps Ryans and Bays, 2001). Dry pumps have major advantages in applications where contamination is a concern. Due to the higher investment costs of a dry pump, it is not expected to make inroads in the petroleum refining industry in a significant way in the next years, except for special applications where contamination and pollution control are an important driver.

12. Fans and Blowers

Fans are used in boilers, furnaces, cooling towers and many other applications. In the chemical industry, 12% of motor related energy use if for fans, corresponding to approximately 8% of the total electricity use in the chemical industry. As in other motor applications, considerable opportunities exist to upgrade the performance and improve the energy efficiency of fan systems. Efficiencies of fan systems vary considerably across impeller types. Overall energy saving potentials in these systems in the U.S. Manufacturing industry are estimated at 5.5% and for the chemical industry at 5.9% (Xenergy, 1998). However, the cost-effectiveness of energy efficiency opportunities depends strongly on the characteristics of the individual system. In the chemical industry,

Fan oversizing. Most of the fans are oversized for the particular application, which can result in efficiency losses of 1-5% (Xenergy, 1998). However, it may often be more cost-effective to control the speed (see below) than to replace the fan system.

In an assessment of the Formosa Plastics Corporation polyethylene plant (U.S. DOE-OIT, 2005a), it was discovered that a much smaller venting system than the one currently installed would meet venting requirements. Installation of a smaller vent blower resulted in electricity savings of 896,000 kWh per year and cost savings of $35,840. The payback time of the project was 0.4 year. Another project identified in the same assessment was the improvement of a product transfer system, consisting of 14 blowers that transfer LLDPE through the various process steps. By increasing the transfer rate and by reducing the idle time via production control and distributive control system monitoring, 3,344,000 kWh of electricity can be saved annually, resulting in annual cost savings of $133,760 (payback time 0.7 years).

Adjustable speed drives (ASDs) and improved controls. Significant energy savings can be achieved by installing adjustable speed drives on fans. Savings may vary between 14 and 49% when retrofitting fans with ASDs (Xenergy, 1998).

In an energy-efficiency assessment of the Anaheim, California site of Neville Chemical Company (U.S. DOE-OIT, 2003e), the assessment team found that fan motors in a cooling tower ran continuously throughout the year despite the variable heat load resulting from the batch operations on the site. Installing variable speed drives on these fan motors (costs $9,103) could save 69,700 kWh of electricity per year with a payback time of 1.7 year. A similar project at the Knoxville, Tennessee, plant of Rohm and Haas would reduce the electric load of the cooling tower by approximately 50% (U.S. DOE-OIT, 2003b). Variable speed drive can also help to reduce energy consumption in combustion air fans in steam boilers. At a fertilizer plant of PCS Nitrogen Inc. in Augusta, Georgia, the installation of a variable speed fan eliminated the generation of excess steam during low load periods, resulting in annual energy savings of 76,400 MMBtu annually (cost savings of $420,000) with a payback time of only 2 months (U.S. DOE-OIT, 2005c).

In an assessment of the motor system in one of the buildings at the 3M corporate headquarters, it turned out that air was continuously supplied to a research pilot plant, whereas ventilation requirements depended on the level of activity in the pilot plant. By adding a direct digital control system and retrofitting of the fan motor with a variable frequency drive (VFD), substantial energy savings were achieved. Simple payback time of the project was estimated at 1.35 years (U.S. DOE-OIT, 2002d). In the same assessment, two 50-hp fans supplying air to various parts of one of the buildings were equipped with VFD's to control the air flow more efficiently. The payback time for this project was only 0.8 years.

High efficiency belts (cog belts). Belts make up a variable, but significant portion of the fan system in many plants. It is estimated that about half of the fan systems use standard V-belts, and about two-thirds of these could be replaced by more efficient cog belts (Xenergy, 1998). Standard V-belts tend to stretch, slip, bend and compress, which lead to a loss of efficiency. Replacing standard V-belts with cog belts can save energy and money, even as a retrofit. Cog belts run cooler, last longer, require less maintenance and have an efficiency that is about 2% higher than standard V-belts. Typical payback periods will vary from less than one year to three years.

13. Compressors and Compressed Air Systems

Compressed air systems consume 28% of motor-related energy use in the chemical industry (Xenergy, 1998), corresponding to 18% of the total electricity use in the chemical industry. Compressed air is probably the most expensive form of energy available in an industrial plant because of its poor efficiency. Typically, efficiency from start to end use is around 10% for compressed air systems (LBNL and RDC, 1998). In addition, the annual energy cost required to operate compressed air systems is greater than their initial cost. Because of this inefficiency and the sizeable operating costs, if compressed air is used, it should be of minimum quantity for the shortest possible time, constantly monitored and reweighed against alternatives. Many opportunities to reduce energy in compressed air systems are not prohibitively expensive; payback periods for some options are extremely short – less than one year. Typical saving potentials in compressed air systems for the manufacturing industry in the United States are estimated at 17 % and for the chemical industry at 18 % (Xenergy, 1998).

A systematic assessment of a facility's compressed air system can yield substantial energy savings as is for example shown by a compressed air system optimization project in a nylon production facility of Solutia Inc. in Greenwood, South Carolina (U.S. DOE-OIT, 2001). Based on a careful evaluation at the system level, various improvements in the compressed air system were identified such as the installation of a compressed air management information system and the repair of sub optimally performing compressors and after coolers. Total savings of the project were 15 GWh or $512,000 with a payback time less than 3 years.

In a plant-wide assessment of a Bayer Polymers plant in New Martinsville, West Virginia (U.S. DOE-OIT, 2003d), major compressed air vents were identified that could be prevented by installing a new compressor type. Electricity saving were estimated at 1.53 million kWh annually, resulting in CO_2 emission reductions of 3.34 million pounds. Project costs were estimated at $ 165,000 with a payback period of 32 months.

An assessment of the compressed air system at the Knoxville, Tennessee plant of Rohm and Haas chemical company resulted in various potential optimization measures including improved compressed air conservation and consolidation of the two air systems in place. Annual savings of electricity were estimated at 3,300 MWh (U.S. DOE-OIT, 2003b).

In an assessment of the Formosa Plastics Corporation polyethylene plant (U.S. DOE-OIT, 2005a), the installation of a new open-type impeller in an ethylene compressor was identified as a project that could reduce electricity use by 8,344,000 kWh per year, resulting in annual cost savings of $333,760. Payback time for the project was estimated at 2.1 years.

An upgrade of the compressed air distribution system at the W.R. Grace facility in Curtis Bay, Maryland, could result in electricity savings of 4,833 MWh. The upgrade includes the installation of a computerized compressor management system to control air supply, using reduced steam pressure and installation of storage capacity. Project capital costs were estimated at $460,600 with a payback period of 1.9 years (U.S. DOE-OIT, 2003g).

Compressed air - maintenance. Inadequate maintenance can lower compression efficiency, increase air leakage or pressure variability and lead to increased operating temperatures, poor moisture control and excessive contamination. Better maintenance will reduce these problems and save energy. Proper maintenance includes the following (LBNL and RDC, 1998, unless otherwise noted):

- Blocked pipeline filters increase pressure drop. Keep the compressor and intercooling surfaces clean and foul-free by inspecting and periodically cleaning filters. Seek filters with just a 1 psi pressure drop. Payback for filter cleaning is usually under 2 years (Ingersoll-Rand, 2001). Fixing improperly operating filters will also prevent contaminants from entering into equipment and causing them to wear out prematurely. Generally, when pressure drop exceeds 2 to 3 psig replace the particulate and lubricant removal elements. Inspect all elements at least annually. Also, consider adding filters in parallel to decrease air velocity and, therefore, decrease pressure drop. A 2% reduction of annual energy consumption in compressed air systems is projected for more frequent filter changing (Radgen and Blaustein, 2001). However, one must be careful when using coalescing filters; efficiency drops below 30% of design flow (Scales, 2002).
- Poor motor cooling can increase motor temperature and winding resistance, shortening motor life, in addition to increasing energy consumption. Keep motors and compressors properly lubricated and cleaned. Compressor lubricant should be sampled and analyzed every 1000 hours and checked to make sure it is at the proper level. In addition to energy savings, this can help avoid corrosion and degradation of the system.
- Inspect fans and water pumps for peak performance.
- Inspect drain traps periodically to ensure they are not stuck in either the open or closed position and are clean. Some users leave automatic condensate traps partially open at all times to allow for constant draining. This practice wastes substantial amounts of energy and should never be undertaken. Instead, install simple pressure driven valves. Malfunctioning traps should be cleaned and repaired instead of left open. Some automatic drains do not waste air, such as those that open when condensate is present. According to vendors, inspecting and maintaining drains typically has a payback of less than 2 years (Ingersoll-Rand, 2001).
- Maintain the coolers on the compressor to ensure that the dryer gets the lowest possible inlet temperature (Ingersoll-Rand, 2001).
- Check belts for wear and adjust them. A good rule of thumb is to adjust them every 400 hours of operation.
- Check water-cooling systems for water quality (pH and total dissolved solids), flow and temperature. Clean and replace filters and heat exchangers per manufacturer's specifications.
- Minimize leaks (see also Reduce leaks section, below).
- Specify regulators that close when failed.
- Applications requiring compressed air should be checked for excessive pressure, duration or volume. They should be regulated, either by production line sectioning or by pressure regulators on the equipment itself. Equipment not required to operate at maximum system pressure should use a quality pressure regulator. Poor quality regulators tend to drift and lose more air. Otherwise, the unregulated equipment operates at maximum system pressure at all times and wastes the excess energy. System pressures operating too high

also result in shorter equipment life and higher maintenance costs. In some cases, the pressure required is so low that the need can be met by a bower instead of a compressor. Considerable energy can in that case be saved, since a blower requires only a small fraction of the power needed by a compressor (Cergel et al., 2000).

Monitoring. Proper monitoring (and maintenance) can save a lot of energy and money in compressed air systems. Proper monitoring includes the following (CADDET, 1997b):

- Pressure gauges on each receiver or main branch line and differential gauges across dryers, filters, etc.
- Temperature gauges across the compressor and its cooling system to detect fouling and blockages
- Flow meters to measure the quantity of air used
- Dew point temperature gauges to monitor the effectiveness of air dryers
- kWh meters and hours run meters on the compressor drive
- Compressed air distribution systems should be checked when equipment has been reconfigured to be sure no air is flowing to unused equipment or obsolete parts of the compressed air distribution system.
- Check for flow restrictions of any type in a system, such as an obstruction or roughness. These require higher operating pressures than are needed. Pressure rise resulting from resistance to flow increases the drive energy on the compressor by 1% of connected power for every 2 psi of differential (LBNL and RDC, 1998; Ingersoll-Rand, 2001). Highest pressure drops are usually found at the points of use, including undersized or leaking hoses, tubes, disconnects, filters, regulators, valves, nozzles and lubricators (demand side), as well as air/lubricant separators, aftercoolers, moisture separators, dryers and filters.

Reduce leaks (in pipes and equipment). Leaks can be a significant source of wasted energy. A typical plant that has not been well maintained could have a leak rate between 20 to 50% of total compressed air production capacity (Ingersoll Rand, 2001). Leak repair and maintenance can sometimes reduce this number to less than 10%. Similar figures are quoted by Cergel et al. (2000). Overall, a 20% reduction of annual energy consumption in compressed air systems is projected for fixing leaks (Radgen and Blaustein, 2001).

The magnitude of a leak varies with the size of the hole in the pipes or equipment. A compressor operating 2,500 hours per year at 6 bar (87 psi) with a leak diameter of 0.02 inches (½ mm) is estimated to lose 250 kWh/year; 0.04 in. (1 mm) to lose 1100 kWh/year; 0.08 in. (2 mm) to lose 4,500 kWh/year; and 0.16 in. (4 mm) to lose 11,250 kWh/year (CADDET, 1997b).

In addition to increased energy consumption, leaks can make pneumatic systems/equipment less efficient and adversely affect production, shorten the life of equipment, lead to additional maintenance requirements and increased unscheduled downtime. Leaks cause an increase in compressor energy and maintenance costs. The most common areas for leaks are couplings, hoses, tubes, fittings, pressure regulators, open condensate traps and shut-off valves, pipe joints, disconnects and thread sealants. Quick connect fittings always leak and should be avoided. A simple way to detect large leaks is to apply soapy water to suspect areas. The best way to detect leaks is to use an ultrasonic acoustic detector, which can recognize the high frequency hissing sounds associated with air leaks. After identification, leaks should be tracked, repaired and verified. Leak detection and correction programs should be ongoing efforts.

Reducing the inlet air temperature. Reducing the inlet air temperature reduces energy used by the compressor. In many plants, it is possible to reduce inlet air temperature to the compressor by taking suction from outside the building. Importing fresh air has paybacks of up to 5 years, depending on the location of the compressor air inlet (CADDET, 1997b). As a rule of thumb, each 5°F (3°C) will save 1% compressor energy use (CADDET, 1997b; Parekh, 2000). For example, reducing the absolute inlet temperature from 25 °C to 10 °C will reduce compressor power input by 5% (Cergel et al., 2000).

Maximize allowable pressure dew point at air intake. Choose the dryer that has the maximum allowable pressure dew point, and best efficiency. A rule of thumb is that desiccant dryers consume 7 to 14% of the total energy of the compressor, whereas refrigerated dryers consume 1 to 2% as much energy as the compressor (Ingersoll-Rand, 2001). Consider using a dryer with a floating dew point. Note that where pneumatic lines are exposed to freezing conditions, refrigerated dryers are not an option.

Optimize the compressor to match load. Plant personnel have a tendency to purchase larger equipment than needed, driven by safety margins or anticipated additional future capacity. Given the fact that compressors consume more energy during part-load operation, this is something to be avoided when possible. In cases where periods exist with low compressed air requirements, it can be beneficial to operate a smaller compressor at full load rather than a large one part-load. Some plants have installed modular systems with several smaller compressors to math compressed air needs in a modular way (Cergel et al., 2000).

Controls. Remembering that the total air requirement is the sum of the average air consumption for pneumatic equipment, not the maximum for each, the objective of any control strategy is to shut off unneeded compressors or delay bringing on additional compressors until needed. All compressors that are on should be running at full-load, except for one, which should handle trim duty. Positioning of the control loop is also important; reducing and controlling the system pressure downstream of the primary receiver results in reduced energy consumption of up to 10% or more (LBNL and RDC, 1998). Radgen and Blaustein (2001) report energy savings for sophisticated controls to be 12% annually. Start/stop, load/unload, throttling, multi-step, variable speed and network controls are options for compressor controls and described below.

Start/stop (on/off) is the simplest control available and can be applied to small reciprocating or rotary screw compressors. For start/stop controls, the motor driving the compressor is turned on or off in response to the discharge pressure of the machine. They are used for applications with very low duty cycles. Applications with frequent cycling will cause the motor to overheat. Typical payback for start/stop controls is 1 to 2 years (CADDET, 1997b).

Load/unload control, or constant speed control, allows the motor to run continuously but unloads the compressor when the discharge pressure is adequate. In most cases, unloaded rotary screw compressors still consume 15 to 35% of full-load power when fully unloaded, while delivering no useful work (LBNL and RDC, 1998). Hence, load/unload controls may be inefficient and require ample receiver volume.

Modulating or throttling controls allows the output of a compressor to be varied to meet flow requirements by closing down the inlet valve and restricting inlet air to the compressor. Throttling controls are applied to centrifugal and rotary screw compressors. Changing the compressor control to a variable speed control has saved up to 8% per year (CADDET, 1997b). Multi-step or part-load controls can operate in two or more partially loaded conditions. Output pressures can be closely controlled without requiring the compressor to start/stop or load/unload.

Properly sized regulators. Regulators sometimes contribute to the biggest savings in compressed air systems. By properly sizing regulators, compressed air will be saved that is otherwise wasted as excess air. Also, it is advisable to specify pressure regulators that close when failing.

Sizing pipe diameter correctly. Inadequate pipe sizing can cause pressure losses, increase leaks and increase generating costs. Pipes must be sized correctly for optimal performance or resized to fit the current compressor system. Increasing pipe diameter typically reduces annual energy consumption by 3% (Radgen and Blaustein, 2001).

Heat recovery for water or space heating preheating. As much as 80 to 93% of the electrical energy used by an industrial air compressor is converted into heat. In many cases, a heat recovery unit can recover 50 to 90% of the available thermal energy for space heating, industrial process heating, water heating, makeup air heating, boiler makeup water preheating, industrial drying, industrial cleaning processes, heat pumps, laundries or preheating aspirated air for oil burners (Parekh, 2000). Paybacks are typically less than one year. With large water-cooled compressors, recovery efficiencies of 50 to 60% are typical (LBNL and RDC, 1998). Implementing this measure recovers up to 20% of the energy used in compressed air systems annually for space heating (Radgen and Blaustein, 2001). Assuming 80% of the power input is converted t heat, a 150 hp compressor can reject as much heat as a 90 kW electric resistance heater or a 400 kBtu/hr natural gas heater when operating (Cergel et al., 2000). In some cases, compressed air is cooled considerably below its dew point in refrigerated dryers to condense and remove the water vapor in the air. The waste heat from these aftercoolers can be regenerated and used for space heating, feedwater heating or process-related heating (Cergel et al., 2000).

Adjustable speed drives (ASDs). Implementing adjustable speed drives in rotary compressor systems has saved 15% of the annual compressed air energy consumption (Radgen and Blaustein, 2001). The profitability of installing an ASD on a compressor depends strongly on the load variation of the particular compressor. When there are strong variations in load and/or ambient temperatures there will be large swings in compressor load and efficiency. In those cases, or where electricity prices are relatively high (> 4 cts/kWh) installing an ASD may result in attractive payback periods (Heijkers et al., 2000). For new compressors featuring Hybrid Permanent Magnet synchronous motor produced by Ingersoll-Rand, energy savings of 28% are claimed during the unit's operating life (Hydrocarbon Processing, 2002).

High efficiency motors (see also Chapter 10). Installing high efficiency motors in compressor systems reduces annual energy consumption by 2%, and has a payback of less than 3 years (Radgen and Blaustein, 2001). For compressor systems, the largest savings in motor performance are typically found in small machines operating less than 10kW (Radgen and Blaustein, 2001). For example, for a compressor that operates 4,368 hr/yr at full load, replacing the burned-out motor of a 150 hp compressor by 96.2% efficient high-efficiency motor instead of a 93% efficient standard motor will save over 17 MWh/yr of electricity, worth about $1,000, assuming an electricity price of $0.06 / kWh (Cergel et al., 2000).

14. Distillation

In the petrochemical industry, distillation is the most important separation process. In distillation, products are separated based on their difference in boiling points. The starting mixture is separated into two fractions: a condensed vapor that is enriched in the more volatile components and a remaining liquid phase that is depleted of these components (EC-IPPC, 2003). Distillations can be divided into subcategories according to the operating mode (batch or continuous), operating pressure (vacuum, atmospheric or pressurized), number of stages, the use of inert gases, and the use of additional compounds to aid separation (U.S. EPA, 1993). Heat is provided by process heaters (see Chapter 8) and/or by steam (see Chapter 7) while process integration (see Chapter 9) is a key issue. Energy efficiency opportunities exist in the heating side and by optimizing the distillation column.

Enhanced distillation controls. Modern process controls for distillation columns are essential to optimize and manage the process for optimal product yield, needed purity, and energy efficiency. Section 6.3 of this Energy Guide describes the key process control system approaches and some key applications. Various suppliers offer distillation controls.

Optimization of reflux ratios. The optimization of the reflux ratio of the distillation column can produce significant energy savings. Reflux optimization for new column designs is a trade-off between the capital costs of adding stages and the operating cost for the utilities providing the reflux and associated re-boil. For existing columns, the optimization of the reflux is determined economically by trading off product yield, purity and energy costs (Best Practice Programme, 1999b). If the characteristics of the feed or product specification required have changed over time or compared to the design conditions, operational efficiency can often be improved. If operational conditions have changed over time or compared to the design conditions, operation efficiency can be improved. The design reflux should be compared with the actual ratios controlled by each shift operator. Steam and/or fuel intensity can be compared to the reflux ratio, product purity, etc. and compared with calculated and design performance on a daily basis to improve the efficiency.

A sub-cooled reflux is usually caused by over-capacity in the condenser, resulting in degradation of the temperature profile within the condenser. This can lead to unnecessary cooling water use or air cooling duty or less steam generation, depending on the utility used in the condenser (Best Practice Programme, 1999b). Improved control can often avoid sub-cooling of the reflux as many case studies have shown. In an unspecified UK case study, controlling the cooling water flow in the condenser with a split range controller optimized the heat duty of main condenser and the subcooler and resulted in an increased steam generation of 4 ton of steam/hr. Payback time for this project was just over 10 weeks (Best Practice Programme, 1999b).

Check product purity. Many companies tend to excessively purify products and sometimes with good reason. However, purifying to 98% when 95% is acceptable is not necessary. In this case, the reflux rate should be decreased in small increments until the desired purity is obtained. This will decrease the reboiler duties. This change will require no or very low investments (Saxena, 1997). In some cases, it may be possible to shift some of the separation duty to more downstream equipment. A column with a limited number of stages purifying a stream to 98% may not be as efficient as a more downstream column with a larger number of stages purifying to 99.9%. In such as case, reducing the purity in the first column to 95% could result in net overall savings (Best Practice Programme, 1999b). In an unspecified case study in the UK, product specification in a debutanizer column was controlled by the flow of steam to the reboiler. To ensure product quality under varying feed concentrations, maximum reflux and reboil ratios were applied, resulting in a product above specification. Installation of an on-line chromatograph resulted in much more on-spec operation of the column and the resulting energy savings paid back the chromatograph in 3 months (Best Practice Programme, 1999b).

Seasonal operating pressure adjustments. For plants that are in locations that experience cold winters, the operating pressure can be reduced according to a decrease in cooling water temperatures (Saxena, 1997). Reported case studies have shown that winter-period energy use can be reduced by up to 25% through application of floating pressure operation (Best Practice Programme, 1999b). However, this may not apply to separation processes operating under vacuum. These operational changes will generally not require any investment.

Column insulation. The desired amount of insulation on a distillation column depends on the individual situation and varies at parts of the column. As with steam distribution pipes, the distillation column should be properly insulated, and re-evaluation on the basis of performance, energy costs and technical developments.

In the case of a column operating in the refrigerated condition, insulation must be used on the condenser and top portion of the column to prevent heat flowing into the column, which would then have to be removed by expensive refrigeration. If the reboiler and bottom sections of the column are also cold insulation will also be required as these sections are part of the coolant cycle (Texas Energy Conservation Program, 1978).

Insulation on the column will prevent the column from being affected by swings in the weather (see also above). For cold columns, prevention of ice condensation may be desired. There are OSHA limits on the maximum permissible bare metal temperature for personnel protection.

Reducing reboiler duty. Reboilers consume most of total distillation column energy use. The reboiler is usually controlled by steam. Without automatic flow control, an excessive steam flow to the reboiler can result, leading to an over-purified product. The reboiler vaporizes liquid in the column, increasing the pressure, which is controlled by providing reflux in the condenser. If a lower pressure steam can be used in the reboiler, this can result in significant energy savings. Options to accomplish this include seasonal pressure adjustments (see above) and the use of thermo-compressors (Best Practice Programme, 1999).

By using chilled water, the reboiler duty can in principal be lowered by reducing the overhead condenser temperature. A study of chilled water use in a 100,000 bbl/day crude distillation unit in a refinery has led to an estimated fuel saving of 12.2 MMBtu/hr for a 5% increase in cooling duty (2.5 MMBtu/hr) (Petrick and Pellegrino, 1999), assuming the use of chilled water with a temperature of 50°F. The payback period was estimated at 1 – 2 years, however, excluding the investments to change the tray design in the distillation tower. This technology is not yet proven for commercial application. This technology can also be applied in other distillation processes.

In specific cases, it can be possible to reduce reboiler duty by using heat pumps. In this concept, the top stream of a distillation column is compressed, allowing condensation at higher temperature. By doing so, the condenser and reboiler can be integrated into a single heat exchanger. Applications of mechanical vapor recompression (MVR) are in practice limited to distillations in which the mixture has a relative volatility close to unity resulting in a reasonably low compression ratio in the compressor (Hugill and van Dorst, 2005). Important examples are propane/propylene splitters (see Chapter 16). Pay-back times are attractive, but the additional capital investment is substantial. Configurations using steam ejectors are described by Meili (2004). A more advanced concept are heat-integrated distillation columns where the compressor is placed mid-way in the column. The most interesting applications are similar to those for MVR, but energy savings up to 50% are projected compared to MVR. Typical applications include the splitters for propane/propylene already mentioned, the splitter for ethylene/ethane and cryogenic air separation (Hugill and van Dorst, 2005).

Feed conditioning. Feed conditioning is one of the most common methods of reducing the energy use of a distillation column. Heating the feed can reduce the load on a reboiler, but the saving potential depends on the split between the top and bottom product. For columns where 80% of the feed is recovered at the top of the column, changing the feed condition from saturated liquid to saturated vapour can halve the reboiler duty, while only moderately changing the condenser duty (Best Practice Programme, 1999b).

Upgrading column internals. Damaged or worn internals can result in increased operation costs. As the internals become damaged, efficiency decreases and pressure drops rise. This causes the column to run at a higher reflux rate over time. With an increased reflux rate, energy costs will increase accordingly. Replacing the trays with new ones or adding a high performance packing can have the column operating like the day it was brought online. If operating conditions have seriously deviated from designed operating conditions, the investment may have a relative short payback.

New tray designs are marketed and developed for many different applications. When replacing the trays it will often be worthwhile to consider new efficient tray designs. New tray designs can result in enhanced separation efficiency and decrease pressure drop. This will result in reduced energy consumption. When considering new tray designs the number of trays should be optimized

Stripper optimization. Steam is injected into the process stream in strippers. Steam strippers are used in various processes. The strip steam temperature can be too high, and the strip steam use may be too high. Optimization of these parameters can reduce energy use considerably. This optimization can be part of a process integration (or pinch) analysis for the particular unit (see Chapter 9).

15. Buildings: HVAC and Lighting

Facility and other non-process use of electricity might be small compared to some other energy consuming processes, they can still represent up to 10% of a facility's electricity use (see Table 4.5). As such, they offer still potential for energy efficiency improvements.

15.1 Energy Efficiency Measures for HVAC Systems

Energy efficient system design. The greatest opportunities for energy efficiency exist at the design stage for HVAC systems in new industrial facilities. By sizing equipment properly and designing energy efficiency into a new facility, a facility can minimize the energy consumption and operational costs of HVAC systems from the outset. This practice often saves money in the long run, as it is generally cheaper to install energy efficient HVAC equipment at building construction than it is to upgrade an existing building with an energy efficient HVAC system later on, especially if those upgrades lead to production downtime.

Recommissioning. Before replacing HVAC system components to improve energy efficiency, the possibility of HVAC system recommissioning should be explored. Recommissioning is essentially the same process as commissioning, but applied to a building's existing HVAC, controls, and electrical systems (U.S. EPA 2004).

Commissioning is the process of verifying that a new building functions as intended and communicating the intended performance to the building management team. This usually occurs when a new building is turned over for occupancy. In practice, commissioning costs are not included in design fees and often compete with other activities. As a result, commissioning is seldom pursued properly. It is critical that the building is commissioned to ensure that energy performance and operational goals are met. To achieve this, ENERGY STAR recommends the following:

- Communicate your energy performance goals during commissioning to ensure that the design target is met. Encourage energy-use tracking that will allow performance comparisons to be made over time.
- Specify detailed commissioning activities in your project contracts. Seek separate funding for commissioning work to ensure that it is given the appropriate level of importance.
- Hire experts that specialize in building commissioning. Include the commissioning firm as part of the design team early in the project.
- Finalize and transfer a set of technical documents including manufacturers' literature for systems and components. Supplement technical literature with summaries of intended operation. Provide additional explanation for innovative design features.

Recommissioning involves a detailed assessment of existing equipment performance and maintenance procedures for comparison to intended or design performance and maintenance procedures, to identify and fix problem areas that might be hampering building energy efficiency. Recommissioning can be a cost-effective retrofit in itself, sometimes generating more savings than the cost of the retrofit measure. For example, recommissioning may help

avoid the need to install new or additional equipment, leading to savings in capital investments.
The U.S. EPA's ENERGY STAR Building Upgrade Manual (U.S. EPA 2004) recommends a stepwise approach to recommissioning, in which a series of strategically-ordered building "tune up" strategies are pursued in order. First lighting and supplemental loads should be assessed, then the building envelope, then controls, then testing, adjusting and balancing, then heat exchange equipment, and finally heating and cooling systems. Most of these steps relate to HVAC system components or factors that will directly affect HVAC system energy consumption (such as building envelope and lighting). For more information, the U.S. EPA's ENERGY STAR Building Upgrade Manual (U.S. EPA 2004) should be consulted (see also http://www.energystar.gov).

Energy monitoring and control systems. An energy monitoring and control system supports the efficient operation of HVAC systems by monitoring, controlling, and tracking system energy consumption. Such systems continuously manage and optimize HVAC system energy consumption while also providing building engineers and energy managers with a valuable diagnostic tool for tracking energy consumption and identifying potential HVAC system problems. Several industrial case studies from the United States indicate that the average payback period for HVAC control systems is about 1.3 years (IAC 2006).

Non-production hours set-back temperatures. Setting back building temperatures (i.e., turning building temperatures down in winter or up in summer) during periods of non-use, such as weekends or non-production times, can lead to significant savings in HVAC energy consumption.

Duct leakage repair. Duct leakage can waste significant amounts of energy in HVAC systems. Measures for reducing duct leakage include installing duct insulation and performing regular duct inspection and maintenance, including ongoing leak detection and repair. According to studies by Lawrence Berkeley National Laboratory, repairing duct leaks in industrial and commercial spaces could reduce HVAC energy consumption by up to 30% (Galitsky et al. 2005a).

One commercial building in Apple Valley, California, adopted a technique called the mobile aerosol-sealant injection system (MASIS) to reduce duct leakage. The application of MASIS resulted in a reduction in overall duct leakage from 582 cfm to 74 cfm, leading to a 34% increase in the overall efficiency of the building's HVAC system (Carrier Aeroseal 2002).

Variable-air-volume systems. Variable-air-volume systems adjust the rate of air flow into a room or space based on the current air flow requirements of that room or space, and therefore work to more closely match HVAC load to heating and cooling demands.

Adjustable-speed drives (ASDs). Adjustable speed drives can be installed on variable-volume air handlers, as well as recirculation fans, to match the flow and pressure requirements of air handling systems precisely. Energy consumed by fans can be lowered considerably since they are not constantly running at full speed. Adjustable-speed drives can also be used on chiller pumps and water systems pumps to minimize power consumption based on system demand.

Heat recovery systems. Heat recovery systems reduce the energy required to heat or cool facility intake air by harnessing the thermal energy of the facility's exhaust air. Common heat recovery systems include heat recovery wheels, heat pipes, and run-around loops. The efficiency of heat pipes is in the 45% to 65% range (U.S. EPA/DOE 2003), while the efficiency of run-around loops can be slightly higher, in the 55% to 65% range (U.S. EPA/DOE 2001).

Fan modification. Changing the size or shape of the sheaves of a fan can help to optimize fan efficiency and airflow, thereby reducing energy consumption. In a case study from the automotive industry, a Toyota plant optimized the sheaves of its fans in lieu of installing ASDs on fans. Toyota found better savings and payback periods with sheave modification than they anticipated to experience from ASDs (Galitsky et al. 2005a).

Efficient exhaust fans. Exhaust fans are standard components in any HVAC system. Mixed flow impeller exhaust fans offer an efficient alternative to traditional centrifugal exhaust fans. Mixed flow impeller fans are typically 25% more efficient that centrifugal fans, and can also be cheaper to install and maintain. The expected payback period for this measure is around two years (Tetley 2001).

Use of ventilation fans. Ventilation fans installed in the ceilings of work areas can help de-stratify the workspace air, leading to better circulation of cool air in summer and warm air in winter, and more even distributions of temperature from floor to ceiling. Such fans can help to reduce the load on building heating systems by helping to "push down" warm air that rises to the ceiling during facility heating months.

Cooling water recovery. If available, secondary cooling water from municipal sources can be leveraged to reduce chiller energy consumption. In Washington, Boeing partnered with Puget Sound Power and Light and the King County Department of Metropolitan Services to recycle secondary treated cooling water into its chiller system. By doing so, Boeing reduced its water consumption by 48 million gallons per year, leading to projected savings of 20% in its cooling energy consumption (Michaelson and Sparrow 1995). As an additional benefit, Boeing also expected to save on refrigerant and treatment chemicals for its cooling tower water.

Solar air heating. Solar air heating systems, such as Solarwall®, use conventional steel siding painted black to absorb solar radiation for insulation. Fresh air enters the bottom of the panels where it is heated as it passes over the warm absorber. Fans distribute the air. Using this technology, Ford Motor Company's Chicago Stamping plant turned the south wall of its plant into a huge solar collector (CREST 2001). Energy savings were estimated to be over $300,000 per year compared to conventional gas air systems. Capital costs were $863,000 ($14.90 per square foot, including installation) resulting in a payback period of less than three years. In addition to energy savings, the system was said to provide clean fresh air for employees, even out hot and cold spots in the plant, and reduce emissions. However, this measure is only of interest for buildings in cold climates, and the potential benefits should be analyzed based on the local conditions of each site.

Building reflection. Use of a reflective coating on the roof of buildings in sunny, hot climates can save on air conditioning costs inside. Two medical offices in Northern California used reflective roofs on their buildings; one reduced air conditioning demand by 8%, the other reduced air conditioning demand by 12% (Konopacki et al., 1998). For colder climates, heat lost due to cool roofs (in winter, for example) also needs to be taken into account, and often negates savings. In addition to location and weather, other primary factors influence energy savings, such as roof insulation, air conditioning efficiency, and building age. Reflective roof materials are available in different forms and colors.

Roof gardens on a flat roof improve the insulation of buildings against both hot and cold by providing both heat (in winter) and air conditioning (in summer). In winter, green roofs can freeze, so they carry a slight heating penalty but often still yield net energy savings (Holtcamp 2001). In addition, a roof garden can increase the lifetime of the roof, provide and reduce runoff, and reduce air pollution and dust. Today, Germany installs over 10 million ft^2 of green roofs a year, helped in part by economic incentives (Holtcamp 2001). The Gap Headquarters in San Bruno (California) installed green roofs in 1997 (Greenroofs.com 2001). In addition to saving energy and lasting longer than traditional roofs, a roof garden absorbs rain, slowing run-off to local storm drains.

Other simple options for decreasing building HVAC energy use exist for certain conditions. Shade trees reduce cooling for hot climates. Shade trees should be deciduous trees (providing shade in the summer and none in the winter) and planted on the west and southwest sides of the building (based on the path of the summer sun) (McPherson and Simpson 1995). Trees planted on the north side of the building in cold climates can reduce heating in winter by shielding the building from the wind. Vines can provide both shade and wind shielding.

Building insulation. Adding insulation to a facility will nearly always result in the reduction of utility bills. Older buildings are likely to use more energy than newer ones, leading to very high heating and air conditioning bills. Even for a new building, adding insulation may save enough through reduced utility bills to pay for itself within a few years (U.S. DOE-OIT 2002f).

Various states have regulations and guidelines for building insulation, for example, California's Energy Efficiency Standards for Residential and Nonresidential Buildings (Title 24) (CEC 2001). Going beyond regulated insulation levels may be economically beneficial and should be considered as part of the design of a new building, as well as for reconstruction of existing buildings. For refrigerated warehouses, much higher levels of insulation are preferred.

Low emittance (Low-E) windows. Low emittance windows are another effective strategy for improving building insulation. Low emittance windows can lower the heat transmitted into a building and therefore increase its insulating ability. There are two types of Low-E glass, high solar transmitting (for regions with higher winter utility bills) and low solar transmitting (for regions with higher summer utility bills) (U.S. DOE 1997). The U.S. DOE supports the development of new window and glazing technology, while ENERGY STAR provides a selection of rated Low-E windows. New window and glazing technology is being developed continuously around the world.[17]

15.2 Energy Efficiency Measures for Lighting

Turning off lights in unoccupied areas. An easy and effective measure is to encourage personnel to turn off lights in unoccupied building spaces. An energy management program that aims to improve the awareness of personnel with regard to energy use can help staff get in the habit of switching off lights and other equipment when not in use.

Lighting controls. Lights can be shut off during non-working hours by automatic controls, such as occupancy sensors that turn off lights when a space becomes unoccupied. Occupancy sensors can save up to 10% to 20% of facility lighting energy use (Galitsky et al. 2005a). Numerous case studies throughout the United States suggest that the average payback period for occupancy sensors is approximately 1 year (IAC 2005).

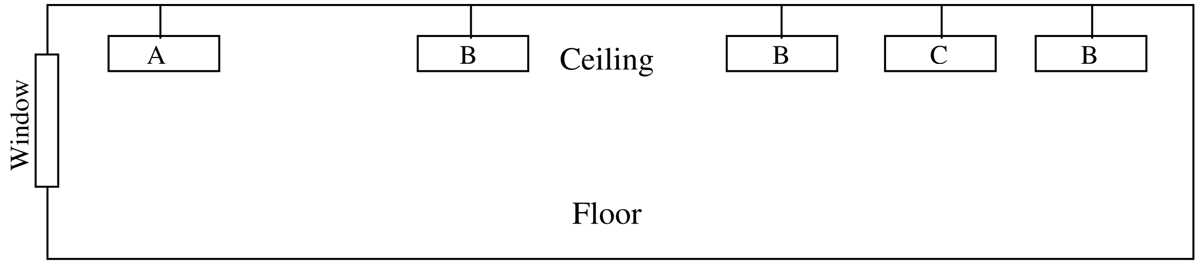
In a case study from the pharmaceutical industry, at the Merck office and storage building in Rahway, New Jersey, lighting panels were programmed to turn off automatically during expected periods of building non-use (override switches in entrance hallways allowed lights to be turned on manually during these times, if needed). Annual savings amounted to 1,310 MMBtu per year, which corresponded to avoided energy-related carbon dioxide (CO_2) emissions of nearly 260 tons per year (Merck 2005).

Manual controls can be used in conjunction with automatic controls to save additional energy in smaller areas. One of the easiest measures is to install switches to allow occupants to control lights. Other lighting controls include daylight controls for indoor and outdoor lights, which adjust the intensity of electrical lighting based on the availability of daylight.

An example of energy efficient lighting control is illustrated by Figure 15.1, which depicts five rows of overhead lights in a workspace. During the brightest part of the day, ample daylight is provided by the window and thus only row C would need to be turned on. At times when daylight levels drop, all B rows would be turned on and row C would be turned off. Only at night or on very dark days would it be necessary to have both rows A and B turned on (Cayless and Marsden 1983). These methods can also be used as a control strategy on a retrofit by adapting the luminaries already present. (For example, turning on the lighting in rows farthest away from the windows during the brightest parts of the day, then turning on additional rows as needed later.)

[17] For more information on Low-E windows see: http://www.efficientwindows.org/.

Figure 15.1 Lighting placement and controls.



Exit signs. Energy costs can be reduced by switching from incandescent lamps to light emitting diodes (LEDs) or radium strips in exit sign lighting. An incandescent exit sign uses about 40 W, while LED signs may use only about 4W to 8 W, reducing electricity use by 80% to 90%. A 1998 Lighting Research Center survey found that about 80% of exit signs being sold use LEDs (LRC 2001). The lifetime of an LED exit sign is about 10 years, compared to 1 year for incandescent signs, which can reduce exit sign maintenance costs considerably. In addition to exit signs, LEDs are increasingly being used for path marking and emergency way finding systems. Their long life and cool operation allows them to be embedded in plastic materials, which makes them well suited for such applications (LRC 2001).

New LED exit signs are inexpensive, with prices typically starting at around $20. The U.S. EPA's ENERGY STAR program website (http://www.energystar.gov) provides a list of suppliers of LED exit signs.

Tritium exit signs are an alternative to LED exit signs. Tritium signs are self-luminous and thus do not require an external power supply. The advertised lifetime of these signs is around 10 years and prices typically start at around $150 per sign.

Electronic ballasts. A ballast regulates the amount of electricity required to start a lighting fixture and maintain a steady output of light. Electronic ballasts can require 12% to 30% less power than their magnetic predecessors (Cook 1998; Galitsky et al. 2005a). New electronic ballasts have smooth and silent dimming capabilities, in addition to longer lives (up to 50% longer), faster run-up times, and cooler operation than magnetic ballasts (Eley et al. 1993; Cook 1998). New electronic ballasts also have automatic switch-off capabilities for faulty or end-of-life lamps.

Replacement of T-12 tubes with T-8 tubes. In many industrial facilities, it is common to find T-12 lighting tubes in use. T-12 lighting tubes are 12/8 inches in diameter (the "T-" designation refers to a tube's diameter in terms of 1/8 inch increments). T-12 tubes consume significant amounts of electricity, and also have extremely poor efficacy, lamp life, lumen depreciation, and color rendering index. Because of this, the maintenance and energy costs of T-12 tubes are high. T-8 lighting tubes have around twice the efficacy of T-12 tubes, and can last up to 60% longer, which leads to savings in maintenance costs. Typical energy savings from the replacement of a T-12 lamp by a T-8 lamp are around 30% (Galitsky et al. 2005a).

Replacement of mercury lights. Where color rendition is critical, metal halide lamps can replace mercury or fluorescent lamps with energy savings of up to 50%. Where color rendition is not critical, high-pressure sodium lamps offer energy savings of 50% to 60% compared to mercury lamps (Price and Ross 1989).

High-intensity discharge (HID) voltage reduction. Reducing lighting system voltage can also save energy. A Toyota production facility installed reduced-voltage HID lights and realized a 30% reduction in lighting energy consumption (Galitsky et al. 2005a). Commercial products are available that attach to a central panel switch (controllable by computer) and constrict the flow of electricity to lighting fixtures, thereby reducing voltage and saving energy, with an imperceptible loss of light. Voltage controllers work with both HID and fluorescent lighting systems and are available from multiple vendors.

High-intensity fluorescent lights. Traditional HID lighting can be replaced with high-intensity fluorescent lighting systems, which incorporate high-efficiency fluorescent lamps, electronic ballasts, and high-efficacy fixtures that maximize output to work areas. These systems have lower energy consumption, lower lumen depreciation over the lifetime of the lamp, better dimming options, faster startup and re-strike capabilities, better color rendition, higher pupil lumens ratings, and less glare than traditional HID systems (Martin et al. 2000).

Daylighting. Daylighting involves the efficient use of natural light in order to minimize the need for artificial lighting in buildings. Increasing levels of daylight within rooms can reduce electrical lighting loads by up to 70% (CADDET 2001; IEA 2000). Unlike conventional skylights, an efficient daylighting system may provide evenly dispersed light without creating heat gains, which can reduce the need for cooling compared to skylights. Daylighting differs from other energy efficiency measures because its features are integral to the architecture of a building; therefore, it is applied primarily to new buildings and incorporated at the design stage. However, existing buildings can sometimes be cost-effectively refitted with daylighting systems.

Daylighting can be combined with lighting controls to maximize its benefits. Because of its variability, daylighting is almost always combined with artificial lighting to provide the necessary illumination on cloudy days or after dark (see also Figure 11.1). Daylighting technologies include properly placed and shaded windows, atria, clerestories, light shelves, and light ducts. Clerestories, light shelves, and light ducts can accommodate various angles of the sun and redirect daylight using walls or reflectors.

More information on daylighting can be found at the website of the Daylighting Collaborative led by the Energy Center of Wisconsin (http://www.daylighting.org/).

16. Process Specific Energy Efficiency Measures

In Chapters 6-15 of this Guide, a wide variety of cross-cutting energy efficiency measures was presented that are used in petrochemical facilities. In this Chapter, energy efficiency measures that can be applied to specific processes in the large volume petrochemical industry are discussed. Even with a focus on the key energy consuming processes (e.g. crackers) it is not feasible to discuss the opportunities in detail. The cited references may serve as a guide to help find more in-depth information on certain process improvements.

16.1 Ethylene Production

For the petrochemical industry, Solomon Associates Ltd. performs energy efficiency analyses and comparisons for refineries and steam cracker plants worldwide. In 1995, the energy efficiency index (EEI) of all cracking activities in North America (including the United States, Canada and Mexico) equaled 175 (Solomon, 1995). This indicates that the energy use of the best available crackers (having an EEI of 100) is 40% lower than the observed energy use in the United States, showing that the potential for energy savings in olefin production is still substantial. Compared to other major ethylene producing regions, the United States is less efficient. Shaw Stone & Webster, one of the leading ethylene technology suppliers estimates the average specific energy consumption of U.S. gas cracker units to be ~20% higher compared to units in the EU and Japan (Bowen, 2006).

Overall energy utilization is one the most significant cost factor influencing the cost of steam cracker units and energy consumption data is therefore very sensitive. In the early 1970's, the increase in oil prices prompted producers to reduce energy consumption. Overall, specific energy consumption of best available cracking technology has roughly declined by a factor two for both naphtha and ethane crackers since the 1970s. However, partly due to the relatively old age of the crackers (over 20 years), several of these post-energy crisis energy efficiency improvements are not yet incorporated in existing crackers (Bowen, 2006). Several of the efficiency measures require replacement or key modifications of process equipment with substantial investment costs. Whether or not these investments are justified depends on many factors both in terms of the investment costs, fuel costs and expected energy savings (EC-IPPC, 2003).

Of the improvements made since the 1970s, about 60% has been in the cracking/quench section with the balance coming from improvements in the recovery section (EC-IPPC, 2003). In the same source, some notable improvements are summarized, some of which we will discuss in a bit more detail below:

<u>Cracking section</u>

- More selective furnace coils.
- Improved transfer line exchangers (TLEs) with higher heat recovery at lower pressure drop.
- Increased fuel efficiency in the cracking furnaces (typically 92-94%).
- Secondary TLEs for gas crackers.
- Use of gas turbine exhaust as furnace combustion air.

Cracked gas cooling and compression

- Higher gasoline fractionator bottom temperature.
- Improved use of heat available in quench water.
- Lower pressure drops in compressor system inter-stages.

Cold fractionation and refrigeration systems

- Additional expander on gas de-methaniser to optimize feed pre-cooling.
- Addition of side re-boilers to provide more efficient cold recuperation.
- Use of extended surface exchangers to improve heat transfer performance.

Utility systems

- Addition of gas turbine/electric generator.
- Optimization of steam and power balance.
- Improved compressor/driver efficiencies.

By upgrading or replacing the cracker furnace, substantial energy savings can be realized. The goal of furnace coil design improvements is to improve heat transfer, minimize coking in the coils and to maximize the yield of desired olefin products (Ren et al., 2006). Sulfur-based inhibitors can be used to reduce coke formation (EC-IPPC, 2003). More long-term options include ceramic coils or ceramic coated coils (already briefly discussed in Chapter 8), allowing oxygen-based combustion at a higher reaction temperature and ceramic (Bowen, 2006).

In normal crackers, the furnace burners use combustion air to provide the oxygen to burn fuels. In case of integration with a gas turbine, combustion air is replaced by the off-gases of a gas turbine that still contain 15-17% oxygen and a temperature of 580 ºC. Integration with a gas turbine could be beneficial if case of high energy costs and an available sink for the excess steam and power produced outside the olefin plant (Albano and Olszewski, 1992). Most olefin plants meet these requirements, especially when they are part of an integrated complex. Typical energy savings can be up to 2.5 MMBtu/ton of ethylene for naphtha crackers (Albano and Olszewski, 1992).

The cracked gas cooling and fractionation section is a very complex system encompassing distillation, refrigeration and absorption processes. The exact flow sequence varies per process design and is also dependent on the type of feedstock applied. Given the enormous temperature differences in the process (cracked gas above 800 ºC and refrigeration below -150 ºC) there are various opportunities for heat integration within the total process. Optimal heat recovery of the high temperature in the cracking furnace can be accomplished using high-temperature quench oil towers to improve heat recovery in the TLE's, optimal design of the convection section in the furnace and the use of secondary TLE's in gas crackers (Bowen, 2006; EC-IPPC, 2003). Heat pump systems such as mechanical vapor recompression (MVR) can be used to efficiently couple heating and cooling requirements. In MVR, distillation overhead is compressed, followed by condensation to provide heat for the reboiler. The technology has been successfully applied in propylene/propane splitters (Worrell et al., 1997) and can save up to 0.9 MMBtu/ton of ethylene (Ren et al., 2006).

It should be noted that the cross-cutting technologies discussed in the previous chapters (e.g. more efficient pumps and compressors) have also contributed significantly to the drop in specific energy consumption for efficient steam crackers as becomes clear from the list above and is also confirmed by Bowen (2006).

16.2 Energy Efficiency Measures in Other Key Processes

Aromatics. As for all large volume organic chemical processes, energy is a major cost factor in the production of aromatics (benzene, toluene and xylenes). The use of energy is essentially still cost-driven, but there is a growing tendency to incorporate as much energy integration as possible. Many opportunities to optimize heat recovery and usage are typically exploited in the design phase of new plants, but many are also applicable as project within existing units. Logically, energy integration not only applies to the aromatics plant as such, but also its surrounding units (e.g. the refinery), and the energy infrastructure as a whole (EC-IPPC, 2003). Licensors for aromatics recovery processes include Kellog Brown & Root, UOP, Lurgi, Uhde, Axens, ABB Lummus and ExxonMobil Chemical Technology licensing (Hydrocarbon Processing, 2005a).

Polymers. Also in the production of various large volume *polymers*, such as polyethylene, polypropylene, polystyrene and polyvinylchloride, various options exist to reduce energy consumption. In the Best Available Technique reference document for polymers published by the European Commission (EC-IPPC, 2006) the following options are mentioned that are considered best practice and reduce energy consumption[18]:

- Introducing an Environmental Management System and the use of advance equipment monitoring and maintenance systems (Chapter 6).
- Using a containment system to avoid emissions. The contained material (unreacted monomer, solvent and polymers) can be recycled (if possible) or used as fuel. An example of such a technique is the recovery of monomer from reciprocating compressors in high pressure PE plants.
- Using power and steam from cogeneration where possible (Chapter 7).
- Recovering the exothermic heat of reaction through generation of low pressure steam.
- Using a gear pump instead of or in combination with an extruder if applicable.
- Online compounding extrusion.
- Re-use of waste products such waste solvents, waste oils and catalyst residues.

Ethylene oxide and ethylene glycol. In Ethylene oxide (EO) and Ethylene glycol (EG) production, the heat balance of the process is very much influenced by the selectivity of the catalyst. The more selective the catalyst is, the less heat is produced in the reactor and the less steam can be exported. However, due to the high costs of the ethylene raw material and the major energy required to produce ethylene, it is always beneficial to use catalysts with a high selectivity. The heat balance is also influenced by the relative size of the EO and EG sections. It is possible to reduce energy consumption by optimal design of the various unit operations (e.g. distillation columns and compressors). The use of multi-effect evaporators in the final

[18] In addition, several measures are included to reduce emissions such as dust and volatile organic compounds.

de-watering of the glycol product can be used to reduce energy consumption as well as the use of heat released in the glycols reactor. Where possible, it is beneficial to recover the CO_2 which is produced by over oxidation of the ethylene feedstock and sell it as a commercial by-product (EC-IPPC, 2003). The relatively low temperatures applied (less than 300ºC (570°F) result in little opportunity for high-value heat recovery (U.S. DOE-OIT, 2004c), but it is still common practice to recover the heat of reaction in ethylene oxide production in the form of steam or via heat exchange. An example of heat integration in an EO/EG plant in South Korea is described by Choi et al. (2000). Heat from the EO stripping column and the CO_2 regenerator could be used to heat the polished water intake of the de-aerator in the adjacent utility plant, resulting in significant cost and energy savings with a payback period of only 8 months.

Ethylene dichloride and vinyl chloride monomer. A number of techniques can be adopted to reduce environmental emissions in the production of ethylene dichloride (EDC) and vinyl chloride monomer (VCM). Major energy losses occur in the quench and recovery sections (U.S. DOE-OIT, 2004c). Given the safety issues involved with chlorinated compounds, it is generally considered best practice to optimize process balancing (e.g. between the direct chlorination and oxychlorination processes) so as to maximize the recycle of process streams (EC-IPPC, 2003). Minimization of waste and optimal recovery of by-products is also included in a Charter issued by the European Council of Vinyl Manufacturers (ECVM) to improve environmental performance and to introduce emission levels considered achievable. In 1999, 64% of the ECVM plants complied with all the requirements of the charter (EC-IPPC, 2003). More long-term options related to EDC/VCM manufacture are the gas phase direct chlorination of ethylene (allowing heat recovery at higher temperature level and resulting in higher process selectivity) and catalytic rather than thermal cracking of EDC to VCM, allowing the process to be conducted at lower temperatures (EC-IPPC, 2003).

Styrene. Two interesting examples of improved heat integration via pinch analysis in the production of styrene in a South Korean plant are described by Choi et al. (2000). By using steam condensate instead of low pressure steam in the ethyl benzene feed system, more energy could be recovered from the reactor, resulting in large energy savings. The payback period of this project was only 1.6 months. Another project involved the re-design of the heat exchanger network by carefully selecting cooling and heating demands of the process. The modification achieved additional heat recovery and also improved operability and had a pay-back time of only 1.4 months.

Acrylonitrile. The main challenge in acrylonitrile production is, comparable to ethylene oxide production, the selectivity of the catalyst in relation to the heat of reaction. The reaction heat is recovered as high pressure steam, which is used downstream to drive compressors and as energy input into separation and purification steps. The various gaseous and liquid by-products (including the very toxic hydrogen cyanide) are recovered and are either used a fuel in furnaces or boilers or sold if sufficient market exists. The re-use of the reaction energy (recovered as high pressure steam) is very important and a proper energy management system is key to the performance of the unit. The main steam use within the plant is for distillation and the main power use is for air compressors. The normal methods of reducing energy use in these units apply (EC-IPPC, 2003). These methods are discussed elsewhere in this guide.

Toluene diisocyanate. In toluene diisocyanate (TDI) production, it is regarded best practice to reutilize the energy re-use potential of the exothermic reaction and of the incineration of waste products via recuperative incinerators (EC-IPPC, 2003).

17. Summary and Conclusions

The U.S. petrochemical industry is the largest in the world producing a wide range of basic and intermediate organic chemicals. The sector employs around 130,000 people and produces products with a total value of shipments exceeding $150 billion. Energy costs represent one of the most important cost factors in the petrochemical industry. The industry spent around $10 billion on fuels and electricity in 2004. Energy efficiency improvement is an important way to reduce costs and increase predictable earnings, especially in times of high energy-price volatility.

Many companies in the U.S. petrochemical industry have already accepted the challenge to improve their energy efficiency in the face of high energy costs and have begun to reap the rewards of energy efficiency investments. Voluntary government programs aim to assist industry to improve competitiveness through increased energy efficiency and reduced environmental impact. ENERGY STAR®, a voluntary program managed by the U.S. Environmental Protection Agency, stressed the need for strong and strategic corporate energy management programs. This study provides information on potential energy efficiency improvements for the petrochemical industry.

This Energy Guide has summarized a large number of energy efficient technologies and practices that are proven, cost-effective, and available for implementation today. Energy efficiency improvement opportunities have been discussed that are applicable at the component, process, facility, and organizational levels. Preliminary estimates of savings in energy and energy-related costs have been provided for many energy efficiency measures, based on case study data from real-world industrial applications. Additionally, typical investment payback periods and references to further information in the technical literature have been provided, when available. A key first step in any energy improvement initiative is to establish a focused and strategic energy management program, as depicted in Figure 6.1, which will help to identify and implement energy efficiency measures and practices across and organization and ensure continuous improvement.

While the expected savings associated with some of the individual measures may be relatively small, the cumulative effect of these measures across an entire plant may potentially be quite large. Many of the measures discussed have relatively short payback periods and are therefore attractive economic investments on their own merit. The degree of implementation of these measures will vary by plant and end use; continuous evaluation of these measures will help to identify further cost savings in ongoing energy management programs.

For all energy efficiency measures presented in this Energy Guide, individual plants should pursue further research on the economics of the measures, as well as on the applicability of different measures to their own unique production practices, in order to assess the feasibility of measure implementation.

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Glossary

ASD	Adjustable-speed drive
CDA	Copper Development Association
CHP	Combined heat and power
CIPEC	Canadian Industry Program for Energy Conservation
cfm	Cubic feet per minute
CO_2	Carbon dioxide
EIA	Energy Information Agency (U.S. Department of Energy)
ft^2	Square feet
GBP	Great Britain Pound (Pound Sterling)
HID	High-intensity discharge
hp	Horsepower
HVAC	Heating, ventilation, and air conditioning
IAC	Industrial Assessment Center
kg	Kilogram
KWh	Kilowatt hour
LED	Light emitting diode
MMBtu	Million British thermal units
MASIS	Mobile aerosol-sealant injection system
MECS	Manufacturing Energy Consumption Survey
MVR	Mechanical vapor recompression
MW	Megawatt
MWh	Megawatt-hour
NAICS	North American Industry Classification System
NO_X	Nitrogen oxides
psi	Pounds per square inch
psig	Pounds per square inch (gauge)
R&D	Research and development
STIG	Steam-injected gas turbine
TBtu	Trillion British thermal units
U.S. DOE	United States Department of Energy
U.S. EPA	United States Environmental Protection Agency
VSD	Variable speed drive
VVC	Variable voltage control

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Appendix A. NAICS Classification Of The Chemical Manufacturing Industry (NAICS 325)

325	Chemical Manufacturing
3251	Basic Chemical Manufacturing
32511	Petrochemical Manufacturing
325110	Petrochemical Manufacturing
32512	Industrial Gas Manufacturing
325120	Industrial Gas Manufacturing
32513	Synthetic Dye and Pigment Manufacturing
325131	Inorganic Dye and Pigment Manufacturing
325132	Synthetic Organic Dye and Pigment Manufacturing
32518	Other Basic Inorganic Chemical Manufacturing
325181	Alkalies and Chlorine Manufacturing
325182	Carbon Black Manufacturing
325188	All Other Basic Inorganic Chemical Manufacturing
32519	Other Basic Organic Chemical Manufacturing
325191	Gum and Wood Chemical Manufacturing
325192	Cyclic Crude and Intermediate Manufacturing
325193	Ethyl Alcohol Manufacturing
325199	All Other Basic Organic Chemical Manufacturing
3252	Resin, Synthetic Rubber, and Artificial Synthetic Fibers and Filaments Manufacturing
32521	Resin and Synthetic Rubber Manufacturing
325211	Plastics Material and Resin Manufacturing
325212	Synthetic Rubber Manufacturing
32522	Artificial and Synthetic Fibers and Filaments Manufacturing
325221	Cellulosic Organic Fiber Manufacturing
325222	Noncellulosic Organic Fiber Manufacturing
3253	Pesticide, Fertilizer, and Other Agricultural Chemical Manufacturing
32531	Fertilizer Manufacturing
325311	Nitrogenous Fertilizer Manufacturing
325312	Phosphatic Fertilizer Manufacturing
325314	Fertilizer (Mixing Only) Manufacturing
32532	Pesticide and Other Agricultural Chemical Manufacturing
325320	Pesticide and Other Agricultural Chemical Manufacturing
3254	Pharmaceutical and Medicine Manufacturing
32541	Pharmaceutical and Medicine Manufacturing
325411	Medicinal and Botanical Manufacturing
325412	Pharmaceutical Preparation Manufacturing
325413	In-Vitro Diagnostic Substance Manufacturing
325414	Biological Product (except Diagnostic) Manufacturing

3255	Paint, Coating, and Adhesive Manufacturing
32551	Paint and Coating Manufacturing
325510	Paint and Coating Manufacturing
32552	Adhesive Manufacturing
325520	Adhesive Manufacturing
3256	Soap, Cleaning Compound, and Toilet Preparation Manufacturing
32561	Soap and Cleaning Compound Manufacturing
325611	Soap and Other Detergent Manufacturing
325612	Polish and Other Sanitation Good Manufacturing
325613	Surface Active Agent Manufacturing
32562	Toilet Preparation Manufacturing
325620	Toilet Preparation Manufacturing
3259	Other Chemical Product and Preparation Manufacturing
32591	Printing Ink Manufacturing
325910	Printing Ink Manufacturing
32592	Explosives Manufacturing
325920	Explosives Manufacturing
32599	All Other Chemical Product and Preparation Manufacturing
325991	Custom Compounding of Purchased Resins
325992	Photographic Film, Paper, Plate, and Chemical Manufacturing
325998	All Other Miscellaneous Chemical Product and Preparation Manufacturing

Appendix B. Overview of U.S. Ethylene plants

Capacities per January 1, 2006 (Oil and Gas Journal, 2006a).

			Capacity	Typical feedstock or feedstock mixture on which listed capacity is based (%)						
Company	**Location**	**State**	**kt / a [1]**	**Ethane**	**Propane**	**Butane**	**Naphtha**	**Gas Oil**	**Other**	**Unknown**
BASF Fina Petrochemicals	Port Arthur	Texas	830				100			
Chevron Phillips Chemicals Co. LP	Cedar bayou	Texas	794	30	20	25	25			
Chevron Phillips Chemicals Co. LP	Port Arthur	Texas	794	70	25	5				
Chevron Phillips Chemicals Co. LP	Sweeny	Texas	923	38	37	25				
Chevron Phillips Chemicals Co. LP	Sweeny	Texas	673	75	25					
Chevron Phillips Chemicals Co. LP	Sweeny	Texas	272	85	15					
Dow Chemical Co.	Freeport (LHC 7)	Texas	630	50	50					
Dow Chemical Co.	Freeport (LHC 8)	Texas	1010	10	20		70			
Dow Chemical Co.	Plaquemine (LHC 2)	Louisiana	520	75	25					
Dow Chemical Co.	Plaquemine (LHC 3)	Louisiana	740		70	10	20			
Dow Chemical Co.	Taft 1	Louisiana	590	20	40		40			
Dow Chemical Co.	Taft 2	Louisiana	410	20	40		40			
DuPont	Orange	Texas	680	100						
Eastman Chemical Co.	Longview	Texas	781	25	67	7	1			
Equistar Chemicals LP (Lyondell)	Channelview	Texas	875	5			95			
Equistar Chemicals LP (Lyondell)	Channelview	Texas	875	5			95			
Equistar Chemicals LP (Lyondell)	Chocolate Bayou	Texas	544				100			
Equistar Chemicals LP (Lyondell)	Clinton	Iowa	476	80	20					
Equistar Chemicals LP (Lyondell)	Corpus Christi	Texas	771	10	30		60			
Equistar Chemicals LP (Lyondell)	La Porte	Texas	789	60	20		20			
Equistar Chemicals LP (Lyondell)	Morris	Illnois	550	80	20					
Exxon Mobil Chemical Co.	Baton Rouge	Louisiana	975	9	8	8	25	25	25	
Exxon Mobil Chemical Co.	Baytown	Texas	2197	58	8	9	25			
Exxon Mobil Chemical Co.	Beaumont	Texas	816	8	8	9	75			
Exxon Mobil Chemical Co.	Houston	Texas	102						100	
Formosa Plastics Corp. USA	Point Comfort	Texas	816	45	15		40			
Formosa Plastics Corp. USA	Point Comfort	Texas	725	45	15		40			
Huntsman Corp.	Odessa	Texas	360							100
Huntsman Corp.	Port Arthur	Texas	635				60		40 (LPG)	
Huntsman Corp.	Port Neches	Texas	180							100
INEOS Olefins and Polymers USA	Chocolate Bayou	Texas	1752	50	35		15			
Javelina Co.	Corpus Christi	Texas	151						100 (ref-gas)	
Sasol North America Inc.	Westlake	Louisiana	444	100						
Shell Chemicals Ltd.	Deer Park	Texas	1406	15		5	50	30		
Shell Chemicals Ltd.	Norco	Louisiana	900	5			35	60		
Shell Chemicals Ltd.	Norco	Louisiana	656	45	5	5	45			
Sunoco Inc.	Marcus Hook	Pennsylvania	225	100						
Westlake Petrochemicals Corp.	Calvert City	Kentucky	195		100					
Westlake Petrochemicals Corp.	Sulphur#1	Louisiana	567	32	60					8
Westlake Petrochemicals Corp.	Sulphur#2	Louisiana	522	100						
Williams Energy Services	Geismar	Louisiana	590	90	10					
Total			**28741**	**37**	**19**	**4**	**32**	**4**	**3**	**2**

[1] 1 kton is 2.20 million lbs

Appendix C. Employee Tasks for Energy Efficiency

Personnel at all levels should be aware of energy use and organizational goals for energy efficiency. Staff should be trained in both skills and general approaches to energy efficiency in day-to-day practices. In addition, performance results should be regularly evaluated and communicated to all personnel, recognizing high achievement. Some examples of simple tasks employees can do are outlined below (Caffal, 1995).

- Eliminate unnecessary energy consumption by equipment. Switch off motors, fans, and machines when they are not being used, especially at the end of the working day or shift, and during breaks, when it does not affect production, quality, or safety. Similarly, turn on equipment no earlier than needed to reach the correct settings (temperature, pressure) at the start time.
- Switch off unnecessary lights; rely on daylighting whenever possible.
- Use weekend and night setbacks on HVAC in offices or conditioned buildings.
- Report leaks of water (both process water and dripping taps), steam, and compressed air. Ensure they are repaired quickly. The best time to check for leaks is a quiet time like the weekend.
- Look for unoccupied areas being heated or cooled, and switch off heating or cooling.
- Check that heating controls are not set too high or cooling controls set too low. In this situation, windows and doors are often left open to lower temperatures instead of lowering the heating.
- Check to make sure the pressure and temperature of equipment is not set too high.
- Prevent drafts from badly fitting seals, windows and doors, and hence, leakage of cool or warm air.
- Carry out regular maintenance of energy-consuming equipment.
- Ensure that the insulation on process heating equipment is effective.

Appendix D. Energy Management Assessment Matrix

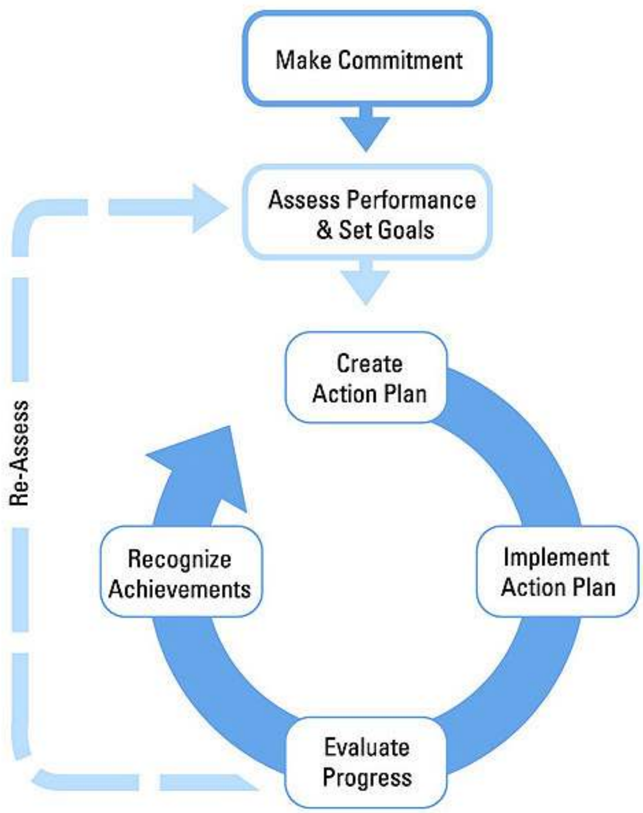
CHANGE FOR THE BETTER WITH ENERGY STAR

Energy Management Program Assessment Matrix

Introduction

The U.S. EPA has developed guidelines for establishing and conducting an effective energy management program based on the successful practices of ENERGY STAR partners.

These guidelines, illustrated in the graphic, are structured on seven fundamental management elements that encompass specific activities.



This assessment matrix is designed to help organizations and energy managers compare their energy management practices to those outlined in the Guidelines. The full Guidelines can be viewed on the ENERGY STAR web site – http://www.energystar.gov/.

How To Use The Assessment Matrix

The matrix outlines the key activities identified in the ENERGY STAR Guidelines for Energy Management and three levels of implementation:

- No evidence
- Most elements
- Fully Implemented

1. Print the assessment matrix.

2. Compare your program to the Guidelines by identifying the degree of implementation that most closely matches your organization's program.

3. Use a highlighter to fill in the cell that best characterizes the level of implementation of your program. You will now have a visual comparison of your program to the elements of the ENERGY STAR Guidelines for Energy Management.

4. Identify the steps needed to fully implement the energy management elements and record these in the Next Steps column.

Energy Management Program Assessment Matrix				
	Little or no evidence	**Some elements**	**Fully implemented**	**Next Steps**
Make Commitment to Continuous Improvement				
Energy Director	No central corporate resource Decentralized management	Corporate or organizational resource not empowered	Empowered corporate leader with senior management support	
Energy Team	No company energy network	Informal organization	Active cross-functional team guiding energy program	
Energy Policy	No formal policy	Referenced in environmental or other policies	Formal stand-alone EE policy endorsed by senior mgmt.	
Assess Performance and Opportunities				
Gather and Track Data	Little metering/no tracking	Local or partial metering/tracking/ reporting	All facilities report for central consolidation/analysis	
Normalize	Not addressed	Some unit measures or weather adjustments	All meaningful adjustments for corporate analysis	
Establish baselines	No baselines	Various facility-established	Standardized corporate base year and metric established	
Benchmark	Not addressed or only same site historical comparisons	Some internal comparisons among company sites	Regular internal & external comparisons & analyses	
Analyze	Not addressed	Some attempt to identify and correct spikes	Profiles identifying trends, peaks, valleys & causes	
Technical assessments and audits	Not addressed	Internal facility reviews	Reviews by multi-functional team of professionals	
Set Performance Goals				
Determine scope	No quantifiable goals	Short term facility goals or nominal corporate goals	Short & long term facility and corporate goals	
Estimate potential for improvement	No process in place	Specific projects based on limited vendor projections	Facility & corporate defined based on experience	
Establish goals	Not addressed	Loosely defined or sporadically applied	Specific & quantifiable at various organizational levels	
Create Action Plan				
Define technical steps and targets	Not addressed	Facility-level consideration as opportunities occur	Detailed multi-level targets with timelines to close gaps	
Determine roles and resources	Not addressed or done on ad hoc basis	Informal interested person competes for funding	Internal/external roles defined & funding identified	

	Little or no evidence	Some elements	Fully implemented	Next Steps
Implement Action Plan				
Create a communication plan	Not addressed	Tools targeted for some groups used occasionally	All stakeholders are addressed on regular basis	
Raise awareness	No promotion of energy efficiency	Periodic references to energy initiatives	All levels of organization support energy goals	
Build capacity	Indirect training only	Some training for key individuals	Broad training/certification in technology & best practices	
Motivate	No or occasional contact with energy users and staff	Threats for non-performance or periodic reminders	Recognition, financial & performance incentives	
Track and monitor	No system for monitoring progress	Annual reviews by facilities	Regular reviews & updates of centralized system	
Evaluate Progress				
Measure results	No reviews	Historical comparisons	Compare usage & costs vs. goals, plans, competitors	
Review action plan	No reviews	Informal check on progress	Revise plan based on results, feedback & business factors	
Recognize Achievements				
Provide internal recognition	Not addressed	Identify successful projects	Acknowledge contributions of individuals, teams, facilities	
Get external recognition	Not sought	Incidental or vendor acknowledgement	Government/third party highlighting achievements	

Interpreting Your Results
Comparing your program to the level of implementation identified in the Matrix should help you identify the strengths and weaknesses of your program.

The U.S. EPA has observed that organizations fully implementing the practices outlined in the Guidelines achieve the greatest results. Organizations are encouraged to implement the Guidelines as fully as possible.

By highlighting the cells of the matrix, you now can easily tell how well balanced your energy program is across the management elements of the Guidelines. Use this illustration of your energy management program for discussion with staff and management.

Use the "Next Steps" column of the Matrix to develop a plan of action for improving your energy management practices.

Resources and Help
ENERGY STAR offers a variety tools and resources to help organizations strengthen their energy management programs.

Here are some next steps you can take with ENERGY STAR:

1. Read the Guidelines sections for the areas of your program that are not fully implemented.

2. Become an ENERGY STAR Partner, if you are not already.

3. Review ENERGY STAR Tools and Resources.

4. Find more sector-specific energy management information at http://www.energystar.gov/.

5. Contact ENERGY STAR for additional resources.

Appendix E. Teaming Up to Save Energy Checklist

The following checklist can be used as a handy reference to key tasks for establishing and sustaining an effective energy team. For more detailed information on energy teams, consult the U.S. EPA's *Teaming Up to Save Energy* guide (U.S. EPA 2006), which is available at http://www.energystar.gov/.

ORGANIZE YOUR ENERGY TEAM		√
Energy Director	Able to work with all staff levels from maintenance to engineers to financial officers. Senior-level person empowered by top management support	
Senior Management	Energy director reports to senior executive or to a senior management council. Senior champion or council provides guidance and support	
Energy Team	Members from business units, operations/engineering, facilities, and regions. Energy networks formed. Support services (PR, IT, HR).	
Facility Involvement	Facility managers, electrical personnel. Two-way information flow on goals and opportunities. Facility-based energy teams with technical person as site champion.	
Partner Involvement	Consultants, vendors, customers, and joint venture partners. Energy savings passed on through lower prices.	
Energy Team Structure	Separate division and/or centralized leadership. Integrated into organization's structure and networks established.	
Resources & Responsibilities	Energy projects incorporated into normal budget cycle as line item. Energy director is empowered to make decisions on projects affecting energy use. Energy team members have dedicated time for the energy program.	
STARTING YOUR ENERGY TEAM		**√**
Management Briefing	Senior management briefed on benefits, proposed approach, and potential energy team members.	
Planning	Energy team met initially to prepare for official launch.	
Strategy	Energy team met initially to prepare for official launch.	
Program Launch	Organizational kickoff announced energy network, introduced energy director, unveiled energy policy, and showcased real-world proof.	
Energy Team Plans	Work plans, responsibilities, and annual action plan established.	
Facility Engagement	Facility audits and reports conducted. Energy efficiency opportunities identified.	

BUILDING CAPACITY		√
Tracking and Monitoring	Systems established for tracking energy performance and best practices implementation.	
Transferring Knowledge	Events for informal knowledge transfer, such as energy summits and energy fairs, implemented.	
Raising Awareness	Awareness of energy efficiency created through posters, intranet, surveys, and competitions.	
Formal Training	Participants identified, needs determined, training held. Involvement in ENERGY STAR Web conferences and meetings encouraged. Professional development objectives for key team members.	
Outsourcing	Use of outside help has been evaluated and policies established.	
Cross-Company Networking	Outside company successes sought and internal successes shared. Information exchanged to learn from experiences of others.	
SUSTAINING THE TEAM		√
Effective Communications	Awareness of energy efficiency created throughout company. Energy performance information is published in company reports and communications.	
Recognition and Rewards	Internal awards created and implemented. Senior management is involved in providing recognition.	
External Recognition	Credibility for your organization's energy program achieved. Awards from other organizations have added to your company's competitive advantage.	
MAINTAINING MOMENTUM		√
Succession	Built-in plan for continuity established. Energy efficiency integrated into organizational culture.	
Measures of Success	Sustainability of program and personnel achieved. Continuous improvement of your organization's energy performance attained.	

Appendix F. Support Programs for Industrial Energy Efficiency Improvement

This appendix provides a list of energy efficiency support available to industry. A brief description of the program or tool is given, as well as information on its target audience and the URL for the program. Included are federal and state programs. Use the URL to obtain more information from each of these sources. An attempt was made to provide as complete a list as possible; however, information in this listing may change with the passage of time.

Tools for Self-Assessment

Steam System Assessment Tool

Description:	Software package to evaluate energy efficiency improvement projects for steam systems. It includes an economic analysis capability.
Target Group:	Any industry operating a steam system
Format:	Downloadable software package (13.6 MB)
Contact:	U.S. Department of Energy
URL:	http://www1.eere.energy.gov/industry/bestpractices/software.html

Steam System Scoping Tool

Description:	Spreadsheet tool for plant managers to identify energy efficiency opportunities in industrial steam systems.
Target Group:	Any industrial steam system operator
Format:	Downloadable software (Excel)
Contact:	U.S. Department of Energy
URL:	http://www1.eere.energy.gov/industry/bestpractices/software.html

3E Plus: Optimization of Insulation of Boiler Steam Lines

Description:	Downloadable software to determine whether boiler systems can be optimized through the insulation of boiler steam lines. The program calculates the most economical thickness of industrial insulation for a variety of operating conditions. It makes calculations using thermal performance relationships of generic insulation materials included in the software.
Target Group:	Energy and plant managers
Format:	Downloadable software
Contact:	U.S. Department of Energy
URL:	http://www1.eere.energy.gov/industry/bestpractices/software.html

MotorMaster+

Description:	Energy-efficient motor selection and management tool, including a catalog of over 20,000 AC motors. It contains motor inventory management tools, maintenance log tracking, efficiency analysis, savings evaluation, energy accounting, and environmental reporting capabilities.
Target Group:	Any industry
Format:	Downloadable software (can also be ordered on CD)
Contact:	U.S. Department of Energy
URL:	http://www1.eere.energy.gov/industry/bestpractices/software.html

ASDMaster: Adjustable Speed Drive Evaluation Methodology and Application

Description:	Software program helps to determine the economic feasibility of an adjustable speed drive application, predict how much electrical energy may be saved by using an ASD, and search a database of standard drives.
Target Group:	Any industry
Format:	Software package (not free)
Contact:	Electric Power Research Institute (EPRI), (800) 832-7322
URL:	http://www.epri-peac.com/products/asdmaster/asdmaster.html

The 1-2-3 Approach to Motor Management

Description:	A step-by-step motor management guide and spreadsheet tool that can help motor service centers, vendors, utilities, energy-efficiency organizations, and others convey the financial benefits of sound motor management.
Target Group:	Any industry
Format:	Downloadable Microsoft Excel spreadsheet
Contact:	Consortium for Energy Efficiency (CEE), (617) 589-3949
URL:	http://www.motorsmatter.org/tools/123approach.html

AirMaster+: Compressed Air System Assessment and Analysis Software

Description:	Modeling tool that maximizes the efficiency and performance of compressed air systems through improved operations and maintenance practices
Target Group:	Any industry operating a compressed air system
Format:	Downloadable software
Contact:	U.S. Department of Energy
URL:	http://www1.eere.energy.gov/industry/bestpractices/software.html

Fan System Assessment Tool (FSAT)

Description:	The Fan System Assessment Tool (FSAT) helps to quantify the potential benefits of optimizing a fan system. FSAT calculates the amount of energy used by a fan system, determines system efficiency, and quantifies the savings potential of an upgraded system.
Target Group:	Any user of fans
Format:	Downloadable software
Contact:	U.S. Department of Energy
URL:	http://www1.eere.energy.gov/industry/bestpractices/software.html

Combined Heat and Power Application tool (CHP)

Description:	The Combined Heat and Power Application Tool (CHP) helps industrial users evaluate the feasibility of CHP for heating systems such as fuel-fired furnaces, boilers, ovens, heaters, and heat exchangers.
Target Group:	Any industrial heat and electricity user
Format:	Downloadable software
Contact:	U.S. Department of Energy
URL:	http://www1.eere.energy.gov/industry/bestpractices/software.html

Pump System Assessment Tool 2004 (PSAT)

Description:	The tool helps industrial users assess the efficiency of pumping system operations. PSAT uses achievable pump performance data from Hydraulic Institute standards and motor performance data from the MotorMaster+ database to calculate potential energy and associated cost savings.
Target Group:	Any industrial pump user
Format:	Downloadable software
Contact:	U.S. Department of Energy
URL:	http://www1.eere.energy.gov/industry/bestpractices/software.html

Quick Plant Energy Profiler

Description:	The Quick Plant Energy Profiler, or Quick PEP, is an online software tool provided by the U.S. Department of Energy to help industrial plant managers in the United States identify how energy is being purchased and consumed at their plant and also identify potential energy and cost savings. Quick PEP is designed so that the user can complete a plant profile in about an hour. The Quick PEP online tutorial explains what plant information is needed to complete a Quick PEP case.
Target Group:	Any industrial plant
Format:	Online software tool
Contact:	U.S. Department of Energy
URL:	http://www1.eere.energy.gov/industry/bestpractices/software.html

ENERGY STAR Portfolio Manager

Description:	Online software tool helps to assess the energy performance of buildings by providing a 1-100 ranking of a building's energy performance relative to the national building market. Measured energy consumption forms the basis of the ranking of performance.
Target Group:	Any building user or owner
Format:	Online software tool
Contact:	U.S. Environmental Protection Agency

URL: http://www.energystar.gov/index.cfm?c=evaluate_performance.bus_portfoliomanager

Assessment and Technical Assistance

Industrial Assessment Centers

Description:	Small- to medium-sized manufacturing facilities can obtain a free energy and waste assessment. The audit is performed by a team of engineering faculty and students from 30 participating universities in the U.S. and assesses the plant's performance and recommends ways to improve efficiency.
Target Group:	Small- to medium-sized manufacturing facilities with gross annual sales below $75 million and fewer than 500 employees at the plant site.
Format:	A team of engineering faculty and students visits the plant and prepares a written report with energy efficiency, waste reduction and productivity recommendations.
Contact:	U.S. Department of Energy
URL:	http://www1.eere.energy.gov/industry/bestpractices/iacs.html

Save Energy Now Assessments

Description:	The U.S. DOE conducts plant energy assessments to help manufacturing facilities across the nation identify immediate opportunities to save energy and money, primarily by focusing on energy-intensive systems, including process heating, steam, pumps, fans, and compressed air.
Target Group:	Large plants
Format:	Online request
Contact:	U.S. Department of Energy
URL:	http://www1.eere.energy.gov/industry/saveenergynow/

Manufacturing Extension Partnership (MEP)

Description:	MEP is a nationwide network of not-for-profit centers in over 400 locations providing small- and medium-sized manufacturers with technical assistance. A center provides expertise and services tailored to the plant, including a focus on clean production and energy-efficient technology.
Target Group:	Small- and medium-sized plants
Format:	Direct contact with local MEP Office
Contact:	National Institute of Standards and Technology, (301) 975-5020
URL:	http://www.mep.nist.gov/

Small Business Development Center (SBDC)

Description:	The U.S Small Business Administration (SBA) administers the Small Business Development Center Program to provide management assistance to small businesses through 58 local centers. The SBDC Program provides counseling, training and technical assistance in the areas of financial, marketing, production, organization, engineering and technical problems and feasibility studies, if a small business cannot afford consultants.
Target Group:	Small businesses
Format:	Direct contact with local SBDC
Contact:	Small Business Administration, (800) 8-ASK-SBA
URL:	http://www.sba.gov/sbdc/

ENERGY STAR – Selection and Procurement of Energy-Efficient Products for Business

Description:	ENERGY STAR identifies and labels energy-efficient office equipment. Look for products that have earned the ENERGY STAR. They meet strict energy efficiency guidelines set by the EPA. Office equipment included such items as computers, copiers, faxes, monitors, multifunction devices, printers, scanners, transformers and water coolers.
Target Group:	Any user of labeled equipment.
Format:	Website
Contact:	U.S. Environmental Protection Agency
URL:	http://www.energystar.gov/index.cfm?c=business.bus_index

Training

ENERGY STAR

Description:	As part of ENERGY STAR's work to promote superior energy management systems, energy managers for the companies that participate in ENERGY STAR are offered the opportunity to network with other energy managers in the partnership. The networking meetings are held monthly and focus on a specific strategic energy management topic to train and strengthen energy managers in the development and implementation of corporate energy management programs.
Target Group:	Corporate and plant energy managers
Format:	Web-based teleconference
Contact:	Climate Protection Partnerships Division, U.S. Environmental Protection Agency
URL:	http://www.energystar.gov/

Best Practices Program

Description:	The U.S. DOE Best Practices Program provides training and training materials to support the efforts of the program in efficiency improvement of utilities (compressed air, steam) and motor systems (including pumps). Training is provided regularly in different regions. One-day or multi-day trainings are provided for specific elements of the above systems. The Best Practices program also provides training on other industrial energy equipment, often in coordination with conferences.
Target Group:	Technical support staff, energy and plant managers
Format:	Various training workshops (one day and multi-day workshops)
Contact:	Office of Industrial Technologies, U.S. Department of Energy
URL:	http://www1.eere.energy.gov/industry/bestpractices/training.html

Compressed Air Challenge™

Description:	The not-for-profit Compressed Air Challenge™ develops and provides training on compressed air system energy efficiency via a network of sponsoring organizations in the United States and Canada. Three levels of training are available: (1) Fundamentals (1 day); (2) Advanced (2 days); and (3) Qualified Specialist (3-1/2 days plus an exam). Training is oriented to support implementation of an action plan at an industrial facility.
Target Group:	Compressed air system managers, plant engineers
Format:	Training workshops
Contact:	Compressed Air Challenge: Info@compressedairchallenge.org
URL:	http://www.compressedairchallenge.org/

Financial Assistance

Below major federal programs are summarized that provide assistance for energy efficiency investments. Many states also offer funds or tax benefits to assist with energy efficiency projects (see below for State Programs). However, these programs can change over time, so it is recommended to review current policies when making any financial investment decisions.

Industries of the Future - U.S. Department of Energy

Description:	Collaborative R&D partnerships in nine vital industries. The partnership consists of the development of a technology roadmap for the specific sector and key technologies, and cost-shared funding of research and development projects in these sectors.
Target Group:	Nine selected industries: agriculture, aluminum, chemicals, forest products, glass, metal casting, mining, petroleum and steel.
Format:	Solicitations (by sector or technology)
Contact:	U.S. Department of Energy – Office of Industrial Technologies
URL:	http://www.eere.energy.gov/industry/technologies/industries.html

Inventions & Innovations (I&I)

Description:	The program provides financial assistance through cost-sharing of 1) early development and establishing technical performance of innovative energy-saving ideas and inventions (up to $75,000) and 2) prototype development or commercialization of a technology (up to $250,000). Projects are performed by collaborative partnerships and must address industry-specified priorities.
Target Group:	Any industry (with a focus on energy-intensive industries)
Format:	Solicitation
Contact:	U.S. Department of Energy – Office of Industrial Technologies
URL:	http://www.eere.energy.gov/inventions/

Small Business Administration (SBA)

Description:	The Small Business Administration provides several loan and loan guarantee programs for investments (including energy-efficient process technology) for small businesses.
Target Group:	Small businesses
Format:	Direct contact with SBA
Contact:	Small Business Administration
URL:	http://www.sba.gov/

State and Local Programs

Many state and local governments have general industry and business development programs that can be used to assist businesses in assessing or financing energy-efficient process technology or buildings. Please contact your state and local government to determine what tax benefits, funding grants, or other assistance they may be able to provide your organization. This list should not be considered comprehensive but instead merely a short list of places to start in the search for project funding. These programs can change over time, so it is recommended to review current policies when making any financial investment decisions.

Summary of Motor and Drive Efficiency Programs by State

Description:	A report that provides an overview of state-level programs that support the use of NEMA Premium® motors, ASDs, motor management services, system optimization and other energy management strategies.
Target Group:	Any industry
Contact:	Consortium for Energy Efficiency (CEE), (617) 589-3949
URL:	http://www.motorsmatter.org/tools/123approach.html

California – Public Interest Energy Research (PIER)

Description:	PIER provides funding for energy efficiency, environmental, and renewable energy projects in the state of California. Although there is a focus on electricity, fossil fuel projects are also eligible.
Target Group:	Targeted industries (e.g. food industries) located in California
Format:	Solicitation
Contact:	California Energy Commission, (916) 654-4637
URL:	http://www.energy.ca.gov/pier/funding.html

California – Energy Innovations Small Grant Program (EISG)

Description:	EISG provides small grants for development of innovative energy technologies in California. Grants are limited to $75,000.
Target Group:	All businesses in California
Format:	Solicitation
Contact:	California Energy Commission, (619) 594-1049
URL:	http://www.energy.ca.gov/research/innovations/index.html/

California – Savings By Design

Description:	Design assistance is available to building owners and to their design teams for energy-efficient building design. Financial incentives are available to owners when the efficiency of the new building exceeds minimum thresholds, generally 10% better than California's Title 24 standards. The maximum owner incentive is $150,000 per free-standing building or individual meter. Design team incentives are offered when a building design saves at least 15%. The maximum design team incentive per project is $50,000.
Target Group:	Nonresidential new construction or major renovation projects
Format:	Open year round
URL:	http://www.savingsbydesign.com/

Indiana – Industrial Programs

Description:	The Energy Policy Division of the Indiana Department of Commerce operates two industrial programs. The Industrial Energy Efficiency Fund (IEEF) is a zero-interest loan program (up to $250,000) to help Indiana manufacturers increase the energy efficiency of manufacturing processes. The fund is used to replace or convert existing equipment, or to purchase new equipment as part of a process/plant expansion that will lower energy use. The Distributed Generation Grant Program (DGGP) offers grants of up to $30,000 or up to 30% of eligible costs for distributed generation with an efficiency over 50% to install and study distributed generation technologies such as fuel cells, micro turbines, co-generation, combined heat & power and renewable energy sources. Other programs support can support companies in the use of biomass for energy, research or building efficiency.
Target Group:	Any industry located in Indiana
Format:	Application year-round for IEEF and in direct contact for DGGP
Contact:	Energy Policy Division, (317) 232-8970.
URL:	http://www.iedc.in.gov/Grants/index.asp

Iowa – Alternate Energy Revolving Loan Program

Description:	The Alternate Energy Revolving Loan Program (AERLP) was created to promote the development of renewable energy production facilities in the state.
Target Group:	Any potential user of renewable energy
Format:	Proposals under $50,000 are accepted year-round. Larger proposals are accepted on a quarterly basis.
Contact:	Iowa Energy Center, (515) 294-3832
URL:	http://www.energy.iastate.edu/funding/aerlp-index.html

New York – Industry Research and Development Programs

Description:	The New York State Energy Research & Development Agency (NYSERDA) operates various financial assistance programs for New York businesses. Different programs focus on specific topics, including process technology, combined heat and power, peak load reduction and control systems.
Target Group:	Industries located in New York
Format:	Solicitation
Contact:	NYSERDA, (866) NYSERDA
URL:	http://www.nyserda.org/programs/Commercial_Industrial/default.asp?i=2

Wisconsin – Focus on Energy

Description:	Energy advisors offer free services to identify and evaluate energy-saving opportunities, recommend energy efficiency actions, develop an energy management plan for business; and integrate elements from national and state programs. It can also provide training.
Target Group:	Industries in Wisconsin
Format:	Open year round
Contact:	Wisconsin Department of Administration, (800) 762-7077
URL:	http://focusonenergy.com/portal.jsp?pageId=4